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Research Article

Evaluation of Seismic Isolation Systems in Terms of Benefit-Cost Analysis by using Survey Technique

Mete Ürkmezyel [1*], Mert Tolon[2]

[1] *Maltepe University, Graduate School of Education, Department of Structural Earthquake Engineering, 34857, İstanbul, Türkiye*

[2] *Maltepe University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering, 34857, İstanbul, Türkiye*

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*Corresponding author: Mete Ürkmezyel
E-mail:meteurkmezyel@gmail.com

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ABSTRACT

This research aims to raise awareness of the necessity and benefits of utilizing seismic isolation systems in buildings, considering the casualties and property losses resulting from past earthquakes. Additionally, the seismicity of Turkey's geography, with its proximity to high-risk fault lines, is evaluated. The study focuses on minimizing or completely neutralizing the destructive effects of seismic forces. The research also delves into a benefit-cost analysis of seismic isolation systems to assess their feasibility. Data obtained from a survey conducted with a selected sample group were preliminarily evaluated and statistically analyzed using the SPSS (Statistical Package for the Social Sciences) computer program. The findings indicate that seismic isolation systems offer significant benefits in reducing earthquake risk and underline their necessity. Based on the findings obtained within the scope of the study, systematic methodology tables were obtained to provide a road map to decision-makers and are recommended as a guide to public authorities. Earthquake, seismic isolation, benefit-cost analysis, survey technique.

1. Introduction

Earthquakes pose a significant threat to human lives and property worldwide and are considered a natural disaster. Earthquake-induced ground motion leads to time-dependent displacements at the foundations of structures, generating dynamic effects within the buildings. Turkey is situated in one of the world's most seismically active regions, making earthquake-resistant design and construction crucial to mitigate potential losses.

Research has been conducted to promote the widespread use of seismic isolation systems in buildings to ensure the safety of human lives and property. In line with the research objective, this study attempts to fill the research gap regarding whether the mandatory inclusion of seismic isolation systems in the Turkish Building Earthquake Regulations or the development of new legislation requiring seismic isolation systems in all newly constructed buildings would be beneficial. During an earthquake, a structure with seismic isolation applied exhibits consistent displacements beyond the level where isolation is implemented, resulting in minimal seismic forces due to extended foundation vibration periods and damping. Consequently, the structure undergoes slow and controlled oscillation, ensuring the safety of both life and property.

Within this context, seismic isolation systems are primarily focused on reducing the structural response to earthquakes through damping rather than increasing the structure's capacity to withstand dynamic loads. The evaluation of benefit-cost analysis takes precedence in determining the feasibility of implementing seismic isolation systems in structures. To ascertain the necessity of applying seismic isolation systems in terms of benefit-cost analysis and life cycle cost, past experiences, particularly casualties and property losses incurred during previous earthquakes, should be reviewed. The primary aim is to investigate situations where the benefits outweigh the costs.

Under the scope of the research study titled "Evaluation of Seismic Isolation Systems in Terms of Benefit-Cost Analysis," the research was reinforced through field surveys in an effort to create a positive impact toward the wider use of seismic isolation systems in structures. The findings identified and aimed to contribute to a comparative understanding of the benefit-cost analysis of seismic isolation systems in buildings. The intended benefit to the country and the sector is to promote the widespread use of seismic isolation systems by demonstrating that the benefit-to-cost ratio in the benefit-cost analysis is higher than the incurred expense, thereby enhancing their adoption across the nation. The increased application of seismic isolation systems in buildings will enhance both life and property safety against earthquakes and contribute to ensuring stability in the country's economy by preventing structural damage during earthquakes (Geazze Islamic University, 1997; Baştuğ, 2004; Yıldırım et al., 2019; Turkish Building Seismic Code-2018 Scientific Committee, 2018).

1.1. Seismic Isolation Systems

1.1.1. Use of Seismic Isolation Systems in Earthquake-Resistant Structures

An earthquake, as defined by (Tolay,2006; İşçi, 2008), results from the sudden rupturing of the Earth's crust due to the accumulation of energy, leading to the propagation of dynamic forces and vibrations in the form of waves, causing tremors on the Earth's surface. Once necessary investigations and analyses have been conducted on structures, strengthening them may be considered an alternative based on the results. Upon scrutinizing the cost and construction time parameters of previously reinforced structures, it has been observed that an extensive reinforcement project's cost and construction time parameters are very close to the cost and construction time parameters of demolishing and redesigning the structure, ascertaining that. In terms of strength, there is no guarantee of achieving the desired level of positive response regarding the earthquake performance of the structure during an earthquake in reinforced structures. Consequently, the use of seismic isolation systems that dampen earthquake forces becomes prominent. Seismic isolation systems can be applied not only to new buildings but also to existing structures based on the results of the necessary investigations and analyses.

In Turkey, the application of seismic isolation systems has recently gained prominence, and pilot projects have been initiated. For instance, this system has been implemented in the construction of new City Hospitals. Under the organization of Başakşehir Municipality in Istanbul, Turkey's first seismic isolator-equipped housing project was completed and implemented in 2023 (Tolay, 2006).

The different types of these application methods are given in the tables and figures below. Table 1 provides a general classification of seismic isolators. Figure 1A depicts a rubber-based seismic isolation device, while Figure 1B shows a friction-based seismic isolation device. Figure 1C illustrates a lead-core rubber bearing, and Figure 1D demonstrates the application of a lead-core rubber isolator.

Table 1: General classification of seismic isolators (Özpalanlar, 2004)

1	Rubber-Based Systems	a) (LDRB) (Low Damping Rubber Bearing) b) (HDNR) (High Damping Natural Rubber) c) (LRB) (Lead Rubber Bearing)
2	Sliding Systems	a) (FPS) (Friction Pendulum System) b) (R – FBI) (Resilient – Friction Base Isolation) c) (CLB) (Cross Linear Bearing) d) (Taisei Shake Suspension System)
3	Rubber-Base Sliding Hybrid Systems	a) (EDF) (Electricite – de France) b) (EERC) (Earthquake Engineering Research Center)
4	Spring Type Systems	

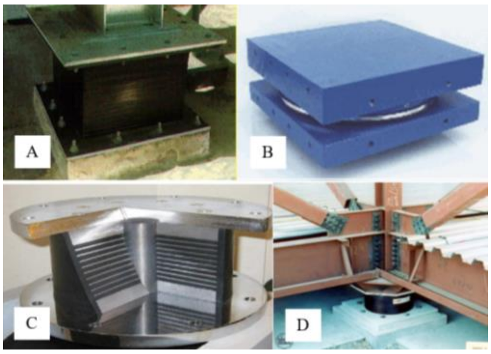

Figure 1: A) Rubber-based seismic isolation device, B) Friction-based seismic isolation device (Tolay, 2006) C) Lead-core rubber bearing (Başdoğan, 2012) D) Application of lead-core rubber isolator (Urgu, 2006).

Table 2: Methodological comparison: Seismic isolation vs. retrofitting techniques vs. energy dissipation devices (Hameed et al., 2023; Lu et al., 2021; Shakya and Wijeyewickrema, 2023; Zhang et al., 2025).

Criterion	**Seismic Isolation**	**Retrofitting Techniques**	**Energy Dissipation Devices**
Performance Level	Achieves "functionality" performance level even under severe earthquakes; maintains structural integrity and elastic behavior	Primarily improves life-safety; often allows significant damage but prevents collapse	Offers targeted damping; can reduce displacements and improve structural resilience
Cost-Benefit Outcome	Demonstrated higher internal rate of return and shorter break-even time in retrofit case studies	Often lower initial cost, but less optimal return over time	Installation costs vary; effectiveness can justify costs, though cost–benefit studies are fewer
Implementation Time & Complexity	Technically complex; requires foundation adaptation and specialist design	Generally simpler and faster to implement at local element or system level	Moderate complexity; installation feasible on existing structures depending on device type
Maintenance Requirements	Long-term durability concerns; periodic inspection of isolators necessary	Routine structural maintenance; minimal added burden beyond standard practice	Device-specific maintenance; some dampers may be replaceable after plastic deformation
Applicability / Scope	Especially suitable for critical facilities (e.g., hospitals, bridges)—enhances rapid post-event functionality	Broadly applicable across building types; particularly used in aging inventory	Applicable to both new and existing structures; valuable when dynamic response reduction is prioritized

In addition to the classification of seismic isolation devices presented above, it is also important to evaluate how seismic isolation is compared with other earthquake engineering strategies in terms of performance, cost–benefit outcomes, implementation complexity, maintenance, and applicability. Such a comparative perspective helps decision-makers and engineers select the most suitable solution based on both technical and economic considerations. Table 2 summarizes these key comparative aspects of seismic isolation, retrofitting techniques, and energy dissipation devices, drawing on relevant findings from recent academic literature.

1.1.2. Regulations and Practices Concerning Seismic Isolation Systems in Structural Earthquake Engineering

Internationally recognized regulations established in developed countries over time have served as references for codes created by developing nations. As an example, the American ASCE 7 code (ASCE 7-16, 2016) pertains to new structures with damping attributes provided by seismic isolation systems in Chapter 18. ASCE 41-17 (ASCE 41, 2017) is a standard prepared by the American Society of Civil Engineers (ASCE) for evaluating and strengthening existing structures.

On the other hand, in the Uniform Building Code (UBC) Equivalent Building Regulations (Division IV EARTHQUAKE DESIGN-Chapter 16), the aim of earthquake provisions is to protect against significant structural losses and damages, particularly for preventing seismic design. The concept of minimum seismic design involves the minimum support, design, and construction of structures and parts (Geazze Islamic University, 1997). This regulation was enacted in the United States in 1997 (Baştuğ, 2004). Considering similar approaches regarding damping device design, the European regulation (Eurocode) utilizes EN 15129. The Japanese Building Earthquake Regulation, BSL (Building Standard Law) - 1981, was last enacted in 1981 by the relevant ministry, MLIT (Ministry of Land, Infrastructure, Transport, and Tourism). Subsequently, new regulations were introduced in 2000 and 2006, with additional sections being added, but there were no changes in the calculation principles. This regulation emphasizes decisive points related to the structural design of buildings but does not have a separate section on damping buildings. The Japanese Society of Seismic Isolation (JSSI) published a guide in 2003 specifically for the design and construction phases of passive-controlled buildings. This guide is actively used in building design in Japan (Yıldırım et al., 2019). Under the scope of the Turkish Building Earthquake Regulation (TBDY-2018), in accordance with the design principles for seismic isolation buildings, the isolation system acts as a bearing element, enabling the system to behave flexibly in the horizontal direction and rigidly in the vertical direction while allowing for significant lateral displacements (Turkish Building Seismic Code-2018 Scientific Committee, 2018).

When conducting structural preliminary design evaluations, it is essential to determine which type and how many isolators will be used in the structure accurately. Whether for a new building or an existing one, it is crucial to examine the condition of the fault at the construction site, investigate the site's characteristics, and consider the structure's features and functional. Typically, seismic isolators should be placed on each load-bearing column in single-storey raft foundation-based structures. However, in double-story raft foundation-based designs, seismic isolators can be placed between two foundations at specific locations, resulting in fewer isolators and cost savings. Nevertheless, the cost of the foundation increases in double-storey designs. In this context, the most cost-effective approach should be determined to decide on the system selection.

To ensure the construction of earthquake-resistant buildings, the Istanbul Project Coordination Unit (IPCU), operating under the Istanbul Governorship, coordinates the use of seismic isolation systems in city hospitals. The Istanbul Project Coordination Unit (IPCU) supervises the administrative, contractor, and control consultancy functions. Discussions with the authorities at the Istanbul Project Coordination Unit (IPCU) have ensured that design, analysis, testing, and application work related to seismic isolation systems in city hospital projects are carried out in accordance with ASCE 7-10 (American Society of Civil Engineers) regulations. Since 2016, the ASCE 7-16 version has also been considered. Concerning the implementation of seismic isolation systems in projects in Turkey, it has been determined that the preferred and used isolators are lead-rubber bearings (LRB) and friction pendulum systems (FPS).

1.1.3. Cost-Benefit Analysis

Cost-benefit analysis is one of the methods for measuring benefits that allows the comparison of the costs required to achieve a product, service, or outcome with the benefits to be obtained. It involves calculating the present value of future gains and enables the comparison of different projects (Ergen, 2008). Moreover, cost-benefit analysis is a valuable technique for determining whether a project is desirable. It involves evaluating and listing all relevant costs and benefits, as well as taking a long view—that is, considering effects in both the near and distant future—and a comprehensive view—that is, accounting for a variety of side effects on a wide range of individuals, industries, regions, etc. Benefit-cost analysis is, as is evident, a crucial tool for determining the relative value of project outcomes concerning their expenses. It enables decision-makers to weigh the pros and cons of several project options and choose the most economical one. The benefit-cost analysis calculates a project's estimated costs and benefits, assisting in the optimal use of resources and ensuring that initiatives chosen have a profitable return on investment.

In this context, for a defined investment project, the benefits and costs it will provide over its entire lifespan are determined in monetary terms. Once benefits and costs are expressed in financial terms, a discount rate is established, and after deducting this rate, the present values of benefits and costs are compared to make a decision on the feasibility of the investment project. If the current value of benefits (F) is greater than the present value of costs (M), proceeding with the investment is considered appropriate. In other words, if $F > M$ or $(F > M) > 1$, the investment project is considered profitable. If the present value of benefits is less than the current value of costs ($F < M$ or $(F < M) < 1$), the investment project is not feasible (Aktan and Sakal, 2022).

2. Materials and Methods

2.1. Survey Systematics

In this study, a binary survey system was employed. Both a pilot survey and the main survey were conducted using Google Forms via email. Initially, a pilot survey was conducted, and necessary adjustments were made based on the results before carrying out the main survey. Surveys are systematic data collection techniques that involve asking questions related to defined hypotheses and issues to source individuals. In social sciences, surveys are tools that standardize observations (Bingöl University, 2022). In a survey conducted by a researcher, it is crucial to determine the sample size to be used in the survey. It is evident that the chosen sample's ability to represent the population is a parameter to be considered for the survey to serve its function (Baştürk and Taştepe, 2013). Methods for assessing the reliability of measurement tools have been developed. An analysis of the questions in this tool is called item analysis. Reliability coefficients are calculated to analyze the reliability of conducted tests. It is essential not to interpret the analysis results of research without conducting reliability and validity analyses. Reliability and validity provide information about the soundness and appropriateness of anything. Here, robustness represents reliability, and suitability represents validity. Validity is a condition related to whether a test measures the property it intends to measure. To claim that a test is valid, it must be able to measure the desired property accurately and without being confused with other properties. The most crucial feature that a valid test should possess is reliability (Terzi, 2009). Survey response rates may vary depending on the mode of administration. It is possible to say that the response rate is higher in face-to-face surveys. A response rate of over 70-80% is expected for surveys. However, to make reliable interpretations and evaluations based on survey results, these rates need to be achieved. As mentioned, survey response rates generally vary between 40-60% (Büyüköztürk, 2005).

2.2. Analysis Method

In seismic isolation systems, effectiveness analysis was conducted using the SPSS (Statistical Package for the Social Sciences) computer program. The aim was to obtain the highest benefit and contribute to the formation and activation of decision-making mechanisms related to the subject.

2.3. Research Model

In our research, binary surveys were conducted using the survey model. The first survey was a pilot survey. In the pilot survey, 71 questions were asked. Data obtained related to seismic isolators and cost-benefit analysis were analyzed, and survey questions were revised based on the hypotheses, resulting in 50 questions for the main survey. Questions that achieved consensus in their answers were removed. Questions with similar meanings and coherence were combined. In some questions with two options for answers, the options were expanded from two to five to provide more variety and categorization. In one question, the options were expanded from a 5-point scale to a 7-point scale to increase the diversity of responses. The same method was used in a second survey application, where the final data related to seismic isolators and cost-benefit were collected. It was determined that seismic isolation systems provided significant benefits. Following this stage, the establishment of decision-making mechanisms or models was facilitated. In this aspect, Figure 2 shows the types of scales and the number of questions in the survey.

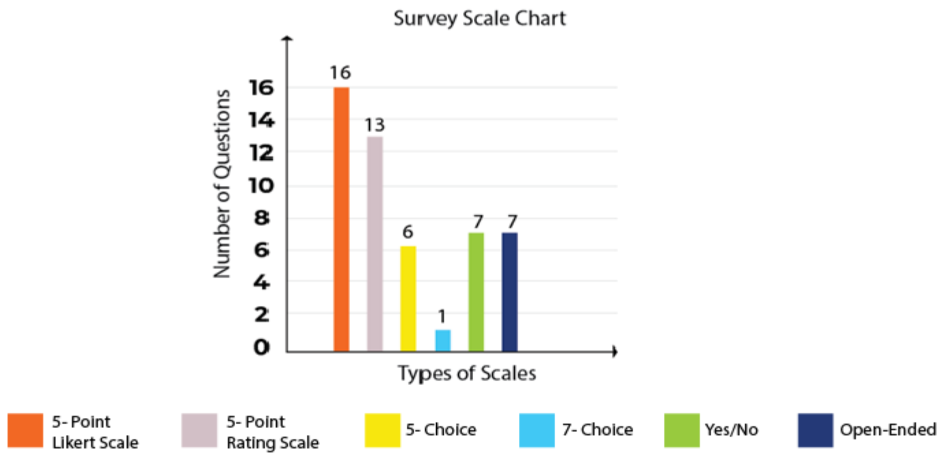

Figure 2: Types of scales and the number of questions in the survey (Ürkmezyel, 2023).

2.4. Universe and Sample

In our research, considering the fact that earthquakes are a universal disaster, we thought of all individuals living within various types of buildings worldwide as the universe. As a sample, we have accepted technical personnel who have been involved in buildings where seismic isolation has been applied in Turkey as a pilot application. Information obtained from the sample group was analyzed to generate relevant data.

2.5. Data Collection

The evidence (data) obtained in our binary survey related to seismic isolator systems' cost-benefit issues and the technical specifications of isolators, including technical material and assembly characteristics, are raw (unprocessed) data. Relevant data were collected from academics at universities in Turkey, technical personnel in prominent construction companies in the construction sector, the Istanbul Project Coordination Unit, technical personnel in the Earthquake Strengthening Association, technical personnel in the Earthquake Isolation Association, and technical personnel in the public sector. The collected data were processed in accordance with the relevant methodologies for use in surveys.

2.6. Data Analysis and Interpretation

To find the highest benefit through comparative analyses, we have processed this raw data into analyzed data. The scientific results obtained were presented both in industry and academia. SPSS (Statistical Package for the Social Sciences) computer software was used for data analysis.

3. Results and Discussion

3.1. Data Collection Methods

The survey created and implemented is an essential source of information and serves as one of the primary tools in this research due to its role as a data collection method. Following the pilot survey application, field survey studies and applications were conducted over a period of 90 days. Another data collection function involved conducting one-on-one personal interviews at the Istanbul Project Coordination Unit (IPCU), which produces projects related to seismic protection in Istanbul (Ürkmezyel, 2023).

3.2. Reliability Analysis

Cronbach's α (alpha) coefficients were calculated to determine the reliability levels of the variables. Three different variables were identified for the calculation of Cronbach's α (alpha) coefficient. In the applied survey, questions containing the variables were identified and grouped. Seven questions were determined for the cost variable, seven questions for the cost-benefit variable, and three questions for the variable related to the implementation of seismic isolation systems. Cronbach Alpha has provided information about internal consistency. It evaluated how consistent the answers given to the items in the three groups were. A value of 0.70 or higher indicates a high level of consistency.

Formula (1) is used to calculate the Cronbach's Alpha coefficient.

$$\alpha = \frac{K}{K-1}\left[1 - \frac{\sum S_J^2}{S_X^2}\right] \quad (1)$$

K= Number of test questions

S_X^2 = Test variance

S_j^2= Variance of item j

As shown in Table 3, the reliability coefficient (Cronbach's α) obtained from the variables is calculated as Cost (0.503), Cost-Benefit (0.891), and Implementation of Seismic Isolation Systems (0.594). A value of 0.70 is considered acceptable for the variables. In this regard, it can be observed that low reliability is obtained for Cost and Implementation of Seismic Isolation Systems, while high reliability is obtained for Cost-Benefit. As is evident, the reliability coefficients obtained from the variables vary between 0.503 and 0.891.

Table 3: Cronbach's α reliability coefficients for cost, cost-benefit, and seismic isolation system application (Ürkmezyel, 2023)

	Cronbach Alpha
Cost	0.503
Cost-Benefit	0.891
Implementation of Seismic Isolation Systems	0.594

3.3. Statistical Findings of the Applied Methodology

3.3.1. The Examination of Participants' Perspectives on Seismic Isolation Systems

The table provided in Table 4 examines the participants' perspectives on seismic isolation systems. Table 3 displays the number of participants, n, the mean (x̄), and the standard deviation (s) regarding seismic isolation systems. Table 3 illustrates the number of participants (n), the mean (x̄), and the standard deviation (s). Through the statistical interpretation of the responses given in the survey regarding the benefits, cost, implementation, periodic inspection, and maintenance aspects of the selected seismic isolation systems as presented in Table 3, it has been observed that adopting seismic isolation systems that effectively dampen earthquake forces and their implementation as a government policy would pave the way for research and development in this field. Furthermore, it has been deemed appropriate to provide state incentives both to investors who produce or will produce these systems and to end-users, the citizens. It has been concluded that the magnitude of the maximum benefit provided by seismic isolation systems in terms of life and property protection during earthquakes exceeds their cost. A perception has been established that the usage rates of seismic isolation systems in both public and private sector buildings in Turkey will increase further. There is unanimous agreement on the necessity of implementing these systems with zero margin for error by competent technical personnel. The need for periodic inspection and maintenance procedures after the implementation of seismic isolation systems has also been emphasized.

3.3.2. The Examination of Participants' Perspectives Based on Their Ages

Firstly, the age variable, initially categorized as "20 or younger," "20-30," "30-40," "40-50," and "50 or older," was recoded into "Up to 30," "30-40," "41-50," and "51 and above." This recoding was applied because there were few participants in the "20 or younger" category.

Table 5 displays the formulas for one-way ANOVA calculations for unrelated measurements. In Table 4, the calculations for ANOVA utilized the formulas from Table 4. ANOVA was performed to assess the significance of the difference between means of unrelated two groups. The square root of the F value was calculated to obtain the t-value for the same data using the unrelated t-test, yielding identical results. The significance level (p) remains constant, thus resulting in no change in outcomes. If ANOVA indicates a significant difference between the means of two groups, as with the t-test, interpretations are based on the magnitudes of the mean values.

KT: The sum of squares

sd: Degrees of freedom

KO: Mean squares

F-Ratio: Test statistic of ANOVA

F: The probability of obtaining by chance is determined based on a theoretical F distribution

p: The significance level

The age variable, according to the recoding, has been analyzed and interpreted as "Up to 30," "30-40," "41-50," and "51 and above" categories. Overall, a positive perspective towards the use of seismic isolation has been observed within the specified age groups. One-way analysis of variance (ANOVA) was performed for unrelated samples for participant age.

Table 4: Averages of participants' perspectives on seismic isolation systems

Item	n (The number of participants)	$\overline{X}$ (The mean)	S (The standard deviation)
10 A	100	3.77	1.30
10 B	86	0.83	1.29
11 A	93	2.08	1.58
11 B	95	3.00	1.56
12 A	98	3.87	1.29
12 B	87	1.24	1.42
14 A	97	3.67	1.28
14 B	82	1.37	1.44
19 A	98	3.97	1.31
19 B	82	0.82	1.33
20	97	4.28	1.09
21	97	3.87	0.87
22	97	4.33	0.80
23	97	3.89	0.97
24 A	93	4.17	1.11
24 B	85	1.18	1.36
25	97	3.98	0.84
26	97	4.31	0.82
29	97	4.20	0.75
31	98	3.56	1.24
32	97	3.89	0.96
33 A	96	4.08	1.18
33 B	80	1.09	1.48
35	97	4.39	0.88
37	97	4.26	0.63
38	98	4.30	0.92
39	96	4.07	0.97
41	97	4.11	0.73
43 A	94	3.10	1.67
43 B	88	2.10	1.81
44	96	4.04	0.89
45	95	4.06	0.85
46 A	95	4.05	1.23
46 B	85	2.44	1.82
47 A	95	3.84	1.32
47 B	82	1.62	1.47
48 A	95	3.53	1.41
48 B	87	2.70	1.87
49 A	96	4.00	1.25
49 B	80	1.41	1.44
50 A	93	3.47	1.46
50 B	87	2.14	1.69

3.3.3. One-Way Analysis of Variance (ANOVA) for Unrelated Samples for Participant Age

The participants' age was subjected to a one-way analysis of variance (ANOVA) for unrelated samples, focusing on selected questions and their analyses. The analysis results are provided in Table 6. Upon examining Table 6, it is observed that the p-values highlighted in yellow indicate significant differences in mean scores for age groups 19A, 19B, 24A and 24B [$p < .05$]. To discern between which groups the differences lie, a post-hoc test was conducted. In Table 6, n represents the number of participants, $\bar{x}$ indicates the mean, s denotes the standard deviation, and p represents the probability value indicating statistical significance.

According to the post-hoc test, for group 19A, the mean score of participants aged "41-50" (mean = 3.30) is lower than the mean scores of those aged "Up to 30" (mean = 4.40) and "30-40" (mean = 4.17). For group 19B, the mean score of participants aged "41-50" (mean = 1.63) is higher than the mean scores of those aged "Up to 30" (mean = 0.29) and "30-40" (mean = 0.73).

For group 24A, the mean score of participants aged "51 and above" (mean = 3.60) is lower than the mean scores of those aged "Up to 30" (mean = 4.32) and "30-40" (mean = 4.48).

For group 24B, the mean score of participants aged "51 and above" (mean = 2.28) is higher than the mean scores of those aged "Up to 30" (mean = 0.50), "30-40" (mean = 1.12), and "41-50" (mean = 1.06).

3.3.4. The Examination of Participants' Perspectives Based on Their Disciplines

The discipline variable, initially categorized as "Civil Engineering," "Environmental Engineering," "Architecture," "Geological Engineering," "Geophysical Engineering," and "Other," was recoded into "Civil Engineering" and "Other." This recoding was performed because there were few participants in categories other than "Civil Engineering.

The independent samples t-test analysis was conducted for the participants' branches.

In the calculations for the t-test analysis, formula (2) is utilized.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\left(\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{(n_1-1)+(n_2-1)}\right)\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \quad (2)$$

t : Test value

X: The mean

n: The number of participants

s: Standard deviation

Table 5: One-Way ANOVA for unrelated measurements (Formulas)

The source of variance	The sum of squares (KT)	Degrees of freedom (sd)	Mean squares (KO)	F-Ratio
Between groups	KT_A	A-1	$[KT_A / A-1] = KO_A$	KO_A / KO_e
With in groups	KT_e	n-A	$[KT_e / n-A] = KO_e$	
Total	KT_T	n-1		

Table 6: ANOVA results of participants' scores obtained from items by age

Item	Group	n (The number of participants)	$\overline{X}$ (The mean)	S (The standard deviation)	p (Represent the probability value	Significant
19 A	1 30 up to	25	4.40	0.91	.029	1-3, 2-3
	2 30-40	29	4.17	1.07		
	3 41-50	20	3.30	1.56		
	4 51 an above	24	3.83	1.52		
19 B	1 30 up to	24	0.29	0.69	.017	1-3, 2-3
	2 30-40	26	0.73	1.22		
	3 41-50	16	1.63	1.59		
24 A	1 30 up to	25	4.32	0.80	.041	1-4, 2-4
	2 30-40	29	4.48	0.74		
	3 41-50	19	4.11	0.94		
	4 51 an above	20	3.60	1.73		
24 B	1 30 up to	24	0.50	0.78	.000	1-4, 2-4, 3-4
	2 30-40	26	1.12	1.18		
	3 41-50	17	1.06	0.90		
	4 51 an above	18	2.28	1.90		

According to the analysis results of the data obtained from our survey, it is observed that participants in the field of Civil Engineering reached more significant results compared to participants from other professional groups. Participants with a specialization in Civil Engineering have achieved positive, constructive, and encouraging results in terms of the design, production, development, implementation, maintenance of seismic isolation systems, and the reflection of financial facilities provided by the government to producers and end-users in this regard.

3.4. Results

Seismic isolation systems are an evolving technology, a technically complete and secure system. They have only recently started to gain recognition in Turkey and are being implemented in city hospitals, airports, and certain strategic private project structures. From the investor's perspective, the cost parameter of the seismic isolation system can trigger associations against the implementation of this system, potentially negatively affecting the development of seismic isolation systems. However, previous studies have found that the cost of seismic isolation systems in a structure account for 12.76% of the total construction cost. It has been determined that as the seismic isolation system develops and competition in the market increases, the cost of this system will decrease. Additionally, previous studies have shown that as the overall construction cost of major projects increases, the cost ratio of the seismic isolation system decreases.

In terms of cost-benefit analysis, even though the implementation of seismic isolation systems in critical strategic structures like city hospitals may be expensive, it is considered meaningful from a cost-benefit analysis perspective because it not only ensures safety but also protects the building and expensive equipment within, potentially making it self-amortizing in a very short time. This indicates that the building's importance is a decisive parameter in choosing whether to prefer seismic isolation systems.

Structures utilizing seismic isolation systems should undergo periodic checks and emergency checks after earthquakes, and detailed inspections should be conducted if any abnormalities are detected during these checks. Parallel to these inspections, these structures need to be continuously monitored with Building Health Monitoring systems. It should be monitored by sensors placed on the structure to determine whether the vibration period of the structure matches the design period. Measurement values should be determined with the help of sensors placed on the structure. Furthermore, it is necessary to establish an automated Decision Support System (DSS) in the computer and software environment that will automatically report the results of the measurement. The data obtained from the Decision Support System should be evaluated by expert engineers. Building Health Monitoring is a relatively new concept in Turkey, and it is recommended to become widespread quickly. In structures using seismic isolation systems, seismic protection calculations and applications should be carried out to prevent damage to non-structural elements such as heating, cooling, ventilation, air conditioning, fire, natural gas installations, and elevator systems due to oscillation and vibration caused by earthquake forces. Additional connections of systems, such as water, natural gas, electricity, and sewage, will be attached to the structure from the outside, and it has been determined that they should be designed flexibly to withstand the vibration and oscillation caused by earthquake forces. When the survey results are evaluated from Turkey's perspective, according to project analyses, two types of seismic isolators are used in public buildings such as city hospitals. These are LRB (Lead Rubber Bearing) and FPS (Friction Pendulum System). FPS (Friction Pendulum System) is produced in Turkey.

However, in the results of surveys regarding public spaces, in public schools, it was determined that seismic isolator installation applications have not yet been carried out, considering the required seismic performance level, approximately 8 hours of service per day, and cost parameters. In some individual applications, works have been conducted in buildings where seismic isolator applications are carried out according to the ASCE 7-10 (American Society of Civil Engineers) regulation. Since 2016, the ASCE 7-16 version has been considered.

In the design, prototype preparation, and production stages of seismic isolators, Design Supervision and Control Services for Special Buildings Under the Regulation of Design of Significant Buildings, which is coordinated by the Ministry of Environment, Urbanism, and Climate Change, are provided by design supervisors who currently continue their inspection duties in Turkey. This regulation was revised and came into force with the publication in the Official Gazette on September 28, 2022. In the early stages of work on these issues, TS EN 15129 Specifications were heavily utilized. Later, the requirement for having the CE (Conformite' Europe'ene) European Conformity Certificate for working on seismic isolation topics was established. Furthermore, it has been stated that the additional tests mentioned in the Turkish Building Earthquake Regulation 2018 should also be performed.

Survey results showed that the fact that Turkey's current building stock needs to be earthquake-resistant has revealed the necessity for these activities to continue increasing as a state policy. As can be understood from the survey application study, the sectoral application experience of the survey participants on seismic isolation is extremely limited (Figure 3). In the 5th question of the survey presented in Figure 3, participants were asked about their years of experience related to seismic isolation systems. Out of 68 respondents, 68.7% reported having 0 years of experience, 20 respondents (20.2%) had 1-5 years of experience, five respondents (5.1%) had 6-10 years of experience, four respondents (4%) had 11-15 years of experience, and two respondents (2%) had 16 years or more of experience. It was found that less than half of the participants have experience in the field of seismic isolation systems.

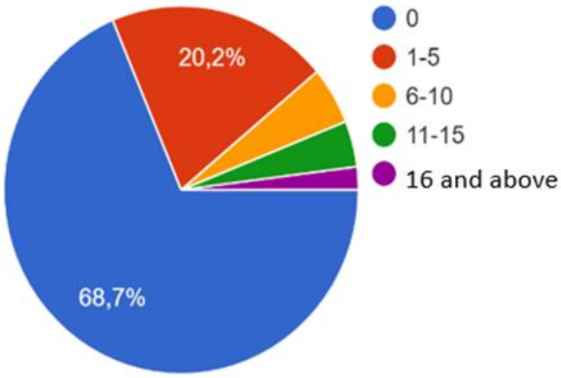

Figure 3: Assessment of participants' years of experience related to seismic isolation systems (Ürkmezyel, 2023).

In the 20th question of the survey presented in Figure 4, participants were asked about their thoughts on whether seismic isolation systems applied to structures on construction sites should be implemented with zero margin of error by competent technical personnel. The results showed that out of 96 respondents, 83 individuals (86.5%) strongly agree or agree, five respondents (5.2%) are undecided, and eight respondents (8.4%) strongly disagree or disagree.

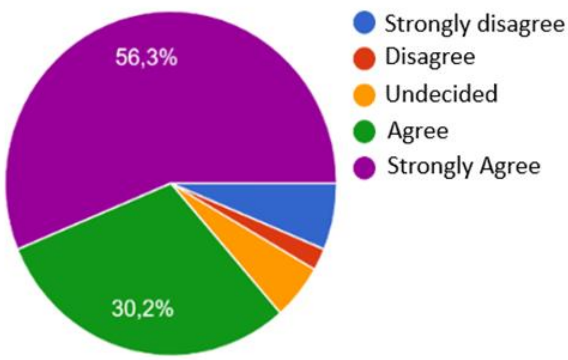

Figure 4: Evaluation of participants regarding the flawless implementation of seismic isolation systems on structures by competent technical personnel at construction sites (Ürkmezyel, 2023)

In the 47th question of the survey presented in Figure 5, respondents were asked about their thoughts regarding the implementation of seismic isolation systems within a certain price range in seismic isolation systems. After analyzing the characteristics and behavior of buildings and foundations, the type and quantity of isolators used in the structure are determined. The type and technical specifications of isolators vary in price.

Therefore, there is a specific price range within the cost system of seismic isolation systems. Participants were asked to mentally evaluate the implementation of the seismic isolation system within this cost system. Three respondents strongly agree at 0 degrees, four respondents at 1 degree, eight respondents at 2 degrees, twelve respondents at 3 degrees, and thirty-one respondents at 4 degrees, and thirty-six respondents at 5 degrees are in complete agreement with the idea of a logical cost system and are in favor of implementing the seismic isolation system. Twenty respondents strongly agree at 0 degrees, twenty-seven respondents at 1 degree, sixteen respondents at 2 degrees, seven respondents at 3 degrees, and five respondents at 4 degrees and 5 degrees believe that it imposes a very significant extra cost on the building formation. The implementation of the seismic isolation system is not essential. If necessary and more cost-effective, they prefer strengthening.

3.5. Discussion

It was observed that more than half of the participants in the survey generally considered themselves insufficient in both theoretical and practical aspects of seismic isolation systems. However, it was also determined that more than half of the participants did not follow current articles and regulations on seismic isolation systems and did not attend conferences. Therefore, it has been established that awareness of seismic isolation systems is insufficient.

When designing a seismic base isolation system for a building, it is necessary to make a preliminary design based on the design information of a previously completed project or technical information obtained from the manufacturer, prepare a prototype of the seismic isolator, and then carry out necessary tests and evaluate the test results. If necessary, corrections should be made in the preliminary design phase. This systematic approach is being implemented as a preliminary work. More than half of the participants in the survey, when evaluating the most crucial difference in functionality between a conventional reinforced concrete building and a building with seismic isolation, believe that a building with seismic isolation provides high performance in terms of earthquake protection. They think that such a building continues to function after an earthquake, is safer, exhibits flexible and ductile behavior, provides a sense of security, is expected to incur minimal damage, and evokes current technology and safety concepts. Based on these results, it is recommended to use seismic isolation systems in buildings. More than three-quarters of the survey participants believe that local or imported seismic isolators used in Turkey have a certain cost. However, they also think that, in return, these isolators provide maximum safety in terms of life and property protection during possible earthquakes. They find that this cost can be justified and, in fact, can bring significant benefits, providing peace of mind.

The majority of the participants in the survey emphasize the importance of an effective periodic inspection and maintenance system for structures with seismic isolation systems. They recommend that such a system should be in place for the continued safety and the smooth operation of seismic isolation systems. They believe that seismic isolation systems should be covered by a periodic inspection and maintenance system throughout their service life.

The majority of the participants in the survey find that periodic inspections are not enough for seismic isolation systems. They believe that, in addition to periodic inspections, there should be "emergency checks" carried out by expert engineers immediately after disasters. Any abnormal conditions found during periodic or emergency checks should be subjected to detailed inspections by expert engineers. Most of the participants in the survey prefer the approach of the Japanese Society of Seismic Isolation (JSSI), which encourages collaboration between the building designer, damper manufacturer, and contractor, as outlined in the guidelines issued by JSSI in 2003. They believe that this approach will positively contribute to achieving the desired performance in buildings.

The survey results suggest that there is a consensus among the participants about the need for seismic isolation systems to be used in all buildings to ensure the safety of life and property. They emphasize that whether in the public or private sector, every building in which people reside or work should have a seismic isolation system. More than a quarter of the participants suggest that, primarily, seismic isolation systems should be used in strategic buildings like city hospitals and airports, considering the greater importance of societal benefits over costs in the public sector.

The majority of the participants, taking into account Turkey's location in one of the major seismic zones and the possibility of strong earthquakes in the future, emphasize the importance of applying seismic isolation systems to all structures, irrespective of their sector (public or private). A significant majority of the participants agree that the cost of ensuring the safety of life and property during severe earthquakes far outweighs the cost of not implementing seismic isolation systems, especially when considering historical earthquakes such as the 1906 San Francisco and 1999 Kocaeli earthquakes, where the costs in terms of life and property damage were high. Two-thirds of the participants believe that the benefits of seismic isolation systems are increasingly recognized and validated after the occurrence of major earthquakes worldwide. As a result, there is a growing demand for these systems in global markets. Considering Turkey's location in a major earthquake-prone zone, many participants suggested that the Turkish government should prioritize the use of seismic isolation systems to protect against earthquake damage.

Figure 6 presents the Cronbach’s Alpha reliability coefficients for the three main variables used in the study: Cost, Cost-Benefit, and Implementation of Seismic Isolation Systems. The widely accepted reliability threshold of 0.70 in the literature is indicated by the red dashed line. The analysis results show that the Cost-Benefit variable, with a value of 0.891, demonstrates a high level of reliability, well above the acceptable threshold. In contrast, the Cost (0.503) and Implementation of Seismic Isolation Systems (0.594) variables fall below the 0.70 threshold, indicating relatively lower levels of internal consistency. These results reveal that, within the scope of this study, the data obtained for the cost-benefit variable are particularly strong in terms of reliability.

4. Conclusion and Recommendations

4.1. Recommendations

In conclusion, the necessity of utilizing seismic isolation systems in buildings to ensure the safety of life and property against earthquakes has been established. It is evident that constructive recommendations will contribute positively to the development of seismic isolation systems within this framework.

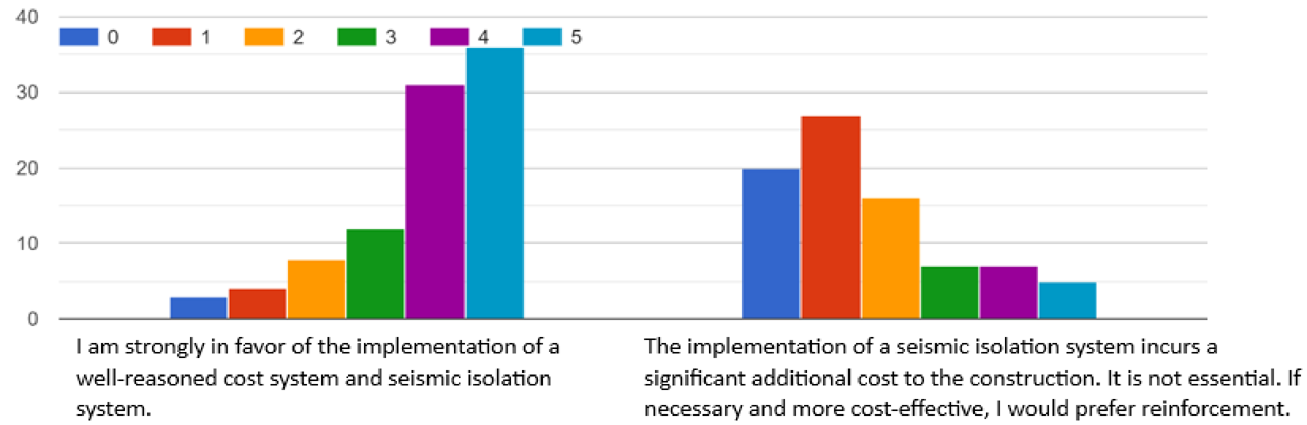

Figure 5: Evaluation of participants regarding the impact of the price parameter of isolators on the implementation (Ürkmezyel, 2023)

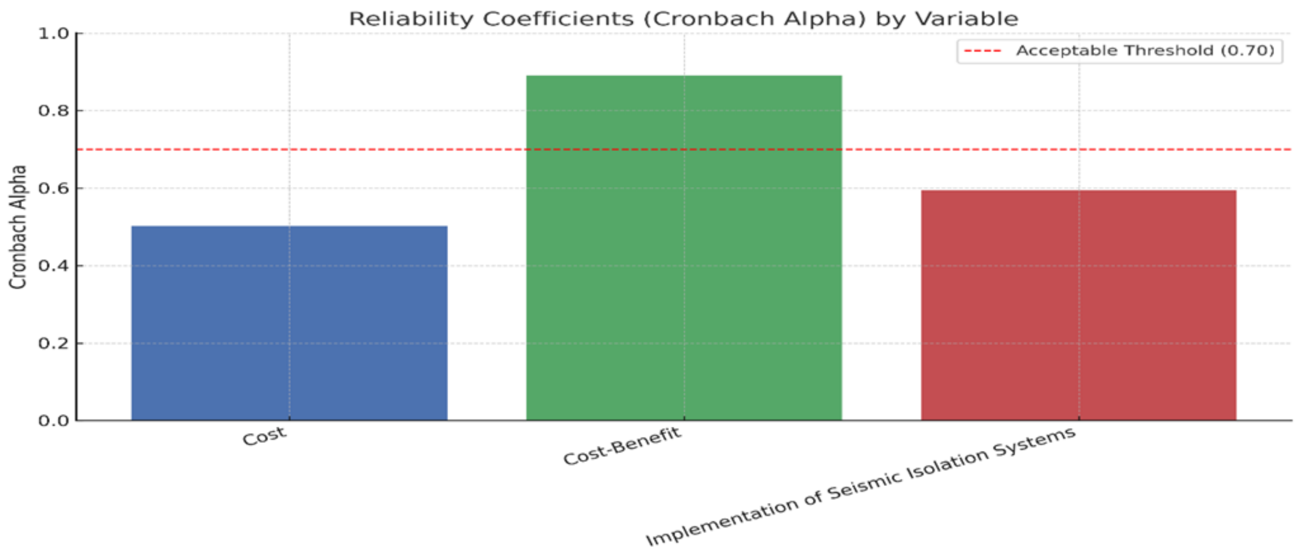

Figure 6: Cronbach's alpha reliability coefficients for the variables used in the study.

This research study suggests that the Turkish public authorities should take action to encourage investors and provide economic support to Turkish citizens by offering credits. This support should facilitate the implementation of seismic isolation systems in the buildings where they reside, ultimately safeguarding the lives and properties of Turkish citizens.

Increasing awareness about the importance of horizontal rigidity in rubber-based seismic isolators (bearings) in counteracting seismic horizontal dynamic forces and ensuring the safety of the structure against damage is essential. For this reason, it is recommended that Turkish standards should be created by relevant scientific and technical committees, with guidance to adapt seismic isolation systems to Turkey's conditions rather than staying solely in the shadow of foreign regulations and standards.

To increase public demand for seismic isolation applications, it is recommended to promote these systems to the general public by using various types of advertisements and technical approaches. Public service announcements in a format understandable to the public should be prepared and broadcast on all TV channels to raise awareness.

Firms producing seismic isolators used in seismic isolation systems in Turkey should not approach this issue purely from a commercial standpoint. These companies should have structural dynamics experts and consultants in their organizations who can assist clients with isolator size, testing, placement recommendations, and related calculations.

To allow professionals working in the field of seismic isolation systems to develop themselves, their employing institutions and organizations should provide them with the opportunity to follow current articles and regulations and attend conferences.

The primary cost driver in seismic base isolation is identified as seismic isolators. To promote the economical use of seismic isolation in buildings, it is recommended that the government, as a policy, incentivizes investors by facilitating the establishment of facilities for seismic isolator production and offering tax cuts and low-interest, long-term bank loans for ease of sales. This is expected to increase the usage rate of seismic isolators in Turkey. Additionally, investors are encouraged to consider investing in this sector, which can be profitable in the medium and long term.

Considering the cost impact of the 50-60-year service life of rubber-based isolators, the high initial investment costs are recognized as a potential deterrent. In this context, it is recommended that the government provide support for urban transformation by offering loans for the implementation of seismic isolation. Furthermore, it is suggested that financial support be provided to end-users for maintenance costs during the service life of rubber-based isolators.

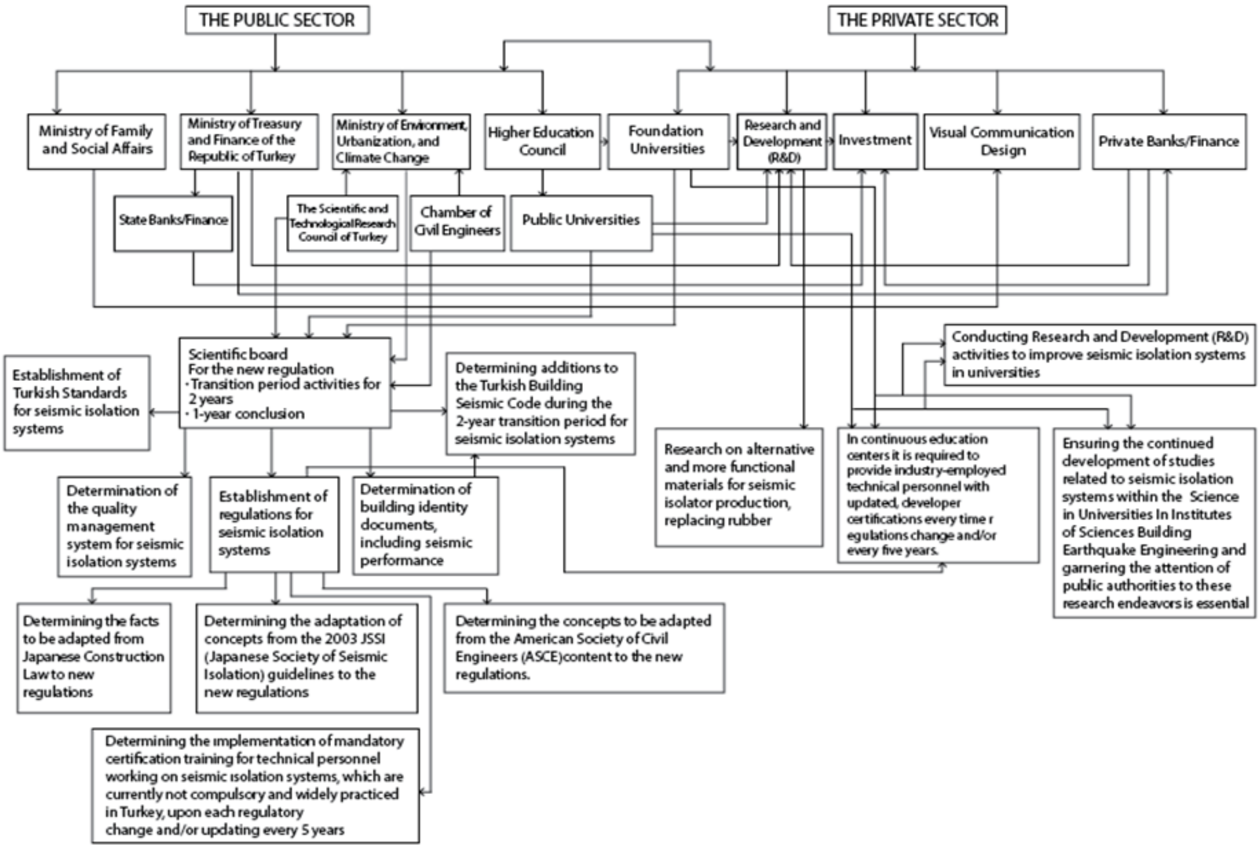

Figure 7: Systematics of the contribution of the public and private Sectors to the development and implementation of seismic isolation systems (Ürkmezyel, 2023).

In Turkish buildings, in addition to the use of energy performance certificates, a general requirement should be introduced to obtain building identity information. A table with QR codes of specific dimensions should be prepared and placed at the entrance of the building. A barcode system application should be developed for mobile phones to access information about the building at two levels. The first level should be accessible to ordinary citizens, providing information about the construction company details, year of construction, compliance with specific earthquake regulations, and earthquake performance of the building. The second level should allow relevant technical personnel in local government organizations to access more specific information about the building with a password. Information about the architectural, reinforced concrete and static, mechanical, and electrical projects, as well as information about the companies that prepared these projects, should be accessible. The obligation to obtain a building identity certificate for all buildings can be included in new legislation or added to the Turkish Building Earthquake Regulation 2018.

The Istanbul Project Coordination Unit (IPKB) has jurisdiction and activities within the boundaries of Istanbul province. It has achieved successful work in the field of seismic isolation system applications for earthquake protection of buildings. In this regard, a general directorate should be established under the coordination of Ministry of Treasury and Finance and the Ministry of Environment, Urbanization, and Climate Change, which will focus on regional coordination units to be established primarily in seven geographical regions of Turkey and in cities identified with seismic risk. These units should be put into operation as regional project coordination units for seismic hazards. It is recommended that regional project coordination units should be established in 81 provinces of Turkey within two years. It is recommended that the use of the building health monitoring system that detects the responsive behaviour of buildings against ground movements and creates a Decision Support System (DSS) should be widespread in Turkey.

The contribution mechanism of the public and private sectors to the development and application of seismic isolation systems is illustrated in Figure 7.

In the context of the public sector, it is recommended that efforts should be made to develop seismic isolation systems and encourage their use by the public. This would positively impact the societal benefit of increasing the adoption rate of seismic isolation systems. In the private sector, particularly at the level of holding companies and joint-stock corporations with solid financing, investments related to seismic isolation systems are suggested. It is also recommended that, especially in the production of seismic isolators, they take advantage of government incentives and establish facilities that can compete internationally, while simultaneously establishing testing centers for isolators that conform to international standards.

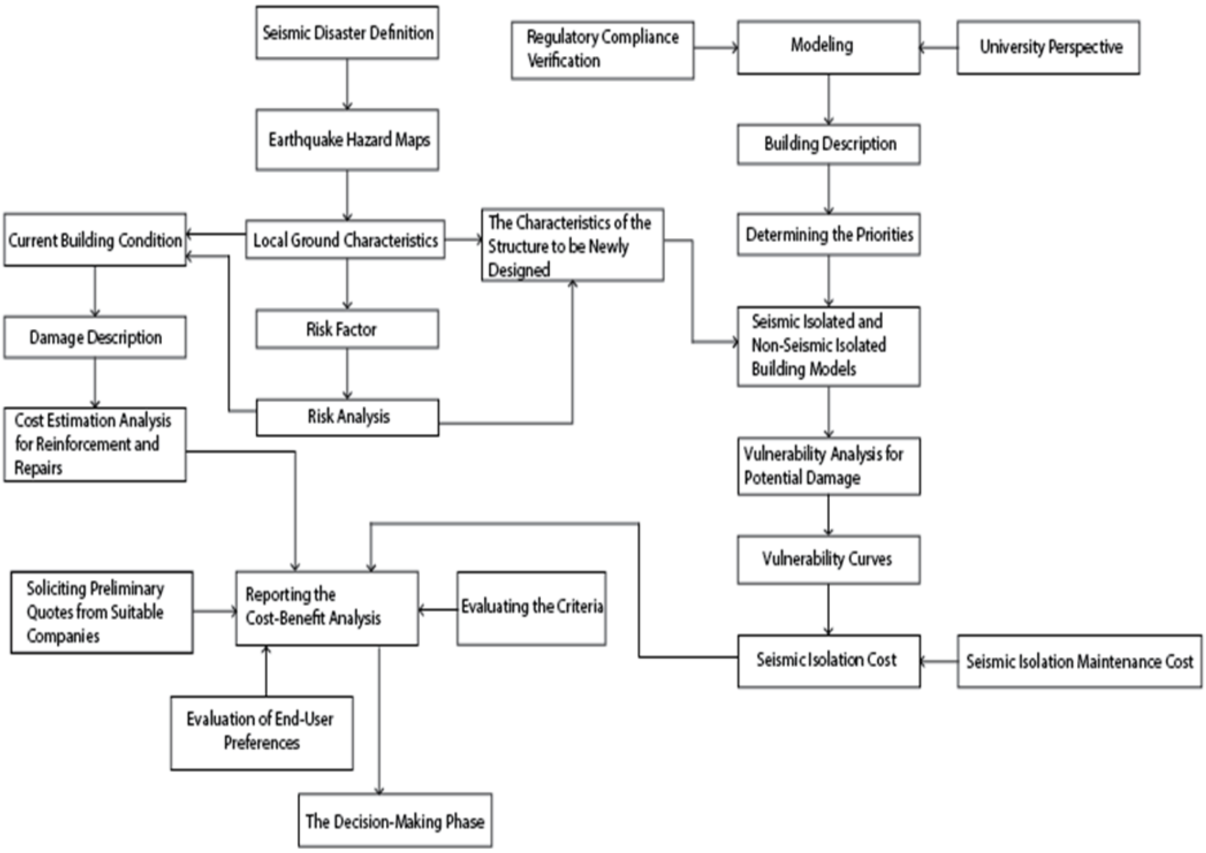

Figure 8: Methodology for benefit-cost analysis of retrofit and/or seismic isolation applications in existing and newly designed buildings (Ürkmezyel, 2023).

The determining factor for the decision on whether to use seismic isolation in newly designed buildings or retrofit existing ones, as depicted in Figure 8, is the cost-benefit parameter.

Analyses conducted on existing structures may lead to the possibility of implementing both seismic isolation and retrofitting measures simultaneously.

The decision-making process involves several key steps:

To begin, defining seismic risk by examining earthquake hazard maps, identifying the local seismic characteristics of the building's location, and considering risk factors is essential. Risk analysis should be conducted and considered as a criterion for both new projects and existing structures. For existing buildings, based on the assumption of damage in the event of an earthquake, a damage definition should be established, and an estimated analysis of retrofitting and repair costs should be performed.

In the case of new construction projects, it is advisable to seek input from universities, ensuring compliance with regulatory standards through appropriate modelling. Following the building's definition, priorities need to be set. Models should be created for both seismic-isolated and non-seismic-isolated structures. After conducting analyses for the building's damage probability, damage probability curves should be drawn, and the costs of seismic isolation and its maintenance should be calculated. In terms of benefit-cost analysis, assessments and reports should consider both the estimated costs of retrofitting and repair and the costs of seismic isolation.

The decision-making process reaches its conclusion by soliciting proposals from suitable firms, evaluating criteria, and considering end-user preferences, leading to a decision on whether retrofitting is needed for existing structures and whether seismic isolation should be employed in newly designed projects.

In conclusion, in line with the results of this research, it is thought that by Evaluating Seismic Isolation Systems in Terms of Benefit-Cost Analysis Using the Survey Technique, both decision-makers and practitioners will maximize the benefit with both road maps developed and the earthquake-safe building stock will increase day by day.

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Artificial Intelligence Statement: The author(s) bear full responsibility for the content and accuracy of their work, including any use of artificial intelligence (AI) technologies, and confirm that they have read the AI Policy, which is accessible on the journal's website.

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