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## Recognition of Current Deficiencies in the Seismic Rehabilitation Procedure of Historical Buildings

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### Abstract

On the one hand, the absence of seismic rehabilitation in conservation projects and restoration of historical buildings and on the other, the territorial characteristics reveal an insufficient cognition and inexperience in conservation. Inadequate knowledge and high level of seismic rehabilitation leads to projects which will not be accepted by conservation authorities owing to massive interventions and ignoring the building value. Therefore, the seismic rehabilitation as a significant issue is obliterated during conservation process. In other words, the effective seismic rehabilitation in conservation process of historical buildings is only possible by recognizing the current deficiencies in seismic rehabilitation procedure of historical buildings and developing its own methodology.

Using logical reasoning, this research tries to represent a theoretical basis of seismic rehabilitation in relation to conservation principles, from the earliest to the most recent approaches, interventions, strategies and rehabilitation solutions. Therefore, this research is theoretical in nature and aims at making seismic rehabilitation of historical buildings distinct from the other ones and divides it to two reinforcement and repairing branches. Thereafter, it focuses on reinforcement branch for its coordination with preventive conservation. Moreover, it offers new definitions of seismic rehabilitation value and the intervention anti-value. The anti-value of intervention will then be recognized for all solutions and rehabilitation levels. Eventually, the intervention network based on the acknowledged rehabilitation aspects such as rehabilitation type, intervention form, rehabilitation cost, returnability limitations and technology type in all solutions is provided. At the end the required infrastructures for exterminating the current deficiencies in seismic rehabilitation of historical buildings are pointed out. Interaction and confrontation of historical conservation ideas and seismic rehabilitation knowledge in defining the strategies and solutions is the prominent feature of this research.

### Keywords

Seismic rehabilitation, Earthquake risk level, Building performance level, Intervention, Value.

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## Introduction

For countries located in the seismic zones, there is no effective measure other than seismic rehabilitation for enhancement of seismic safety and reduction of vulnerability. For this reason, seismic rehabilitation of valuable historical buildings is one of the main practices in historic restoration for countries that are susceptible to earthquakes. The current seismic rehabilitation is consisted of a set of rules, regulations, procedures and techniques that are ratified to increase the seismic safety of existing buildings and not necessarily approved for historical buildings. In other words, issues and guidelines for seismic rehabilitations are unable to provide any specific strategy and tactics for historical buildings due to different structure and features of every building, so that seismic rehabilitation of historic cultural monuments is not considered within the scope of their practice and application. Therefore, the seismic rehabilitation procedures in these kinds of buildings require a quite different specific methodology due to their limitations. In this methodology, the measure of value is the most important criterion for acceptance or rejection of strategies and tactics, though conventions and charters differ in definitions and measurement values and do not follow the same doctrine.

Although the value of historical buildings will decrease after the seismic rehabilitation procedures that require intervention and alterations in various aspects of the building, the durability, lifetime and value of the building will increase after prolonging the building's seismic longevity.

This research question is what are the effective strategies for seismic rehabilitation of historical buildings that are each different in value and limitations?

## Research methodology

This study uses logical reasoning for presenting the theoretical studies on seismic rehabilitation literature combined with preservation principles and provides a theoretical base from the early measures

to up-to-date approaches, intervention and strategies. Therefore, this research is theoretical in nature and reflects the theoretical structures of seismic rehabilitation and analyses its various aspects in historical buildings with an interpretive analytical approach. It also discusses the formation roots and the development procedure and tries to pave the way for conservation cycle by revealing the entity of seismic rehabilitation in historical buildings and recognition of the difficulties and shortcomings in this area.

## Research background

Analysis of seismic behavior in historical buildings is difficult due to the problems of numerical modeling and nonlinear behavior of materials. These problems also result from lack of mechanical properties of materials and structures and the geometric complexity. Nonlinear analysis is the best method for understanding the seismic behavior of historical buildings (Loli, et al, 2015) (Lourenco, 2001: 137). Moreover, the fine, large and homogeneous modeling techniques have been introduced in commercial and non-commercial software (Page, 1978: 1267). Regarding seismic actions and remedial measures for the structural conservation and restoration of cultural heritage, strategies are effectively articulated (Giorgio Croci, 2016: 380) (Tim L, 2015). Researches are also completed about strategies to reduce vulnerability to earthquakes in deteriorated fabrics (Imani, et al, 2016: 67). In addition, the specific methodology for seismic rehabilitation of historical buildings has been developed by linking three categories of financial costs, resistance capacity and architectural value (Meshki, 2002: 87). However the referred methodology is unable to make a logical connection between the standards and is difficult to understand since it is developed based on complex exponential functions.

## Approaches in restoration of historical buildings

Three main approaches to seismic rehabilitation of

historical buildings have been identified. These three approaches are resulted from content analysis of the approaches that have been studied in the past two decades. These approaches are as follows.

• **First approach: Repair**

The repairing approach is based on the non-preventive repairs. Changes in damaged structure of historical buildings including reconstruction, rehabilitation and in some cases renovation are allowed for the building to continue its historical life (Vatani Oskouyi, 2011: 9).

• **Second approach: Reinforcement**

The reinforcement approach is based on the preventive repairs. Changes in damaged structure of historical buildings including reconstruction, rehabilitation are allowed for the building to continue its historical life (Vatani Oskouyi, 2011: 9).

**Third approach: monumental**

This approach does not allow any intervention in historical buildings (Jokilhetto, 2008: 345). Since we have accepted the principle for restoration of historical buildings, there is no room for addressing the third approach in this study. Therefore, it can be indicated that only the two approaches presented in Fig. 1 are considered in insufficient understanding of seismic rehabilitation phenomenon in historical buildings. Innovation and pioneering approaches are required in this field in order to recognize the seismic restoration of historical buildings. Having reviewed the different strategies of seismic rehabilitation of historical buildings in this approach, the buildings are divided into two groups.

The first group doesn't consider the intervention in seismic rehabilitation as a necessary action due to the low level of risk in the region or specific quality characteristics or other causes. For this category of buildings, it is better not to argue the structure and merely consider and conserve the architectural and decorating properties.

The second group includes historical buildings that urgently need seismic rehabilitation. Moreover, rehabilitation strategies consider intervention measures in various aspects. Therefore, recognition

of rehabilitation according to restoration limitation is considerably significant.

**Intervention**

In the field of historical monuments conservation, intervention allows us to enter the normal pace of life of a building and to change and implement intended effects and actions (Staniforth, 2010: 52) which can prolong the building's life or result in damage. Here, the term intervention is used since the natural process from construction to destruction of buildings can be changed or intervened. However, in modern conservation, intervention includes any activity that causes disturbance, invasion or modification in a monument (ICOMOS New Zeland, 1993: 2010). This modification is visually latent, evident or conventional in monuments.

**Latent intervention**

The structural intervention (Fig. 1) refers to a form of intervention in which the building's physical appearance after the seismic rehabilitation and restoration is the same as it was before the restoration. In other words, the seismic rehabilitation measures are not visible in the outer layer and building's façade.



Fig. 1. Two approaches in restoration of historic buildings.  
Source: authors.



Fig. 2. Latent intervention in in restoration of columns in Ali Qapu. Photo: Reza Abouei.



Fig. 3. Evident intervention in Kharraqn tower. Photo: Reza Abouei.

**Evident intervention**

In this type (Fig. 2) obvious internal and external members are added to consolidate the buildings which may lead the building to lose its original authenticity and physical structure after the seismic rehabilitation.

**Prescriptive intervention**

The prescriptive intervention (Fig. 4) is an economic and reliable intervention which is trained and inherited from past generations. By recognizing and understanding the key role of tradition, rituals and social movements and their relation with traditional restoration that is succeeded over the years before the modern restoration, seismic rehabilitation can be majorly developed in terms of simple principles,

methods and strategies. Some prescriptive solutions for structural rehabilitation of historical buildings are as follows:

- Increasing the quality of materials through the modification of mortar or masonry units
- Rehabilitation of load-bearing walls by reducing the height or the free length of the wall and elimination of detachments
- Rehabilitation of roof through decreasing the load and reforming, cohering and correcting the placement of roof on walls.
- Rehabilitation of load bearing walls connections to each other, ceilings and portions
- Rehabilitation of chaining system
- Adding bracing walls and buttress

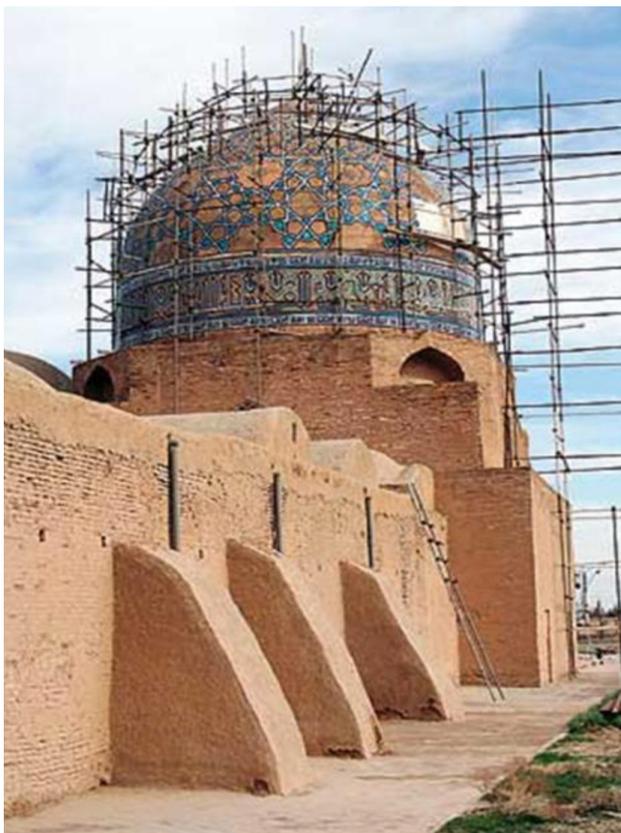


Fig. 4. Adding buttress walls to Jameh Mosque of Saveh. Photo: Reza Abouei.

### An overview of deficiencies

Investigating and selecting the optimal solution among a set of possible solutions require a decision-making knowledge; a type of knowledge that simultaneously identifies the decision variables and constraints in order to accomplish the goal. The intervention type and possible strategies for seismic rehabilitation of historical buildings are different from other buildings. Therefore, they have different decision variables and constraints. Incomplete understanding of seismic rehabilitation purpose in historical buildings leads to confusion in understanding of decision variables and constraints. A look to the deficiencies is an evidence of the claim. The prevalent culture and the need for seismic rehabilitation of historical buildings

The first deficiency is that the most extensive seismic rehabilitation programs have been implemented after massive and destructive earthquakes when the amount of public attention and awareness to the risk has had increased to the highest level. The restoration

operation of damaged buildings in the earthquake and reinforcing the intact buildings had led to a major development program based on regulations that roughly changed after the earthquake. In Italy, the earthquake in Friuli in 1976 and Irpinia in 1980 led to a substantial rehabilitation program to reinforce and restore the stone buildings (Coburn, 1995: 14).

### Negligence and acceptance of non-native and non-economic knowledge

Implementation of rehabilitation programs in countries that have implemented them results in reduction of losses from the future earthquakes. However, the rehabilitation programs can be expensive and the lack of adequate financial resources and time limitations are considered as the second deficiency (Mohebi Moghaddam, 2008: 166).

The accepted criteria for buildings with no historical value and importance include the cost of repairing or reinforcement which is no more than 80% of residual value of the building. Nevertheless, the buildings with historical values are free of these measures. Inevitably, we have to consider the financial resource limitations as one of the major indices in seismic rehabilitation of historic buildings (Ibid).

The default program of seismic rehabilitation in historical buildings is base isolation which is costly and time consuming. Following this strategy and source limitations, the country's most valuable historical monuments are going to be destroyed. In order to make the seismic rehabilitation strategies more efficient, the authorities have to decide to offer novel and innovative courageous solutions. Therefore, more research for finding cost efficient securing methods (repair, reinforcement) of great historical monuments is needed.

### Incomplete assessment of optimal solutions in seismic rehabilitation

Several techniques have been used and developed to repair, reinforce and improve the seismic performance of structures in recent years. The coherence and performance of existing components and added

elements integrated with the existing elements has a key role in improving the building's safety under the forces of an earthquake. Considering that during an earthquake, the exposed structural elements are under the influence of reciprocating forces, it is necessary that the reinforcing and repairing connective elements between the existing and added members be designed for the proper transmission of reciprocating forces and their reactions (Vatani Oskouyi, 2011:18). Regarding the mentioned ideas, the seismic rehabilitation can be discussed from two perspectives.

### Centralized rehabilitation

In a monument with appropriate cohesion but weak resistance, the resistance and stiffness of a limited number of members can be increased. Upgrading the rest of the case that are not rehabilitated, they can be controlled as members and subordinate components according to their imposed changes during the earthquake

### Distributed rehabilitation

The other strategy in rehabilitation of historical buildings is to use reinforcement components that are distributed in the entire building. In addition to integrating of the total building, this type of rehabilitation has more uniform distribution of the whole building capacity. In addition, the imposed force to the foundation is also severely reduced. Reinforced structural integrated systems are more economic and show more resistance and better performance to earthquake forces rather than when they are split to two discrete structures (existing and reinforced) (management and planning organization of the country, 18, 360). Undoubtedly, the third deficiency can be attributed to the lack of consensus on the approaches outlined for seismic rehabilitation of the historical buildings (Fig. 5).

### Improper practices and intervention types in seismic rehabilitation of historical buildings

It has to be accepted that the historical buildings constructed in the past have undergone many tensions.

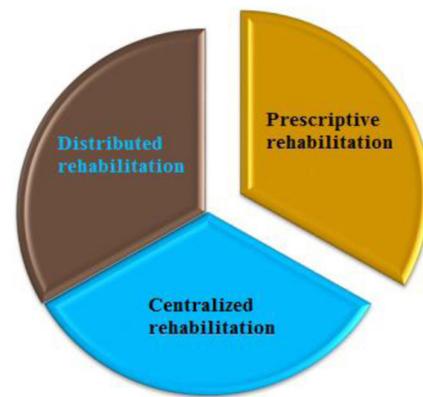


Fig. 5. Common and accepted methods of seismic rehabilitation in restoration of historical buildings. Source: authors.

Thus, by choosing the level of seismic rehabilitation, we have to intervene in building structure (external, internal). As shown in Fig. 6, accepting the conservation and seismic rehabilitation of historical buildings by the first approach (reinforcement) significantly requires less intervention than the second approach (repair). However, accepting the reinforcement or repair in seismic rehabilitation of the historical buildings is very complex.

### Lack of attention to the acceptable levels of seismic rehabilitation of historical buildings

The fifth deficiency is the absence of a clear purpose based on principles of restoration in the seismic rehabilitation of historical buildings. To achieve the rehabilitation goal, the definitions of performance levels and the risk of earthquake are needed. Different levels of performance can be defined for a variety of historical buildings based on the users and their significance. Considering the location of these buildings, several earthquakes can be defined as the considered earthquake, so that rehabilitation measures are devised due to the different levels of rehabilitation presented in Diagram 1 Each level of occupancy in a particular building describes a combination of limitations for damaging of structural and non-structural elements (FEMA, 1988: 16).

In some points of view, selecting the level of seismic rehabilitation of historical buildings is practically based on value engineering, so that the

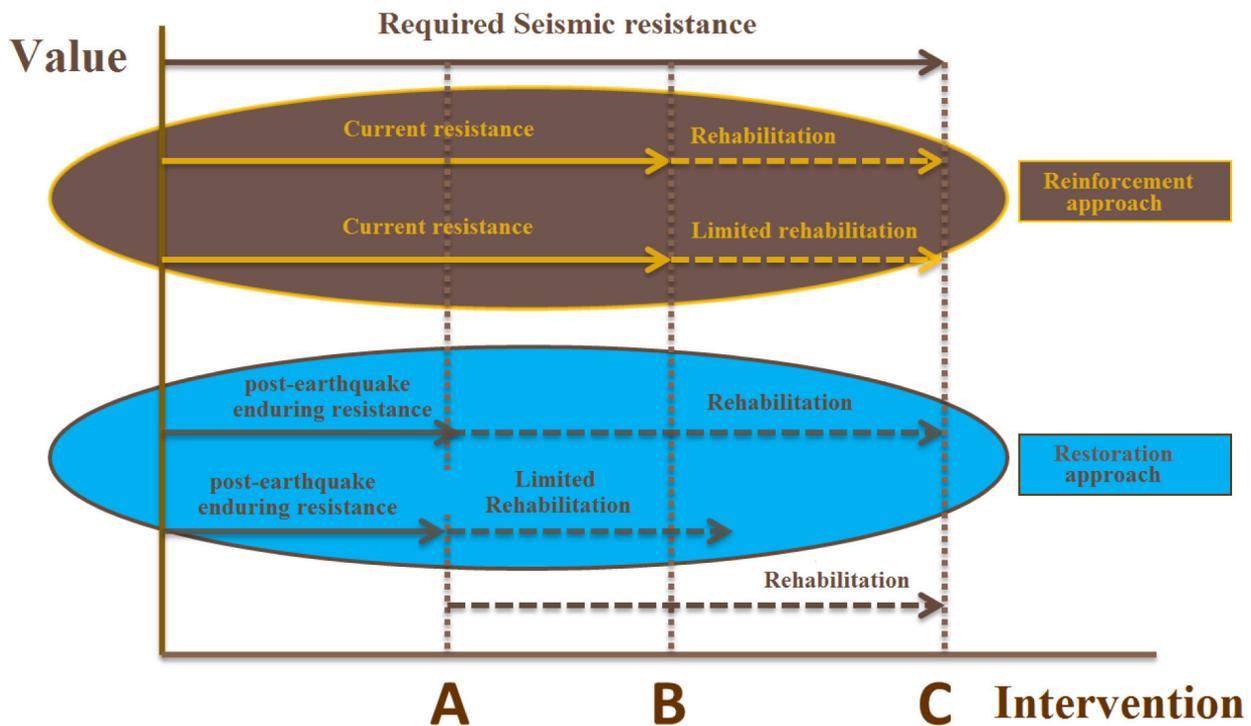


Fig. 6. The relevance and effectiveness of the two approaches of reinforcement and repair with cost and intervention indices. Source: authors.



Diagram 1. Expressing the levels of seismic rehabilitation targets based on risk level and performance. Source: authors.

seismic rehabilitation of buildings eventually leads to increasing of the building value. Whatever the initial value of the building is estimated based on the current situation, it should be recognized that the rehabilitation procedure, which leads to a change in the aspects of building value, decreases the initial value. In return, the prolonging of building’s seismic life can equalize or increase the building value and compensated the decrease in the initial value due to interventions for seismic rehabilitation (Fig. 7) represents the relevance of performance level to the extent of intervention and damage. As a result, decisions making on the level of seismic rehabilitation is a multidimensional and complex matter and dependent on the extent of intervention, vulnerability and most importantly the building value.

### Indefinite philosophy in seismic rehabilitation of historical buildings

The absence of a holistic philosophy in reinforcement of historical buildings can be considered as the sixth deficiency. Although, as shown in Fig. 8 several factors are involved in seismic rehabilitation of these buildings, most focuses are on the increasing of the resistance and stiffness in the whole structure and reduction of the earthquake forces. However, less attention has been paid in reducing the earthquake forces.

Generally, criteria of building rehabilitation should be chosen to respond to the target performance level. It has to be noted that the increase in plasticity can partially compensate for the lack of resistance. However, in case of increasing in deformation, the

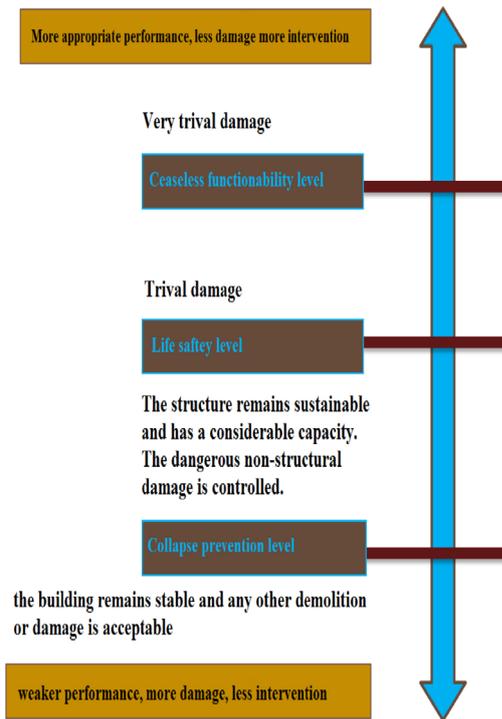


Fig. 7. Strategies in seismic rehabilitation philosophy. Source: authors.

damage to non-structural elements and ornaments that do not have the ability to change begins to rise. The cheapest and easiest way is to increase the lateral resistance and stiffness, though it may not be the best way. Determining the method which has to be used in reinforcement plan requires detailed consultation with experts, so that the building performs as it is expected during an earthquake (Coburn, 1990: 398).

**Contradiction of seismic longevity index and returnability principle in historical buildings**

The seventh deficiency is the contradiction of seismic longevity indices in historical buildings, the utilized materials and their lifespan in seismic rehabilitation, as well as the speed of technology growth and emergence of new innovations and the returnability principle. The overall combination of these factors leads to complex and multivariate equations is seismic rehabilitation of historical buildings.

Seismic longevity in valuable historical buildings is completely different from the new ones, so that seismic life of new buildings is rarely estimated more than a hundred years. In contrast, we believe that the

seismic life of historical buildings is limitless. In addition, the materials used in seismic rehabilitation have a specific life expectancy and after this period, they are expected to be removed and replaced with new materials for the future reinforcements without changing the building. This relationship in Fig. 9 represents seismic rehabilitation measures and compares life expectancy of the rehabilitation projects with the lifespan of the building and returnability, although there is a difference between returnability and effectiveness of seismic rehabilitation (Crochi, 1988: 312).

**Discussion**

Recognizing decision variables as well as the limitations in achieving the goal is influential. The

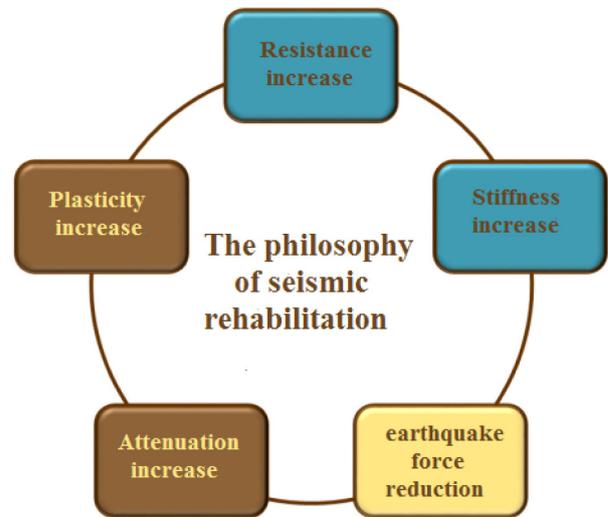


Fig. 8. Building lifespan and returnability principle. Source: authors.

limitations of seismic rehabilitation procedure in historical buildings are depicted in Fig. 10 Here, the procedure efficiency depends on comprehensive choices. The research literature and theoretical foundations indicates that despite the expertise and acceptable access to software and technical documentation, the problem does not lie within seismic rehabilitation analysis process.

Considering the mentioned ideas about the value of seismic rehabilitation and anti-value of intervention, the research comes to this result that value and anti-

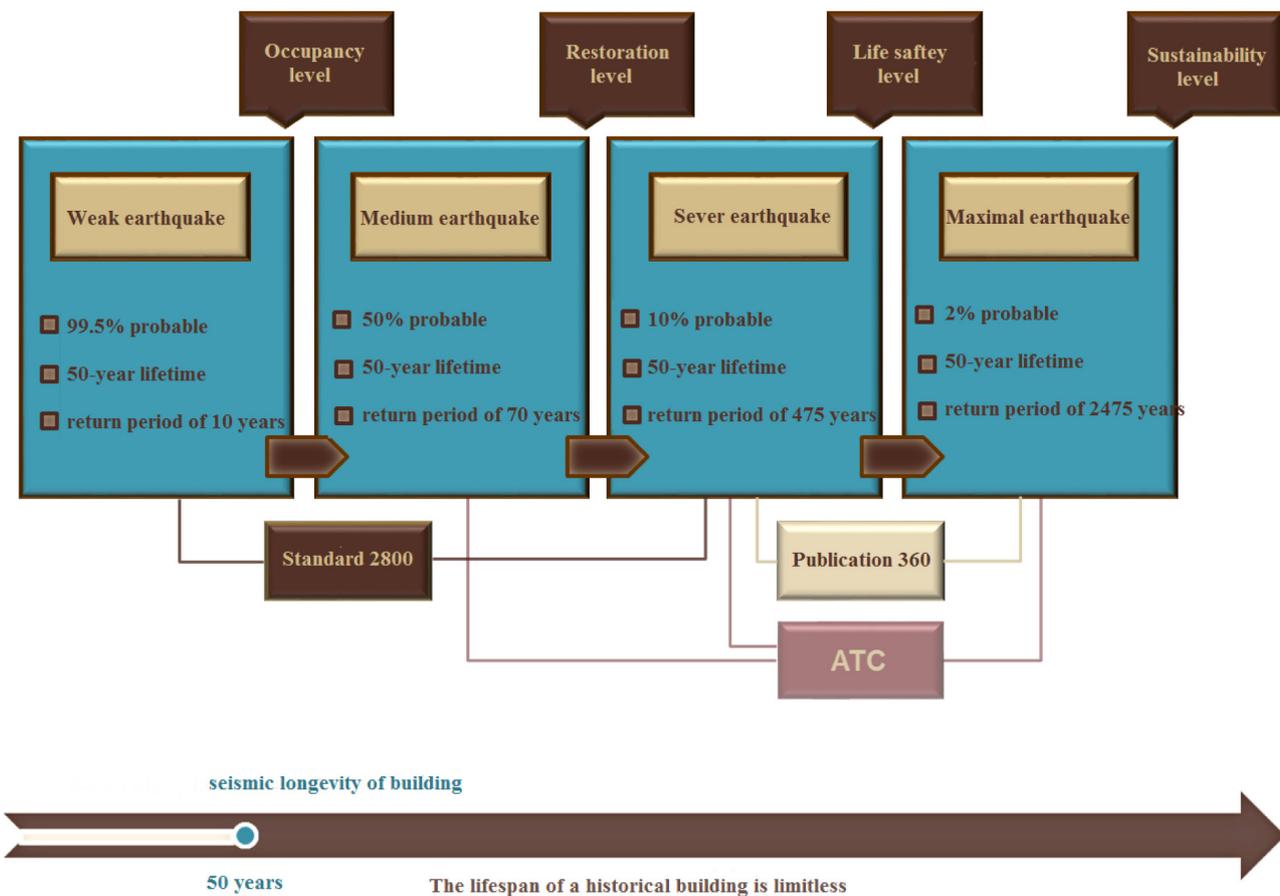


Fig. 9. Seismic rehabilitation procedure in historical buildings. Source: authors.

value decision variables and the objective function of seismic rehabilitation of historical buildings are in practice the maximum value at the end of the process. This means that the seismic rehabilitation of historical buildings has to add to a building's value. Whatever the initial value of a building before rehabilitation is estimated based on the current situation, great changes and anti-value of  $V''$  is expected after implementing rehabilitation strategies. The anti-value solution is simulated in Fig. 11 due to the interventions. If the rehabilitation level increases as Fig. 4, the seismic longevity of the building can rise to  $V'$ . As a result, if the initial value before seismic rehabilitation is estimated as  $V_0$  and the building value after rehabilitation is considered as, the seismic rehabilitation of historical buildings is justifiable when the relations of (1), (2), (3) and (4)

are satisfied.

Relation (1)

$$V_T \geq V_0$$

Relation (2)

$$V_0 + V' - V'' \geq V_0$$

Relation (3)

$$V' - V'' \geq 0$$

Relation (4)

$$V' \geq V''$$

Determining  $V_0$  or the initial value of a building is an extremely complex issue and a big challenge. By eliminating the initial value as a fixed value in relation 2, relation 4 is created. At the end, relation 4 is introduced as a term for accepting the seismic rehabilitation of historical building with reinforcement approach.

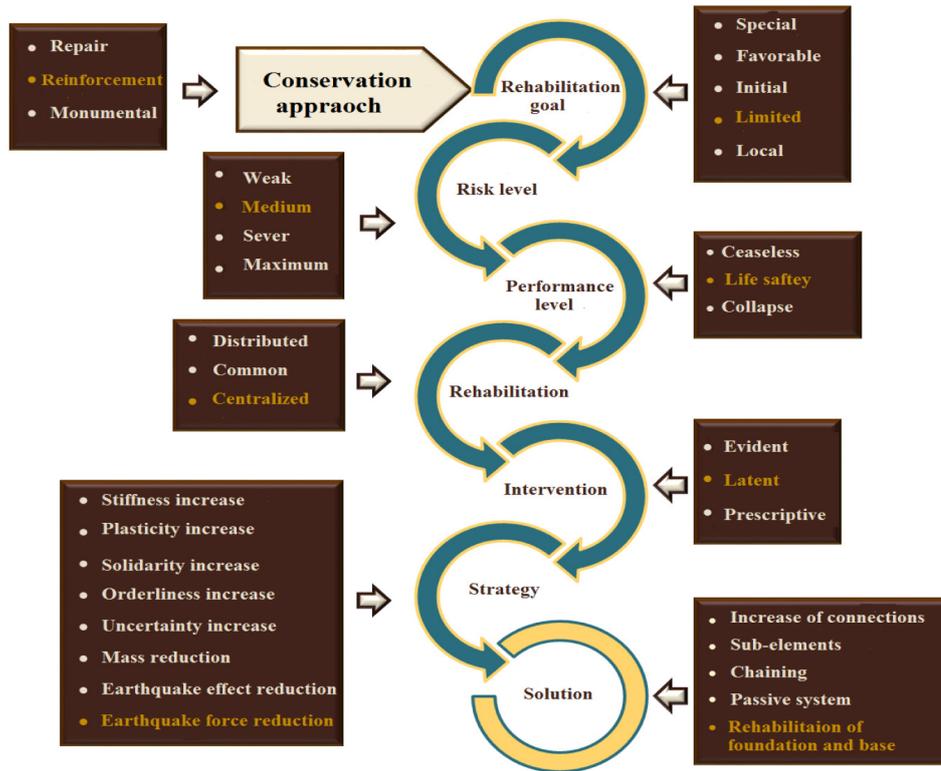


Fig. 10. Anti-value networks in all solutions. Source: authors.

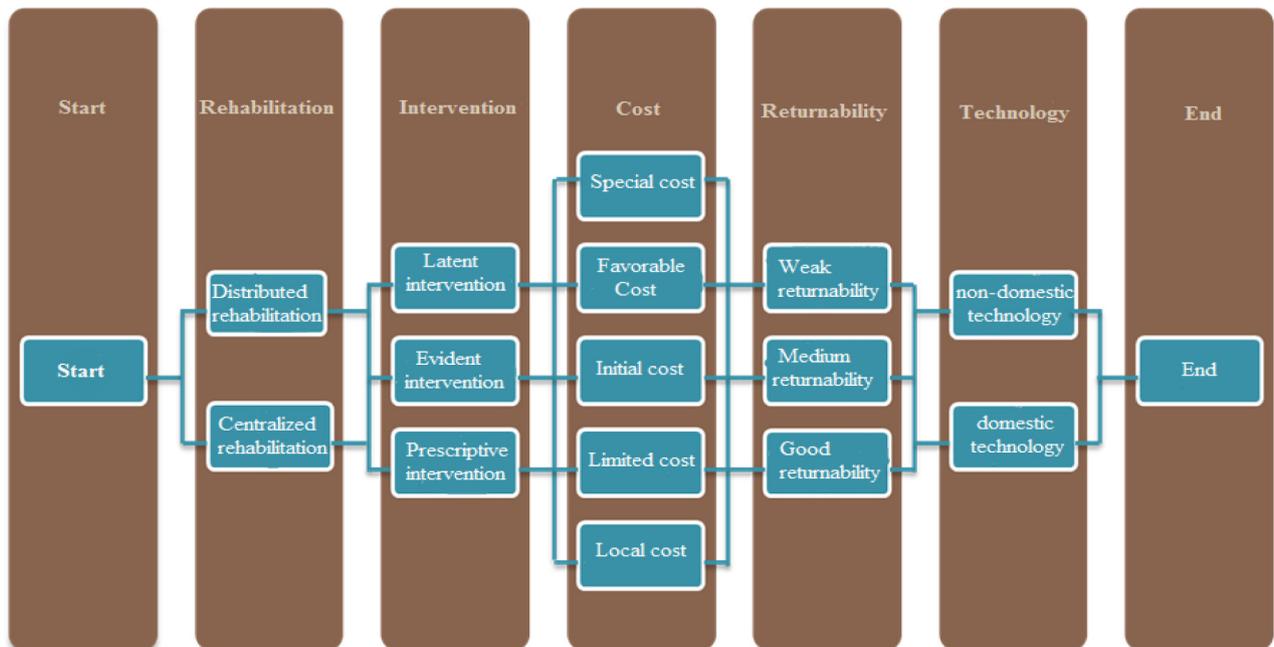


Fig. 11. Anti network of value in all strategies. Source: authors.

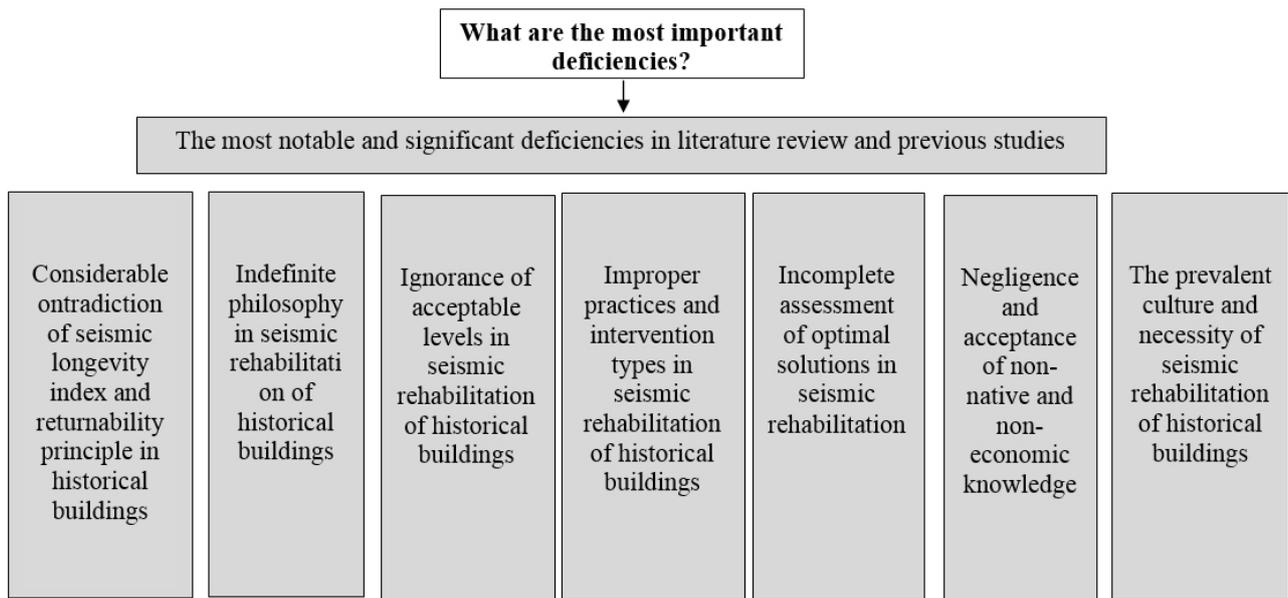


Fig. 12. Main deficiencies in seismic rehabilitation procedure. Source: authors.

## Conclusion

Summing up the deficiencies (Fig. 12) which are resulted from the literature review and the views based on the principles of conservation and seismic longevity of historical buildings and their content categorization reveals the absence of methodology in confronting the so-called seismic rehabilitation phenomenon in historical buildings.

A high variety of structural configuration, architecture and decoration, before and after the rehabilitation, have made the engineering judgment and prescriptive criteria as the most important initiative in rehabilitation projects. Various solutions have been introduced and implemented for seismic rehabilitation of historical buildings and some selected strategies are not necessarily the most valuable ones. Selecting the right solution for every building in seismic rehabilitation of historical buildings requires collective wisdom along with specific methodology with the following characteristics:

- Selecting the right rehabilitation solution based on value-based methodology.
- Developing criteria for assessing the created anti-value by increasing the seismic longevity based on each level of rehabilitation.
- Developing criteria for assessing the created anti-value due to intervention for every rehabilitation strategy.
- Introducing a model that is capable of simultaneous processing of values and anti-value in available solutions.
- Developing and expanding of the model in order to extract the optimal solution.
- Offering adaptability of the model to future strategies

Finally, in response to the research questions, it should be noted that each country has its own tradition and style in seismic rehabilitation of historical buildings. In other words, no proper solution had been devised disregarding of the culture and indigenous knowledge. They are all stemmed from the needs, necessities and technical and general specifications. Therefore, creating decision-making teams called Provincial Committees that are consisted of restoration and civil engineering in relation to historical structures and conservation concepts in order to prioritize the historical buildings for seismic rehabilitation is essential. Moreover, selecting the optimal solution based on value-based methodology of the proposed solutions with constant monitoring of seismic rehabilitation process is proposed for each of the historical buildings.

## Reference list

- *Country's Management and Planning Organization*. (2007). Instructions for seismic rehabilitation of current masonry buildings, publication 376.
- *Country's Management and Planning Organization*, (2006). Instructions for seismic rehabilitation of current 6 buildings, publication 360.
- Coburn, A., et al. (1995). *Technical Principles of Building for Safety*. London: Intermediate Technology Publications.
- Croci, G. (1988). *The Conservation and Structural Restoration of the Architectural Heritage*. Southampton: Computational Mechanics Publications.
- Croci, G. (2016). *Conservation and structural restoration of architectural heritage*. Translated to Persian by: Shirazi, B. A. & Hejazi, M. *Tehran: Daftar- e pajouheshhaye farhangi*.
- FEMA306. (1998). *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings*, prepared by American society of civil. Engineers for Federal Emergency.
- FEMA356. (2000). *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, prepared by American society of civil. Engineers for Federal Emergency.
- Icomos (International Council on Monuments and Sites). (1993). *Icomos New Zealand Charter for the Conservation of Places of Cultural Heritage Value*. Icomos New Zealand, Auckland.
- Imani, B., et al. (2016). Urban Decay Vulnerability Mitigation Strategies Against Earthquake [Rahbordha- ye kahesh- e asibpaziri bafthaye farsoode dar barabar- e zelzele]. *Bagh- e Nazar*, 13(39): 67-82.
- Iranians Management Services Co. (2011). *Seismic rehabilitation practices and lessons [Tajrobiyat va darshaye behsazi larzeyi]*, First edition. Tehran: elm- o adab.
- Jokilhto, J. (2008). *A history of architectural conservation*. Translated to Persian by: Talebian, M. H. & Bahari, Kh., First edition. Tehran: Rozane.
- Mohebi Moghaddam, B. (2008). *An introduction to seismic rehabilitation methods for current buildings [Ashnayi ba raveshhaye behsazi larzeyi sakhtemanhaye mojoud]*. First edition. Tehran: Fadak isatis.
- Loli M, Anastasopoulos, I. & Gazetas, G. (2015). *Nonlinear analysis of earthquake fault rupture interaction with historic masonry buildings*. *Bulletin of Earthquake Engineering*, 13(1): 83-95.
- Lourenco, P. B. (1994). *Analysis of Masonry Structures with Interface Elements*. Delft: Delft University of Technology.
- Meshki, H. (2002). *Presenting seismic rehabilitation procedures in historical buildings [Era'e farayand- e moghavem sazi larzeyi dar banahaye tarikhi]*. Tehran: Earthquake research center.
- Page, A.W. (1978). Finite element model for masonry. *ASCEJ.Struc. Div.*, 2011. 104 (8): 1267-1285.
- Staniforth, S. (2010). *Slow Conservation*. *Studies in Conservation*, ( 55): 74-80.
- Tim L. G. Michiel, S. (2015). Seismic Retrofitting Techniques for Historic Adobe Buildings. *International Journal of Architectural Heritage*, 9 (8): 1059-1068.
- Vatani Oskouyi, A. (2009). *Methods and implementation details of seismic rehabilitation [ravesh-ha va joziyate ejrayi behsazi sakhtemanha dar barabar- e zelzele]*. Third edition, Tehran: Shahid Rajaei Teacher Training University.