Multi-criteria post-earthquake decisions priorities for tall buildings in Kuwait City

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Abstract

Despite the fact that Kuwait is a zone of low to moderate seismicity, the effects of earthquakes can be harmful especially on tall buildings. After any earthquake, decision- makers are in face of a great challenge of taking an action or not; therefore, some minor and visual damage indicators can help them in their job. This study aims at prioritizing minor and visual damage indicators for tall buildings in Kuwait City. The descriptive method was used in this study where the analytic hierarchy process (AHP) was used to prioritize the experts' opinions that were collected by a questionnaire. The results showed that the existence of seismic force resisting system is the top damage indicator followed by the number of floors and visual damage. On the other hand, the construction year and duration of the earthquake came as the lowest damage indicators.

Keywords; AHP, Post-Earthquake, Kuwait, Decision Making

Introduction

After any disturbing event, decision-makers face a great challenge of dealing with it immediately. For earthquakes, post-trauma involves the emergency management operations in case of strong and moderate earthquakes where damage can be easily identified (Poggi et al., 2021; Grimaz, Malisan & Pividori, 2022). Defining and establishing actions is the main challenge faced by the decision makers in the areas that are classified as low seismicity where damage is hard to be assessed. In such case, defining the main priorities for taking actions is essential. For tall buildings, usually the damage is multiplied; therefore, even in low seismicity, damage should be evaluated and necessary actions should be made.

Kuwait is considered as a low to moderate seismicity area, where the stronger estimated earthquake in this area can reach 5 degrees on Richter scale (Almutairi, 2018). Therefore, considering the situation of post-earthquake is an urgent call for this region in light of the lack of such studies until the time of this study.

Kuwait City is characterized by its vertical urban expansion, where tall buildings form the skyline of the city (Alghais & Pullar, 2018). Such vulnerable structures are exposed to damage in various levels (Ghahari et al., 2022); however, such damage cannot be always observed in case of low seismicity (Kang et al., 2019). Therefore, decision makers should determine, which buildings are more exposed to damage and which need a corrective action. In this study, the minor and visual damage indicators for tall buildings in Kuwait. City were prioritized using the AHP method.

Methodology

The descriptive correlational design was followed in this study to find the weights of the decision priorities for tall buildings after recorded earthquakes where the damage indicators presented the criteria for the analysis. First, the main damage indicators that are discussed in the literature for the regions of low earthquake activity like Kuwait were collected. Then, the researcher has taken the experts opinions on ranking the main damage indicators that they think are the main damage indicators that are taken into consideration after earthquakes when making decisions. In this study, the AHP approach was adopted to make the prioritization.

The study tool

In order to collect the main data, a questionnaire was developed by the researcher based on the studies of (Molina Hutt et al., 2016; Brownjohn & Pan, 2001). The following are the main and sub criteria in the final version of the questionnaire that was validated by the scientific methods.

Table 1: The main and sub criteria

Main criteria	Sub-criteria	Symbol
Occupancy Type (O)	Residential	RS

	Commercial	CO
	Industrial	ID
Number of Floors (F)	15-25 Floors	F1
	26-35 Floors	F2
	36-45 Floors	F3
	More than 45 Floors	F4
Construction Year (C)	Old	OL
	Contemporary	CT
	New	NE
Seismic Force Resisting System (SFRS)	None	N
	Existed	Y
Duration of the Earthquake (D)	Short	SH
	Long	LO
Visual Damage (V)	Cracks in the Façade	CF
	Displacement	DI
Evaluation Reports (E)	Occupants Reports	CR
	Engineers Reports	ER
	Owner Reports	OR

Sample and population

The study population consisted of all the experts including civil protection operators, technicians and decision-makers in Kuwait. The study sample consisted of (35) experts in the ministry of public work and local municipalities in Kuwait. The convenience sampling technique was followed in selecting the sample members.

AHP approach

The analytic hierarchy process (AHP) is considered as a well-known multi-criteria method where the most important alternatives are found by rating the alternatives and aggregating them based on the highest weight. The previous process is done under a main goal, which include a number of criteria and sub-criteria.

The methodology application includes finding the importance weights that are related to the criteria while defining the main goal by pairwise criteria comparison. If C; and Care the criteria to be compared, the decision maker will give a grade for each one based on his judgment of their importance related to each other considering the main goal. After given a semantic scale for each criteria based on its importance, it converted into a number a_{jk} Then, the reciprocal of C over C (relative importance) can be defined as.

$$a_{kj} = 1/a_{kj}$$

Then, by using ajk, a reciprocal pairwise comparison matrix (A) is made, for all k and j, where a-1. The criteria weights are calculated by estimating the main eigenvector win matrix A, as follows.

$$AW = \lambda_{max}W$$

After normalizing (w), it becomes the criteria priorities vector; while max is the principal eigenvalue in matrix A with only positive values of the resultant eigenvector w. This method incorporates also established procedures to check the provided decision maker judgments consistency.

By the same procedures, the alternatives weights based on each criterion will be calculated. After that, the total alternatives weights are estimated by the weighted summation equation below.

(overall weight of alternative i)

$= \Sigma_{j(\text{weight of alternative i with respect to GX weight of C, with respect to the goal})}$

The AHP method popularity comes from its intuitive appeal, flexibility, simplicity and its mix between qualitative and quantitative methods. The following steps were followed to calculate the weights of each criteria and sub-criteria.

1. **Structuring the hierarchy model for prioritizing the criteria**: in this step, the AHP hierarchy model is formulated where it contains the goal, main criteria and the sub-criteria and the alternatives. The aim of this model is to find the most important criteria of damage indicators that can help the decision makers to choose from the alternatives. This goal is in the first level of the model followed by the criteria, sub- criteria, while the alternatives are in the bottom of the model, as in Figure (1) below.

Damage Indictors

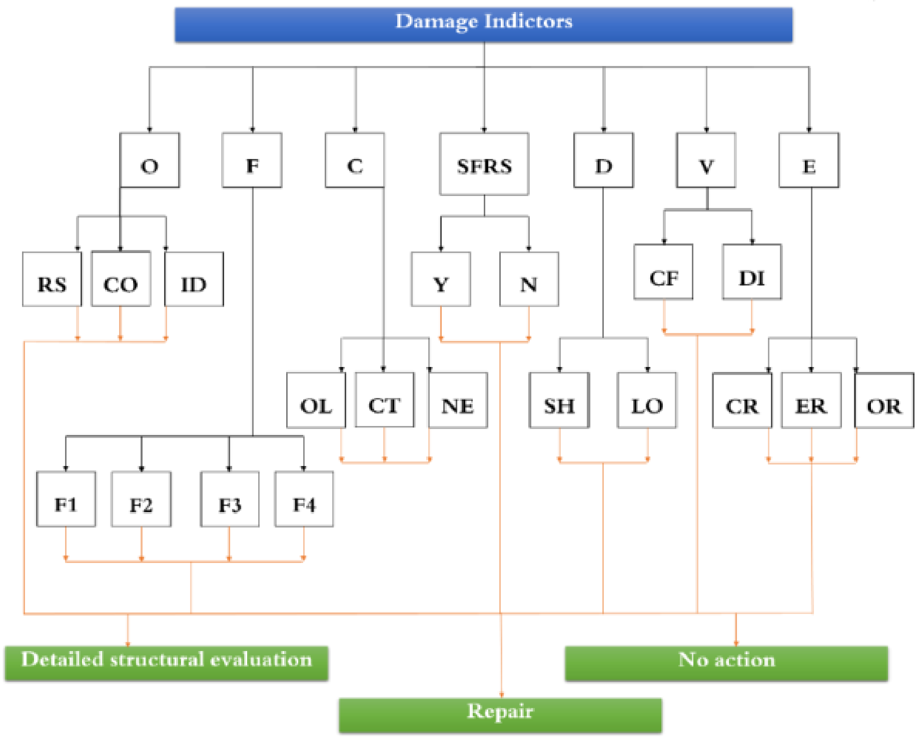

Figure 1: The AHP hierarchy model

2. **Developing the Pair-wise comparison matrix**: The Pair-wise comparison matrix was developed based on the experts' opinions on the questionnaire where each criteria. was given a numeric rating, which indicates the importance of each criteria in relative to other criteria (Onder & Dag, 2013).

3. Developing the normalized matrix: The normalization matrix was developed by dividing each number in a column of the pair-wise comparison matrix by the sum of its column (John et al., 2014).

4. Developing the priority vector: The priority vector was developed by calculating the mean of each row of the normalized matrix (Stein and Ahmad, 2009).

5. Calculating the consistency ratio: the weighted sum was determined for each row of the pair-wise comparison matrix by summing the multiples of the entries using the priority of its corresponding (column) alternative (Whitaker, 2007). Then, the weighted sum of each row was divided by its corresponding (row) alternative priority. After determining Amax value, consistency index, CI, of the n alternatives was computed by:

$$CI = (1_{max} – n)/(n−1)$$

In order to compute the consistency ratio, the random index RI was determined according to Table (2) below.

Table 2: Average random consistency index (RI) as a function of pair-wise comparison matrix size (Alonso and Lamata, 2006).

Size of matrix	3	4	5	6	7	8	9	10
RI	0.525	0.90	1.12	1.248	1.342	1.406	1.450	1.485

6. Develop the priority matrix: After phase 2 and 5 for all the capabilities, the results of stage 4 were summarized in the priority matrix where the column entries were the priority vectors for each criteria and sub-criteria (Dabbagh & Lee, 2014).

Results

The results of the AHP analysis are presented in this section, where the sub-criteria were discussed first and then the main criteria were compared after calculating their relative weights.

Occupancy Type

Table (3) represents the priority matrix of the of the occupancy type criteria. The results show that commercial occupancy followed by residential are the main occupancy types, while industrial occupancy does not have the same importance.

Table 3: Pair-wise comparison of the occupancy type criteria Factor

	RS	CO	ID	Factor weight
RS	1	3	0.50	0.3647
CO	0.30	1	5	0.3661
ID	2	0.20	1	0.2692

Number of Floors

Table (4) represents the priority matrix of the number of floors criteria. The results show that the highest buildings have the highest weights and attention from the decision makers.

Table 4: Pair-wise comparison of the number of floors criteria.

	F1	F2	F3	F4	Factor weight
F1	1	3	0.25	3	0.3025
F2	0.30	1	2	0.20	0.1000
F3	4	0.50	1	0.14	0.2242
F4	0.30	5	7	1	0.3733

Construction Year

Table (5) represents the priority matrix of the construction year criteria. The results show that old buildings are taking the biggest attention when making post-earthquake decisions.

Table 5: Pair-wise comparison of the construction year criteria

	OL	CT	NE	Factor weight
OL	1	3	8	0.6349
CT	0.30	1	0.20	0.1145
NE	0.125	5	1	0.2507

Seismic Force Resisting System

Table (6) represents the priority matrix of the Seismic Force Resisting System criteria. The results show the absence of Seismic Force Resisting System is the most important criteria for post-earthquake decision making process.

Table 6: Pair-wise comparison of Seismic Force Resisting System criteria

	N	Y	Factor weight
N	1	6	0.8596
Y	0.16	1	0.1404

Duration of the Earthquake

Table (7) represents the priority matrix of the duration of the earthquake criteria. The results show that long earthquakes are more important indicators to consider when making decisions related to tall buildings.

Table 7: Pair-wise comparison of duration of the earthquake criteria

Visual Damage

	SH	LO	Factor weight
SH	1	0.125	0.1181
LO	8	1	0.9445

Table (8) represents the priority matrix of the visual damage criteria. The results show that cracks in the façade are more important than displacements to consider in post- earthquake decision making.

Table 8: Pair-wise comparison of visual damage criteria

	CF	DI	Factor weight
CF	1	7	0.8761
DI	0.14	1	0.1240

Evaluation Reports

Table (9) represents the priority matrix of the evaluation reports criteria. The results show that the owner reports are the most important followed by the occupants' reports.

Table 9: Pair-wise comparison of the evaluation reports criteria

	CR	ER	OR	Factor weight
CR	1	5	0.14	0.3165
ER	0.20	1	3	0.3026
OR	7	0.30	1	0.3810

The main damage indicators

Table (10) represents the priority matrix of the main damage indicators. The results show that the existence of Seismic Force Resisting System criteria is the most important one, followed by the number of floors and visual damage. On the other hand, duration of the earthquake had the lowest weight.

Table 10: Pair-wise comparison of the main damage indicators

	O	F	C	SFRS	D	V	E	Factor weight
O	1	6	0.125	0.20	0.30	0.125	2	0.0958
F	0.16	1	6	2	3	0.50	7	0.2056
C	8	0.16	1	0.20	0.50	0.25	4	0.0936
SFRS	**5**	**0.50**	**5**	**1**	**4**	**7**	**8**	**0.2676**
D	3	0.30	2	0.25	1	0.30	0.16	0.0569
V	8	5	4	0.14	3	1	0.25	0.1718
E	0.50	0.14	0.25	0.125	6	4	1	0.1088

Discussion

The results showed that the commercial occupancy had the highest weights where such result can be attributed to the fact that most of the tall buildings in Kuwait are commercial buildings. However, such buildings are characterized by curtain walls and glazing facades. Inca et al. (2019) reported that glazing and curtain walls are highly exposed to in-plane racking during earthquakes. In regarding the number of floors criteria, the results showed that that the highest buildings have the highest weights and attention from the decision makers, where taller buildings respond differently compared to shorter buildings

(Molina Hutt et al., 2022). Tall buildings tend to go through prolonged shaking more than shorter buildings as they usually have lower damping (McGuire et al., 2021; Mahmoud, 2019). Old buildings also had a high weight among others where the structures were not earthquake resistant as in modern structures. The results showed also that the absence of Seismic Force Resisting System is the most important criteria for post-earthquake decision making process, where such system keeps the structure from collapsing or blowing over (Hu, Wang & Qu, 2020). Moreover, long earthquakes were found to be an important indicator to consider any action. According to Zamani et al. (2022), tall buildings are mainly vulnerable to long-distance earthquakes, which was confirmed by Ghahari et al. (2022) who argued that tall structures are more influenced by slow shaking or long period. Visual damage was also ranked as an important damage indicator, where this indicator implies that there is a serious damage as lower damage cannot be easily captured (Harirchian et al., 2020). This study has several limitations including the type of buildings that was limited to tall buildings and the area of the study.

Conclusion

As reporting damage in low seismicity areas is a challenge for the post-earthquake decision making process, decision makers should be equipped with solid criteria for determining the actions to be made in such situations. In this study, visual and minor damage indicators were tested for tall buildings in Kuwait City in order to help the decision makers to prioritize them. The multi-criteria hierarchical analysis (AHP) method was employed to give weights for seven main criteria and their associated sub-criteria. The criteria were then arranged in a descending order as follows; EFRS, number of floors, visual damage, evaluation reports, occupancy type, construction year and finally duration of the earthquake.

This study recommends conducting further studies that include more building types and larger areas. Using fuzzy multi-criteria methods will help in comprehending the results of this study. Moreover, comparing the results of this study with areas with different seismic activity can be beneficial. This study will contribute in enhancing the decision making process in the post-earthquake events where such information is vital.

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