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PRIORITIZATION OF METHODS FOR SEISMIC RETROFITTING OF STRUCTURES

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Abstract

Nowadays, one of the main challenges in the seismic risk mitigation plan is selecting the most appropriate methods to retrofit existing structures that were not designed according to the modern building codes. Each seismic retrofit method has its particular benefits with respect to different criteria. Therefore, selecting the best method for seismic retrofitting of a given structure is generally considered as a complex problem. Multi criteria decision making (MCDM) methods are essential tools for decision makers to solve similar problems in several fields. These methods are used to select the best or preferred alternative from a finite set of alternatives. In this study, a novel probabilistic based prioritization procedure using AHP-MCDM method is proposed to rank different seismic retrofit methods for a given structure. In this regard, two types of criteria (seismic and non-seismic) are applied. Ratio of mean annual frequency of exceeding collapse prevention (CP), life safety (LS) and immediate occupancy (IO) performance levels for retrofitted structure to its original state are used as seismic criteria and architectural concerns, cost and duration of retrofit work as non-seismic criteria. To illustrate the application of suggested procedure, three retrofit methods (RC jacketing, steel jacketing and CFRP wrapping) are compared for a typical residential RC building located in the central region of Tehran. According to the obtained results, despite the common attitude in seismic retrofit design, the most predominant criteria, in decision making for seismic upgrading of deficient structures, are not generally those related to seismic performance of the structure.

Keywords: Seismic retrofit, Multi criteria decision making, Analytic hierarchy process, Incremental dynamic analysis, Performance level, Fragility curve.

1. Introduction

Nowadays, one of the main challenges in the seismic risk mitigation plan is selecting appropriate methods to retrofit existing structures that were not designed according to modern building codes.

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Nomenclatures

A	Pair-wise comparison matrix
a_{ij}	Pair-wise comparison of relative importance
g	Peak ground acceleration, m/s^2
k & k_0	Hazard curve parameters
n	Number of elements of the matrix **A**
Sa(T1)	Spectral accelerations at the fundamental structural period
T	Time
W	The normalized right eigenvector

Greek Symbols

ϕ	CDF of the standard normal distribution
η	Damping ratio
λ	Lognormal parameter
λ_{Dsi}	Mean annual frequency of exceeding particular damage state
λ_{max}	Largest eigenvalue
ξ	Lognormal parameter

Abbreviations

AHP	Analytical Hierarchy Process
CDF	Cumulative distribution function
CI	Consistency index
CP	Collapse prevention
CR	Consistency ratio
IDA	Incremental dynamic analysis
IM	Intensity measures
IO	Immediate occupancy
LS	Life safety
MAF	Mean annual frequency
MCDM	Multi criteria decision making
RCI	Random consistency index

There are many retrofit methods to improve performance of the structures in the earthquake; each has particular benefits with respect to different criteria, i.e., structural performance, cost and duration of work, available workmanship, architectural and historical concerns. Therefore, selecting the best retrofit method for a given structure is generally considered as a complex problem. Multi criteria decision making (MCDM) methods are essential tools for decision makers to solve similar problems in several fields. These methods are used to select the best or preferred alternative from a finite set of alternatives. On the other hand, due to probabilistic nature of earthquake ground motions and response of the structures and related uncertainties, probabilistic based approach should be applied in decision analysis. In this study, a novel probabilistic based procedure to prioritize different methods for seismic retrofitting of a given structure, using the most popular MCDM method, known as AHP (Analytical Hierarchy Process, [1]) is proposed. In this regard, two types of criteria (seismic and non-seismic) are applied. Ratio of mean annual frequency of exceeding collapse prevention (CP), life safety (LS) and immediate occupancy (IO) performance levels for retrofitted structure to its original state are used as seismic criteria and architectural concerns, cost and duration of retrofit work as non-seismic criteria.

The decision making procedure is consisting of the following five steps which also represent the structure of this paper:

a) Selecting the alternatives (seismic retrofit methods).
b) Computing seismic evaluation criteria, using the following sub-steps:
    1. Hazard curve determination.
    2. Ground motions selection.
    3. Incremental dynamic analysis (IDA).
    4. Performance levels definition.
    5. Deriving fragility curves.
    6. Computing mean annual exceedance frequency of CP, LS and IO performance levels for original and retrofitted structures.
c) Definition of non-seismic evaluation criteria.
d) Using AHP to prioritize alternatives based on seismic and non-seismic criteria.
e) Computing consistency ratio (CR) that shows how consistent the evaluation of the criteria is.

2. Analytical Hierarchy Process

Analytical AHP is one of the most well-known multi criteria decision making procedures due to its simplicity, accuracy, popularity and its theoretical robustness. It can handle both qualitative and quantitative criteria and most important it has the capability to measure the consistency of the results [2]. The AHP incorporates subjective and objective alternatives into a single measure in a hierarchical or network framework and based on a ratio scale and pair-wise comparisons the rank of each alternative is assessed. AHP is used in various industrial applications. Partovi et al. [3], used it for operations management decision making; Meredith and Mantel [4], applied AHP as an effective tool for project selection; Dey and Gupta [5], used AHP for cross-country petroleum pipeline route selection; Dey [6], studied risk of operation in cross-country petroleum pipeline using AHP; Javanbarg et al. [7], use it for priority evaluation of seismic mitigation in pipeline networks; Alexudi et al. [8], use it for deriving fragility curves of interdependent lifelines.

The followings are AHP essential steps:

a) Structuring the hierarchy and collecting input data by pair-wise comparisons.
b) Using the eigenvalue method to compute priorities.
c) Calculating consistency ratio (CR) of results to check the reliability of the judgments; in case of inconsistency, the procedure continues until consistency is accomplished.

2.1. Structuring the hierarchy and collecting data by pair-wise comparison

In order to structure the hierarchy, the levels of a decision problem are broken down until a bottom level criterion is reached. Once the hierarchy of the problem is established, the relative importance (weights) of all decision elements is explicitly computed through ratio scale approach. Pair-wise comparison of these elements within the same hierarchical level, with respect to the parent elements in the next higher level, is established. Conversions used to translate verbal preferences into numerical judgments, are shown in Table 1. According to the preferences of an expert, the numerical scales range from 1 to 9. The derived pair-wise comparisons of relative importance $a_{ij} = w_i/w_j$ of all decision elements and their reciprocals $a_{ji} = 1/\ a_{ij}$ are inserted into a reciprocal square matrix, A = $\{a_{ij}\}$, as shown in Eq. (1).

$$\mathbf{A} = \begin{bmatrix} {}^{w_1}/_{w_1} & {}^{w_1}/_{w_2} & \cdots & {}^{w_1}/_{w_n} \\ {}^{w_2}/_{w_1} & {}^{w_2}/_{w_2} & \cdots & {}^{w_2}/_{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ {}^{w_n}/_{w_1} & {}^{w_n}/_{w_2} & \cdots & {}^{w_n}/_{w_n} \end{bmatrix} \tag{1}$$

Table 1. Conversion Table Used in AHP to Translate Verbal Preferences into Numbers [1].

Verbal Judgment	Numerical Judgment
Equally Preferred	1
Equally to Moderately	2
Moderately Preferred	3
Moderately to Strongly	4
Strongly Preferred	5
Strongly to Very Strongly	6
Very Strongly Preferred	7
Very Strongly to Extremely	8
Extremely Preferred	9

2.2. Eigenvalue method

In the eigenvalue method [1], the normalized right eigenvector i.e., W = $\{w_1, w_2, . . . , w_n\}$ associated with the largest eigenvalue (λ_{max}) of the square matrix A, provides the weighting values for all decision elements :

$$A\times W = \lambda_{max} \times W \tag{2}$$

The analytical solution of Eq. (2) provides the relative weights of each decision elements.

2.3. Consistency ratio of the judgments

To measure the degree of inconsistency in the square matrix A, consistency index (CI) is used. The CI is defined as:

$$CI = (\lambda_{max} - n) / (n - 1) \tag{3}$$

where n and λ_{max} are the number of elements and the largest right eigenvalue of the matrix A respectively; Saaty [1], compared the estimated CI with the same index derived from a randomly generated square matrix, called the random consistency index (RCI) shown in Table 2. The consistency ratio (CR) is the ratio of CI to RCI for the same order matrix. Generally, a CR of 0.10 or less is considered acceptable; otherwise matrix A will be revised to improve the judgmental consistency.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}} \tag{4}$$

Table 2. The Random Consistency Index (RCI) [2].

n	1	2	3	4	5	6	7
RCI	0.00	0.00	0.52	0.89	1.11	1.25	1.35

3. Procedure for Prioritization of Methods for Seismic Retrofitting of Structures

In this procedure, different seismic retrofit methods, which are designed for a given structure, are prioritized considering both seismic and non-seismic criteria. In this regard, the following procedure should be used.

3.1. Selecting the alternatives (seismic retrofit methods)

In this step, different seismic retrofit methods, which are designed for a given structure, selected for prioritizing procedure.

3.2. Computing seismic evaluation criteria

The ratios of the mean annual exceedance frequencies of CP, LS and IO performance levels of retrofitted to original structure denoted by RCP, RLS and RIO, respectively are three probabilistic based quantitative seismic criteria applied in this study (Criterion 1 to 3). To obtain their values, following steps should be taken:

Step 1- Hazard Curve Determination

Seismic hazard curve is plotted using return periods versus the magnitudes of spectral accelerations at the fundamental structural period [Sa (T1)], considered here as the earthquake intensity measure (IM). Seismic hazard curve can be approximated as a linear function on a log-log scale for a relatively wide range of intensities as follows [9, 10]:

$$\lambda(Sa(T1)) = k_0[Sa(T1)]^{-k} \tag{5}$$

where, $\lambda(\mathrm{Sa(T1)})$is mean annual frequency of exceeding Sa(T1), k and k_0 are constant coefficients.

Step 2- Ground Motions Selection

Regarding site specifications, a set of ground motions should be selected which their response spectra match a site-specific target response spectrum.

According to Shome and Cornell [11], for mid-rise buildings only 10–20 records as spectral acceleration at the fundamental period of the structure [Sa (T1), η =5%] should be selected.

Step 3- Incremental Dynamic Analysis

Structural damage is simulated based on the incremental dynamic analysis (IDA) [12]. IDA is a parametric nonlinear analysis through which the structural model is subjected to several ground motion time histories, each scaled into several intensity levels, until that record causes the structural collapse, identified by runaway inter-story drift. IDA can describe the evolution of structural response in whole investigated range of seismic intensities and synthetically explain the record-to-record variability effects. In this step, IDAs are performed for both original and retrofitted structures. IDA curve is generally a plot of maximum inter-story drift ratios versus earthquake intensity measures (IM).

Step 4- Performance Levels Definition

The first important step of a damage analysis is defining a measure for quantifying the building's seismic damage. In this study, IO, LS and CP are selected as the performance levels of the structure. IO performance level is assumed to represent the yield capacity of structure. The relationship between spectral acceleration and the maximum inter-story drift ratio is linear up to the yield point [13] therefore, IO performance level is considered as the spectral acceleration at which the IDA curve leaves the linear path. The collapse capacity of the structure is defined as the spectral acceleration at which the structure experiences dynamic instability, i.e., the slope of the IDA curve approached zero [14]. The intermediate level denoted LS is clearly fallen between the points of IO and CP, and depends on the building occupancy. There is no obvious way of determining the inter-story drift ratio that threatens life safety. In this paper, this intermediate level of performance is identified in the middle of IO and CP performance levels therefore, the LS performance level is considered as a drift ratio (or spectral acceleration) in the half-way between these two performance levels [15, 16].

Step 5- Fragility Curve Determination

The relationship between the probability of structural damage and earthquake intensity measure (IM) is graphically illustrated by fragility curves [17, 18]. Fragility curves are generally modeled by a lognormal cumulative distribution function [19, 20] and express the probability of reaching or exceeding a particular damage state, for a given earthquake intensity. In this study, fragility curves are constructed in terms of spectral acceleration at the average fundamental periods of structures [21] and expressed in the form of two-parameter lognormal distribution functions. The conditional probability of being or exceeding, a particular damage state DSi, given the spectral acceleration [Sa(T1)] is defined by the following relationship:

$$P(DS \geq DSi|Sa(T1)) = \emptyset\left(\frac{\ln X - \lambda}{\zeta}\right) \quad (6)$$

where ϕ is cumulative distribution function (CDF) of the standard normal distribution; X is the lognormal distributed spectral acceleration; and λ and ζ are the mean and standard deviation of ln(X).

Step 6- Computing Mean Annual Frequencies of Exceeding Performance Levels

The mean annual frequency of exceeding certain damage performance level, (DSi) is computed by integrating the damage fragility curve with the hazard curve, as:

$$\lambda_{\mathrm{DSi}} = \int_{\mathrm{Sa}} \mathrm{P}(\mathrm{DS} \geq \mathrm{DSi}|\mathrm{Sa})\, |\mathrm{d}\lambda(\mathrm{Sa}(\mathrm{T1})) \quad (7)$$

where, λ_{DSi} is the mean annual frequency of exceeding particular damage state (DSi), $\mathrm{P}(\mathrm{DS} \geq \mathrm{DSi}|\mathrm{Sa})$ is the probability of exceeding DSi, at Sa(T1) and $\mathrm{d}\lambda(\mathrm{Sa}(\mathrm{T1}))$ is the differential of the mean annual frequency of exceeding Sa(T1).

3.3. Definition of non-seismic evaluation criteria

Any non-seismic criteria as financial, social, historical and political factors that affect the choice of the retrofit method could be selected for the prioritization procedure. In this study, three non-seismic criteria are adopted. Installation cost and duration of work are two quantitative criteria (criterion 4 and 5) and architectural concern is a qualitative criterion (criterion 6).

3.4. Prioritization alternatives using AHP

The AHP in such cases is conducted in three steps:

a) Weigh the criteria, using pair-wise judgments.
b) Compute the relative ranks of decision alternatives using pair-wise judgments with respect to each independent criterion.
c) Computing consistency ratio (CR) that shows how consistent the evaluation of the criteria is.

4. Case Study

4.1. Structural model of original building

A 5-story RC frame which is typical residential building stock in the central region of Tehran used in this work. The structure has been designed according to the primitive version of the Iranian seismic design standard [22]. The regularity in plan and in elevation of the structural system allows the analysis of the planar model instead of the 3D model. The typical 2D frame and the sections of beams and columns are shown in Fig. 1. The details of reinforcements of building are illustrated in this figure as well. The floors are one way concrete joist system. The concretes adopted for frames have a mean cylinder compressive strength of 18 MPa, and the reinforcement steels have mean yield strength of 300 MPa. The beam's loads are evaluated by considering the floor's tributary length equal to the frames spacing (5 m); the floor's loads are 6 kN/m^2 dead and 2 kN/m^2 live. The finite-element program SeismoStruct [23] is applied here in all analyses. Structural members are modeled using distributed-plasticity fiber elements, which use member cross-section properties and material constitutive behavior to explicitly define element hysteretic behavior.

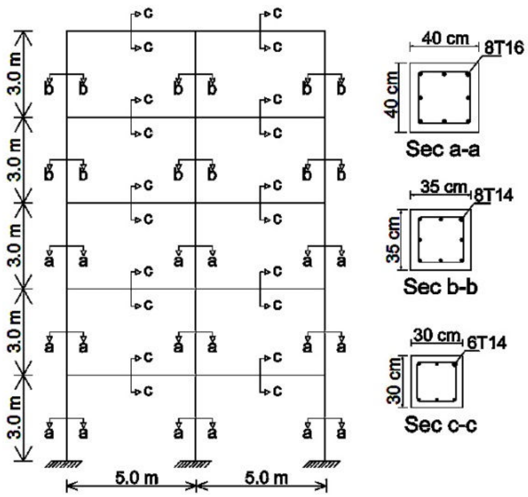

Fig. 1. Typical 5-story RC Frame and the Sections of Beams and Columns.

4.2. Structural model of retrofitted buildings

Three retrofit methods are studied in this work. These methods are designed to satisfy Basic Safety Objective (BSO) requirements of the Iranian Seismic Rehabilitation Code [24].

a) RC jacketing of columns (denoted by R1): A jacket, consists of a 10 cm thick layer of reinforced concrete, cast around each column. Extensive longitudinal and transverse reinforcement is added in the new layer of concrete. Reinforcement steel with mean value of yield strength of 400 MPa and concrete with mean value of 28-days cylinder compressive strength of 24 MPa are adopted, Fig. 2(a).

b) Steel Jacketing of columns and attaching steel plates to the bottom of the beams (denoted by R2): The thickness of steel plates is 2cm and the mean value of yield strength of steel is 240 MPa, Fig. 2(b).

c) Wrapping of columns with CFRP sheet and bonding CFRP laminates under beams (denoted by R3): Mechanical properties of CFRP sheets and laminates are listed in Table 3. The CFRP behaviour is modelled using the Tri-linear FRP material in SeismoStruct.

Table 3. CFRP Mechanical Property.

	Module of Elasticity (GPa)	Tensile Strength (MPa)	Thickness (mm)
CFRP Sheet	240	3900	0.117
CFRP Laminate	165	2500	1.400

4.3. Ground motion time histories

Twenty records, used in this study, are retrieved from FEMA 440 [25] for site class C, having response spectra relatively similar to that of soil type II in Iranian seismic code [26]. These ground motion records are listed in Table 4.

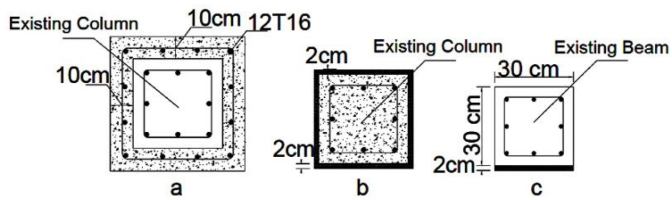

Fig.2. (a) RC Jacketing of Columns, (b) Steel Jacketing of Columns, (c) Attaching Steel Plate to the Bottom of the Beams.

Table 4. Ground Motions Selected for Soil Type II of Iranian Seismic Code.

No.	Earthquake Name	Station Number	Magnitude	PGA(*g*)
1	Imperial Valley	5051	6.8	0.204
2	San Fernando	80055	6.5	0.11
3	San Fernando	269	6.5	0.136
4	Landers	12149	7.5	0.171
5	Loma Prieta	58378	7.1	0.156
6	Loma Prieta	57373	7.1	0.17
7	Loma Prieta	58065	7.1	0.504
8	Loma Prieta	47006	7.1	0.56
9	Loma Prieta	58135	7.1	0.441
10	Loma Prieta	58130	7.1	0.113
11	Loma Prieta	576064	7.1	0.124
12	Loma Prieta	47377	7.1	0.073
13	Loma Prieta	58163	7.1	0.068
14	Loma Prieta	1652	7.1	0.244
15	Morgan Hill	47006	6.1	0.097
16	Morgan Hill	57383	6.1	0.286
17	Palmspring	5069	6	0.131
18	Northridge	23595	6.8	0.072
19	Northridge	24278	6.8	0.514
20	Northridge	24271	6.8	0.204

4.4. Hazard curve

The average fundamental periods of the frames in this study, is about 1 second. Therefore, the spectral acceleration at this period is used as the earthquake intensity measure [21]. The seismic hazard curve, shown in Fig. 3, is plotted using the data available in the "Seismic hazard analysis research" conducted by engineering faculty of Tehran University [27], for Greater Tehran Region. The parameters k_0 and k in Eq. (5), obtained by a regression in the logarithmic plane, are 0.0007 and 2.43 for the central region of Tehran, respectively.

4.5. Damage analysis and fragility curves

Lognormal distribution parameters and fragility curves for IO, LS and CP performance levels of original and retrofitted RC frames are shown in Table 5 and Figs. 4 to 6 respectively. The mean annual exceedance frequencies of IO, LS and CP performance levels for these structures, obtained by probabilistic damage analyses, are shown in Table 6.

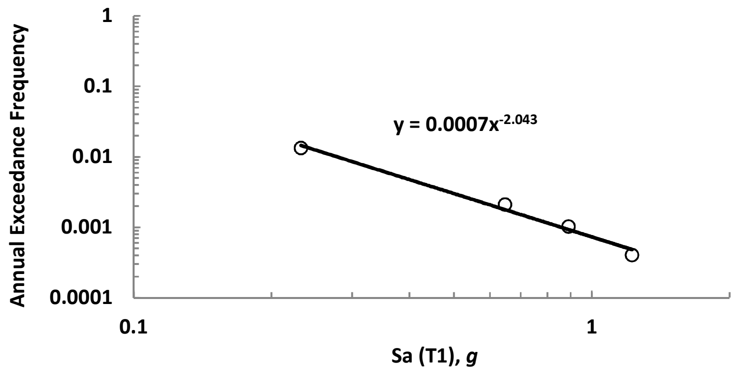

Fig. 3. Seismic Hazard Curve of the Central Region of Tehran at T=1s in the Logarithmic Scale.

Table 5. Lognormal Parameters (λ and ζ) for IO, LS, CP Performance Levels of Original and Retrofitted Structure.

	IO		LS		CP	
	λ	ζ	λ	ζ	λ	ζ
Original	-1.187	0.464	0.005	0.474	0.525	0.495
R1	-1.184	0.369	0.373	0.398	0.947	0.420
R2	-0.908	0.308	0.436	0.393	0.983	0.422
R3	-1.057	0.385	0.445	0.404	1.014	0.423

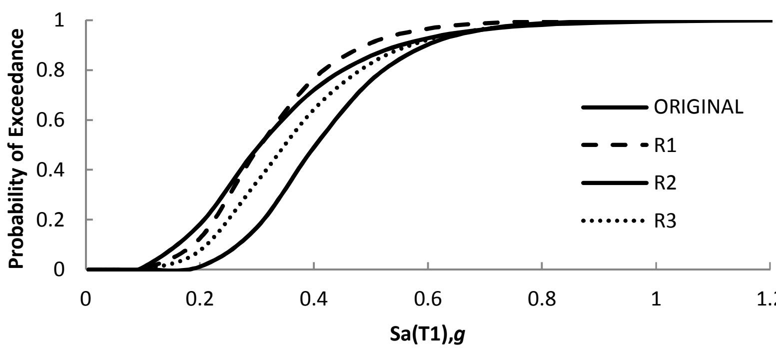

Fig. 4. Fragility Curves of Structures for the IO Performance Level.

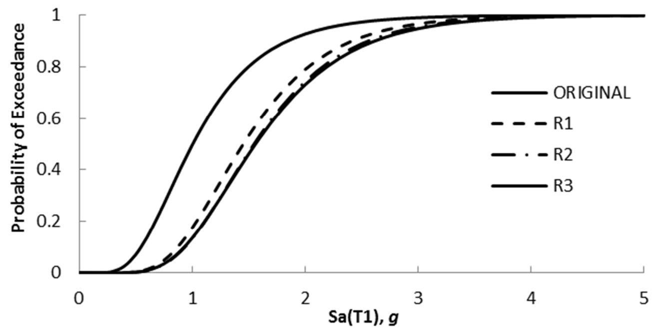

Fig. 5. Fragility Curves of Structures for the LS Performance Level.

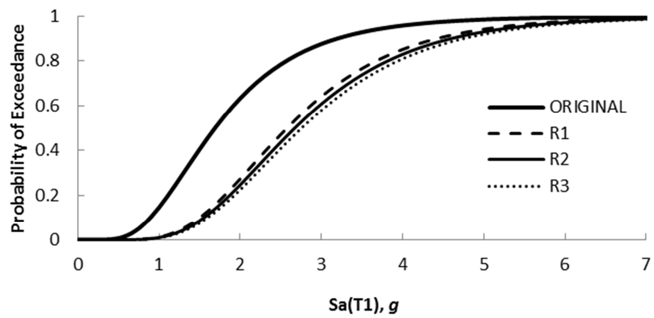

Fig. 6. Fragility Curves of Structures for the CP Performance Level.

Table 6. Mean Annual Frequency (MAF) of Exceeding IO, LS, CP Performance Levels ($\times 10^{-4}$).

	Original	R1	R2	R3
MAF of IO	128.29	108.88	55.46	94.86
MAF of LS	13.72	5.05	3.82	4.05
MAF of CP	4.47	1.62	1.33	1.29

4.6. Ranking seismic retrofit methods

In Table 7, values of each criterion for three retrofit methods are presented. The values of non-seismic criteria are obtained from a survey of actual clients and contractors.

Table 7. Values of Seismic and Non-seismic Criteria for Each Retrofit Method.

	Symbol	Criteria	R1	R2	R3
Seismic Criteria	C1	R_{CP}	0.85	0.43	0.74
	C2	R_{LS}	0.37	0.28	0.30
	C3	R_{IO}	0.36	0.30	0.29
Non-seismic Criteria	C4	Cost of Work (US $)	23000	42000	63000
	C5	Duration of Work (Days)	150	120	90
	C6	Architectural Concerns	Major	Moderate	Minor

4.6.1. Weighting the evaluation criteria

To make final decision on selecting the best seismic retrofit method, a quantitative evaluation of the relative importance (weight) of each criterion is needed. The weights reflect the relative importance of each criterion with respect to the other criteria in the choice of the best solution. In this example, 15 comparisons between criteria in terms of relative importance have been performed, and the **A** matrix given in Eq. (8) was obtained. To clarify about some of the adopted a_{jk} values in Eq. (8), a brief discussion is given below:

R_{CP} is considered to be as important as architectural concerns since even small architectural intervention may disrupt the normal use of the building and very important than the other criteria (a_{1k} >1, k=2, 3, 4, 5) since the collapse of the structure results in severe loss. R_{LS} is assumed to be less important than architectural concerns and moderately important than the other criteria (a_{2k} >1, k=3, 4, 5). R_{IO}, cost and duration of work are assumed as important as each other (a_{3k} =1, k=4, 5 & a_{45} =1) since all of them result in monetary loss and finally as mentioned about the importance of the architectural concerns in residential building it is generally important than the other criteria except R_{CP}.

$$A=[a_{ij}]=\begin{bmatrix} 1 & 3 & 5 & 3 & 3 & 1 \\ \frac{1}{3} & 1 & 3 & 2 & 2 & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{3} & 1 & 1 & 1 & \frac{1}{5} \\ \frac{1}{3} & \frac{1}{2} & 1 & 1 & 1 & \frac{1}{5} \\ \frac{1}{3} & \frac{1}{2} & 1 & 1 & 1 & \frac{1}{5} \\ 1 & 3 & 5 & 5 & 5 & 1 \end{bmatrix} \tag{8}$$

After all pair-wise comparisons are made, the A matrix is filled. Then from Eq. (2), weighting values for all decision elements and vector W are obtained as follows:

$$\text{W} = \{w_i\} = \{0.3, 0.138, 0.064, 0.074, 0.074, 0.349\}. \tag{9}$$

The weights are used to rank the criteria according to their relative importance as shown in Table 8. The weights have a significant influence on the final decision and represent a subjective part of the procedure. In this decisional problem, the alternatives with the best evaluations in respect to architectural concerns and R_{CP} , which are relatively the most important criteria, have more chances to be selected, whereas the evaluations according to the R_{IO}, cost and duration of work will play a less critical role in the final decision.

Table 8. Ranking Criteria According to Their Weight.

Ranking Order	Weight (w_i)	Criterion
1	0.349	Arch. Concerns
2	0.300	R_{CP}
3	0.138	P_{LS}
4	0.074	Cost & Duration
5	0.064	R_{IO}

4.6.2. Consistency check of the compression among the criteria

A consistency check of the pair-wise comparisons is useful to ensure that there is no intolerable conflict, and the final decision is not a result of random prioritization. In the case of inconsistent expert judgments, the procedure aimed to build up the **A** matrix has to be redone, in a more careful and logical manner. The pair-wise comparisons are considered to be perfectly consistent when the following condition is verified: if criterion 1 is defined to be more important than criterion 2 by a factor a_{12}, and criterion 2 is assumed to be more important than criterion 3 by a factor a_{23}, then criterion 1 should be more important than criterion 3 by the factor $a_{13} = a_{12} \times a_{23}$. In this ideal case, $a_{12} = w_1 / w_2$ and $a_{23} = w_2 / w_3$; therefore, $a_{13} = w_1/w_3 = (w_1/w_2)(w_2/w_3) = a_{12} \times a_{23}$.

In this example, since for n = 6, from Table 2, RCI is equal to 1.25, the **A** matrix can be considered consistent enough since CR = 1% < 10% as per Eq. (4).

4.6.3. Evaluation of seismic retrofit alternatives based on the seismic and non-seismic criteria

In Tables 9 to 14 pair-wise comparison matrixes of three alternatives with respect to the each criterion are shown. In these tables priority vector of each alternative as well as values of CR are shown. As the values of CR are less than 0.1 in all tables, all judgments are acceptable.

Values of pair-wise comparison of alternatives with respect to each quantitative criterion (C1 to C5) are obtained by dividing their values for each criterion. For architectural concerns (C6), the values of pair-wise comparison are obtained from Table 1 using the following description: CFRP wrapping is considered to be extremely preferred with respect to RC jacketing and strongly preferred with respect to steel jacketing, since the minimum interference in building residential performance after installation is favoured. Steel Jacketing is assumed to be strongly preferred with respect to RC jacketing due to its smaller thickness.

Table 9. Pair-wise Comparison Matrix for R_{CP} (CR=0).

R_{CP}	R1	R2	R3	Priority Vector
R1	1	0.51	0.87	0.242
R2	1.98	1	1.72	0.479
R3	1.15	0.58	1	0.279
				∑=1.000

Table 10. Pair-wise Comparison Matrix for R_{LS} (CR=0).

R_{LS}	R1	R2	R3	Priority Vector
R1	1	0.76	0.81	0.282
R2	11.31	1	1.07	0.371
R3	1.23	0.93	1	0.347
				∑=1.000

Table 11. Pair-wise Comparison Matrix for R_{IO} (CR=0).

R_{IO}	R1	R2	R3	Priority Vector
R1	1	0.83	0.81	0.291
R2	1.20	1	0.97	0.349
R3	1.23	1.03	1	0.360
				∑=1.000

Table 12. Pair-wise Comparison Matrix for Cost of Installation (CR=0).

Cost	R1	R2	R3	Priority Vector
R1	1	1.83	2.74	0.523
R2	0.55	1	1.50	0.286
R3	0.36	0.67	1	0.191
				∑=1.000

Table 13. Pair-wise Comparison Matrix for Duration of Installation (CR=0).

Time	R1	R2	R3	Priority Vector
R1	1	0.51	0.87	0.255
R2	1.98	1	1.72	0.319
R3	1.15	0.58	1	0.425
				∑=0.999

Table 14. Pair-wise Comparison Matrix for Architectural Concerns (CR=0.03).

Arch. Concerns	R1	R2	R3	Priority Vector
R1	1	0.20	0.11	0.063
R2	5	1	0.33	0.265
R3	9	3	1	0.672
				∑=1.000

4.6.4. Ranking of alternatives and selecting the best retrofit method

The priority matrix, an overall priority ranking of the seismic retrofit alternatives, is shown in Table 15. The retrofit methods are ranked according to their overall priorities. Thererfore the best retrofit method among three methods is CFRP wraping due to its largest priority ranking. In fact, the low architectural impact on the building and the good score in respect to CP and LS performance levels determined the rank.

Table 15. Periority Matrix for Different Retrofit Methods (CR=0.01).

	R_{CP}	R_{LS}	R_{IO}	Cost	Time	Arch. Concerns	Priority Vector
R1	0.242	0.282	0.291	0.523	0.255	0.063	0.228
R2	0.479	0.371	0.349	0.286	0.319	0.265	0.365
R3	0.279	0.347	0.360	0.191	0.425	0.672	0.406

5. Conclusion

Selecting the most appropriate methods to retrofit existing structures that were not designed according to the modern building codes is very challenging issue since each seismic retrofit method has its particular benefits with respect to different seismic and non-seismic criteria. Despite the common attitude in seismic retrofit design, the most predominant criteria, in decision making for seismic upgrading of deficient structures, are not generally seismic criteria which related to seismic performance of the structure or at least, they should be considered together with other non-seismic criteria. Due to probabilistic nature of earthquake ground motion and responses of structures, and related uncertainties, probabilistic based seismic criteria should be adopted in prioritizing procedures. In this study, a novel probabilistic based procedure to evaluate and rank the different solutions for the seismic retrofit of existing structures using AHP-MCDM method is proposed. The AHP has some critical aspects which more than others affect the final ranking and selecting the best retrofit method, i.e., the choice of the pertinent criteria that reflects the stakeholder's attitude, definition of the weight for each criterion, which is a subjective step and finally, the conversion of the qualitative judgments into crisp numbers that is a non-trivial process. Therefore, the consistency ratio is useful to control and disaggregate the decision process. To illustrate the application of the proposed procedure an example referring to a pre-code RC building representing typical existing residential building stocks, in the central region of Tehran is studied. Three retrofit methods (RC jacketing, Steel jacketing and CFRP wrapping) have been considered for the investigated case. Results indicate the confinement of elements by CFRP is the best choice. In fact, the low architectural impact on the building and the good score in respect to CP and LS performance levels determined the rank.

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