EVALUATION OF SEISMIC SAFETY CONSIDERATIONS OF NON-ENGINEERED HOUSES IN PAKISTAN

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ABSTRACT: *Evaluation of seismic safety of houses in Pakistan considering the modified seismicity of the region after 2005 Kashmir earthquake is an important question in deciding the future seismic mitigation strategies. But there is no right answer because a large number of uncertainties and complexities are involved in accessing the affect of ground motions on structures. Here, we worked to answer the questions which are of core importance in deciding the future seismic mitigation strategies. The work is discretized in five parts as follows. First; Assessment of percentage of seismically vulnerable houses in Pakistan, second; Evaluation of modification in construction after 2005 Kashmir earthquake, third; Evaluation of expected damage if same earthquake occurs again and importance of work out a plan to enhance seismic safety of houses against such events, fourth; Evaluation of important factors to be considered while proposing procedures to enhance seismic safety of houses, Fifth; Comparison of different sources to convey useful information about seismic safety of houses in general public. Owing to complexities and uncertainties, it is difficult to answer aforementioned queries. Therefore, we used an indirect approach and contacted 100 (qualified) professionals and researchers and asked their opinions and observations. After analyzing their responses the findings are summarized. The results of this study show that more than 75% of houses in Pakistan are seismically vulnerable. The study also reveals that construction practices in Pakistan are either unimproved or slightly enhanced as compared to the construction practices before 2005 Kashmir earthquake and a massive devastation is expected if a similar earthquake strikes again in Pakistan. The results of this study are useful to decide the future seismic mitigation strategies.*

Keywords: *Kashmir Earthquake, Seismic Safety, Non-Engineered Houses, Seismic Damages.*

1. INTRODUCTION

On October 8, 2005 an intense earthquake of magnitude 7.6 struck the northern areas of Pakistan and Pakistan administrated Kashmir. This earthquake was among the most devastating seismic activities. As, there was no history of strong ground shaking in recent past before this event, therefore consideration of seismic safety of houses was not a prime concern. It is remarkable to note that there were only seven earthquakes larger than M4.0 in Pakistan since 1965 (Fig. 1).

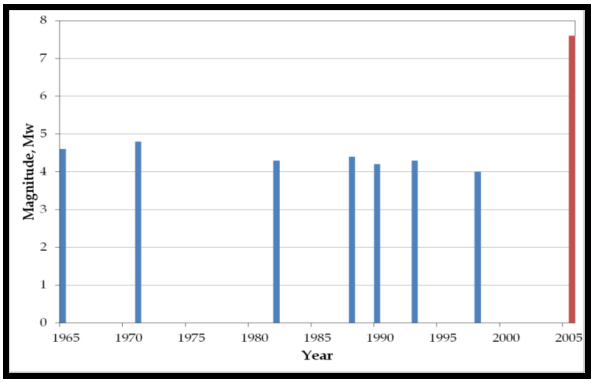


Figure 1. Earthquake with magnitudes greater than 4.0 in Pakistan since 1965

This earthquake resulted in more than 86,000 fatalities, 106,000 people injured and 4 million people left homeless in northern Pakistan and Azad Jammu and Kashmir [1, 2]. The damage and collapse of the houses during the 2005 Kashmir earthquake posed a serious threat to the seismic safety of houses in other parts of the country in context of modified seismicity of the region [3, 4].

Particularly, non engineered structures pose a serious threat to their inhabitants during earthquakes as proved by 2005 Kashmir earthquake, in which most of the 32,000 destroyed structures were non-engineered. Such a large scale devastation of civil structures attracted researchers from all parts of the world to analyze damage causes and suggest seismically efficient reconstruction techniques [5, 6, 7]. Application of proposed approaches in local environment is challenged by a number of factors [8].

In context of modified seismicity of the region [3, 4], it is necessary to evaluate the seismic safety of houses. In essence, owing to a number of uncertainties and complexities, it is difficult to quantify the seismic safety of houses. For evaluation we need to have a simple and robust method which must be sensitive to uncertain parameters. Meanwhile, it is required that method for evaluation of seismic safety of houses must be free from influence of individual decisions and personal influences.

Knowing the complexities involved in accessing safety of houses (in community/country) this work encompasses assessment/evaluation of seismic safety of residential houses in Pakistan, which can be an important contribution in proposing the future seismic mitigation strategies.

2. METHODOLOGY

Due to uncertainty and complexity associated with seismic event and structural response, it is important to consider a variety of aspects to evaluate the phenomenon related to seismic safety of houses.

Therefore, in this study an indirect approach is used, which is termed as 'cumulative response of professionals and researchers'. One of the advantages of using this approach is diverse opinion; i.e. based on experience and exposure, each

person being surveyed possesses different information about the questions being asked, the diversity of feedback thereby reduces the uncertainty involved. The other main advantage of using this approach is insensitivity to personal decision, as the presented result is based on opinion of different professionals and researchers.

In this work we contacted 100 individuals who are related to construction industry of Pakistan in different capacities; such as design engineers, site engineers, architects and others. It is noteworthy that only qualified professionals were surveyed. By this definition, a person related to construction industry of Pakistan without proper qualification for his job was not considered eligible for this survey.

To access seismic safety of houses in Pakistan, evaluation process is discretized as following.

1. Percentage of seismically vulnerable houses which posed serious threat to the inhabitant.
2. Modification of construction practices after 2005 Kashmir earthquake.
3. Evaluation of expected damage if similar earthquake strikes again and importance to work out a plan for safety of non-engineered houses during earthquake.
4. Factors to be considered while proposing future seismic mitigation strategies
   a. No requirement of specialized instruments
   b. Aesthetics of structures are not disturbed
   c. Required material is easily/locally available
   d. Skilled labor is not required
   e. Proposed method should be economical
5. Most convenience source to convey information about seismic safety
   a. Print media
   b. Electronic media
   c. Social networking sites
   d. Internet (Google, Wikipedia, etc)

The authors reckon that the aforementioned queries are most important in deciding guidelines to enhance the seismic safety of non-engineered houses in Pakistan. In light of response of professional engineer to aforementioned queries, the analysis is made and presented in followings.

3. PERCENTAGE OF SEISMICALLY VULNERABLE HOUSES IN PAKISTAN

To access the expected damage due to future earthquake, it is necessary to know the percentage of seismically vulnerable houses. It will also show the importance and urgency in proposing measures to enhance the seismic safety of houses in Pakistan.

Among 100 professionals to whom we contacted, each may have a different response depending on his/her exposure and experience. Fig. 2 shows their response both in the discretized and cumulative percentage. It is important to note here that the response may also have spatial variation. However, we will focus to a generalized discussion.

To know the seismically vulnerable houses in Pakistan the following question was asked to the professionals and researchers; '*A construction without any advice of an Architect and/or Engineer is termed as non-engineered construction. In your opinion, what is the percentage of one to two floor non-engineered houses in Pakistan?*'

The response of 100 professionals and researchers is in Fig. 2.

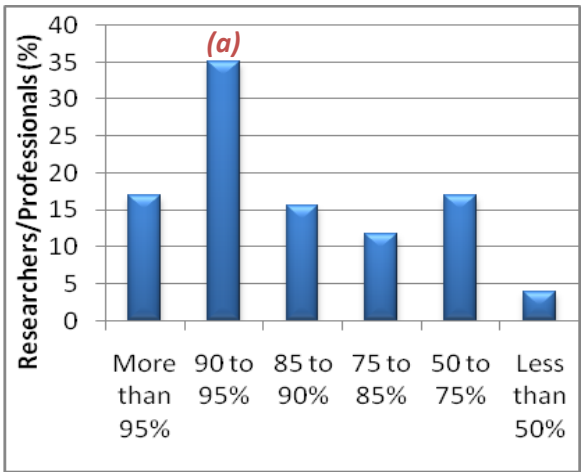


Figure 2a. Discertized Percentage of seismically vulnerable houses in Pakistan in view of Professionals and researchers

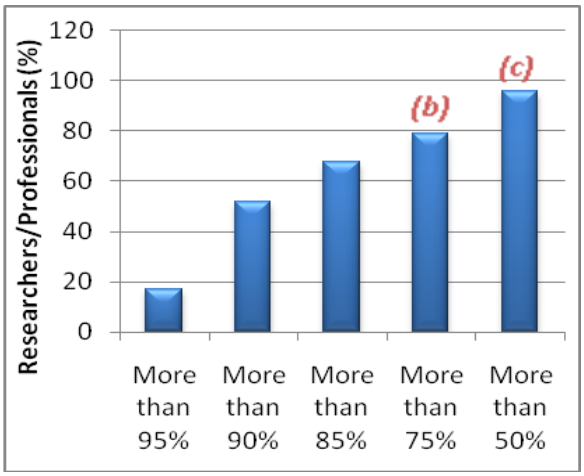


Figure 2b. Cumulative Percentage of seismically vulnerable houses in Pakistan in view of Professionals and researchers.

In bar plot the vertical bar named as (a) in Fig. 2(a) shows that the most frequent value of the obtained distribution function suggests 90 to 95% of houses are non-engineered structures. The cumulative percentage of the results presented in Fig. 2(a) is given in Fig. 2(b). It is interesting to note that in bar plot shown in Fig. 2(b), the vertical bar named as (b) shows that 80% professionals and engineers are agreed that more than 75% of houses are non-engineered structures, while the vertical bar named as (c) shows that 95% of professional and engineers are agreed that 50% of houses are non-engineered structures. This reveals that approximately all professionals and researchers are unanimously agreed that at least every second house in Pakistan poses serious threat to the inhabitants. This is really an alarming situation for the society and needs to be considered seriously.

The seismic vulnerability of non-engineered houses is a fact, and to access the seismic vulnerability of houses we asked the following question to the professionals and researchers; '*Considering the percentage of non-engineered houses mentioned by you, how do you rank the seismic safety of such construction?*'

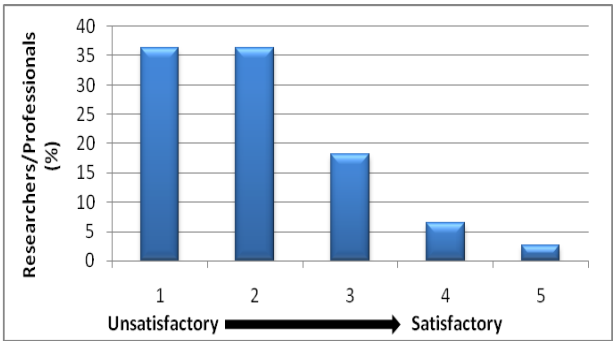


Figure 3. Seismic performance of houses in Pakistan, in view of professionals and researchers

The response was recorded corresponding to a scale of 1 to 5. Scale-1 ranks the seismic safety of non-engineered houses to be 'unsatisfactory' and scale-5 corresponds to 'satisfactory' condition. The results are plotted in Fig. 3. The rank of seismic safety (1 to 5) is shown along horizontal axis, while the percentage of responses corresponding to each level is plotted along vertical axis. The peak response corresponds to scale-1 and 2. The cumulative response of the scale 1, 2 and 3 is 90% of the total. This shows that 90% of professionals and researchers are agreed that the seismic performance of houses in Pakistan is unsatisfactory.

4. MODIFICATION IN CONSTRUCTION PRACTICES AFTER 2005 KASHMIR EARTHQUAKE

After experiencing devastation of 2005 Kashmir earthquake, it was required to modify the construction practices and techniques accordingly. Authors acknowledge the efforts and contributions by the private and public sector to enhance the seismic safety of structures in Pakistan, some of which are summarized here.

After Kashmir earthquake, seismic zoning of Pakistan was revised in light of modified seismicity of area [3, 4] and building code of Pakistan [9] was enriched with seismic provision. A number of public sector organizations (such as ERRA, NDA, etc) and NGOs (Non Government Organizations) strived to train labor and educate community for the said purpose. Considering this background; we asked the following question from professionals and researchers; '*After experiencing the devastation of 2005 earthquake, we were supposed to improve the construction techniques. In context of seismic safety, how do you compare the present construction practices with construction procedures before 2005 earthquake?*'

Respondents were asked to rank the modification in construction practices on a scale of 1 to 5, where scale-1 corresponds to 'same as before 2005 earthquake' and scale-5 corresponds to 'considerably enhanced.

The responses are summarized here in Fig. 4. The horizontal axis represents a progressively increasing scale from 1 to 5 describing the enhancement of construction practices after Kashmir earthquake, and vertical axis shows the percentage of responses corresponding to each scale. The most frequent value of the obtained distribution function is corresponding to scale-3; while scale-1 and scale-2 have 8% and 16% response respectively. It is pertinent to mention that scale-1 represents unimproved construction practices when compared with pre-earthquake construction; scale-2 shows slightly enhanced construction practices and similarly scale-3, 4 and 5 represent progressively improving construction practices.

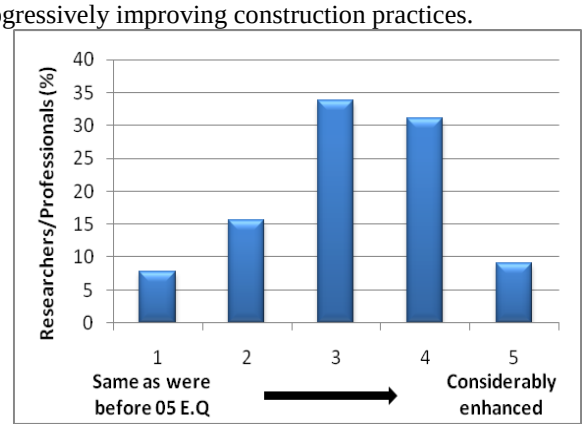


Figure 4. Comparison of construction practices pre- and post-Kashmir earthquake

The sum of scale 1, 2 and 3 is 58%, showing that an overwhelming majority of 58% of respondents are agreed that either construction practices in Pakistan are unimproved or slightly enhanced as compared to the construction practices before 2005 Kashmir earthquake.

5. IMPORTANCE TO WORK OUT A PLAN TO ENHANCE SEISMIC SAFETY OF HOUSES IN PAKISTAN

After experience a devastating earthquake in 2005, we were expected to increase the safety level against the future earthquakes. Considering the aforementioned analysis of the modification in construction practices after 2005 Kashmir earthquake in Pakistan, the professionals were inquired about the expected damage to the buildings if a similar earthquake strike in the future, for this purpose following question was asked from them; *'At present, if a similar intense earthquake strikes again, how much devastation is expected?'*

The results are plotted in Fig. 5. The most frequent value of the obtained distribution shown in Fig. 5 suggests that considering the current construction practices only 10 to 25% less devastation will occurs as compared to 2005 Kashmir earthquake, if a similar seismic activity occurs in Pakistan. Moreover, results shows that cumulatively 80% professional and researchers are agreed that there is a chance that more than 75% of the 2005 earthquake's devastation may occurs if a similar magnitude earthquake strikes again in Pakistan, which is a massive amount of destruction.

Therefore, considering the present construction practices and the massive amount of expected damage there is a dire need to contemplate a plan to enhance seismic safety of non-engineered houses. In this regards, to highlight the importance to work out better strategies for seismic safety of houses, we collected opinions of professionals and researchers by asking the following question; *'Considering the present construction practices of non-engineered houses in Pakistan, how important is to contemplate/work out a plan for seismic safety of non-engineered houses?'*

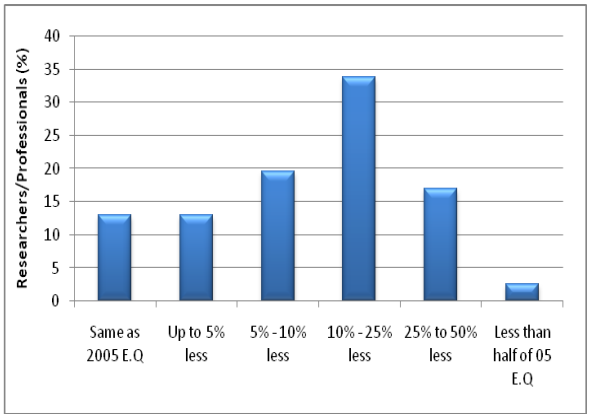


Figure 5. Expected devastation in Pakistan, if a similar earthquake strikes again

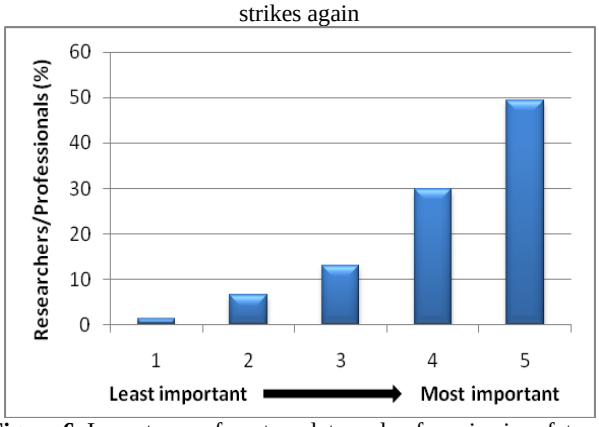


Figure 6. Importance of contemplate a plan for seismic safety of houses in Pakistan

The respondents were requested to rank the importance on a scale of 1 to 5. Fig. 6 shows responses to the above mention query, a clear peak is observed at scale-5 which corresponds to 'most important' to work out a plan for seismic safety of houses in Pakistan. It is also clear from the Fig. 6 that 92% of responses correspond to scale-3 to scale-5; which depicting that researchers and professionals are agree that it is most important to improve future seismic mitigation strategies and to improve construction practices for non-engineered houses.

6. FACTORS TO BE CONSIDERED WHILE PROPOSING FUTURE SEISMIC MITIGATION STRATEGIES

A good number of procedures are proposed by researchers to enhance the seismic safety of houses [5,6], such as PP-band method [10, 11], etc. The application of said approaches in the community is challenged by a number of factors, such as financial constraints, availability of materials and tools, requirement of skilled labor, etc. [8]. Considering this aspect it is required to evaluate importance of different factors while formulating the guidelines for seismically safe construction.

To evaluate these factors we asked the following question from professionals and researchers; '*Considering the acceptability by local community, what importance should be given to the following while formulating procedures for seismic enhancement of structures?*

- *Specialized instruments are not required*
- *Aesthetics of structure are not disturbed*
- *Required material is easily/locally available*
- *Skilled labor is not required*
- *The proposed method should be economical'*

Importance for these factors is recorded along a scale 1 to 5, scale-1 corresponds to least importance and scale-5 corresponds to maximum importance to these factors. The responses from the professionals are presented in Fig. 7 and discussed in detail in the following sub-section.

Specialized instruments are not required:

While formulating the procedures to enhance the seismic safety of non-engineered houses it is most important to consider that the proposed method should be simple and easily adoptable in local community. For that purpose there should be no requirement for the specialized instruments to implement the proposed method in the field. To highlight the importance of this fact the same question was asked from the professionals and researchers on a scale of 5 and the results are plotted in Fig. 7(a).

Clear peak is observed with 27% of the respondents at scale-3 which corresponds to moderate importance (Fig. 7(a)). Cumulatively only 40% of respondents agreed that less importance should be given to this factor while in view of 60% of respondents considerable importance should be given to the fact that to propose procedures to enhance seismic safety of houses no specialized instruments should be required.

Aesthetics of structures are not disturbed:

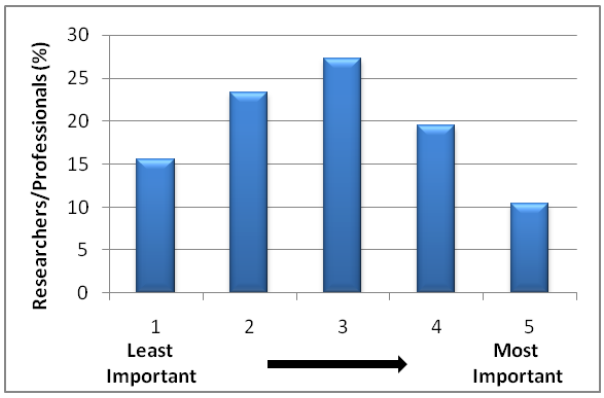
A number of procedures have been proposed by the researchers to enhance the safety of residential houses. In most of the methods aesthetics of the structure is compromised against safety of house, such as use of bamboo reinforcement to prolong collapse time of non-engineered houses [5, 6].

Therefore, these methods are least acceptable in local community and there is a need to propose such methods in which aesthetics of the houses are not disturbed. To highlight this aspect we inquire the same question from professionals and researchers that how important it is to not disturb the aesthetics of the structure while proposing a procedure to enhance seismic safety of houses and the results are presented in Fig. 7(b).It can be clearly seen from the Fig. 7(b) that 42% of the professionals and researchers responded to scale-5 and cumulatively in view of 90% of the professionals and researchers, aesthetics of the structure is most important in proposing methods and strategies to enhance seismic safety of houses.

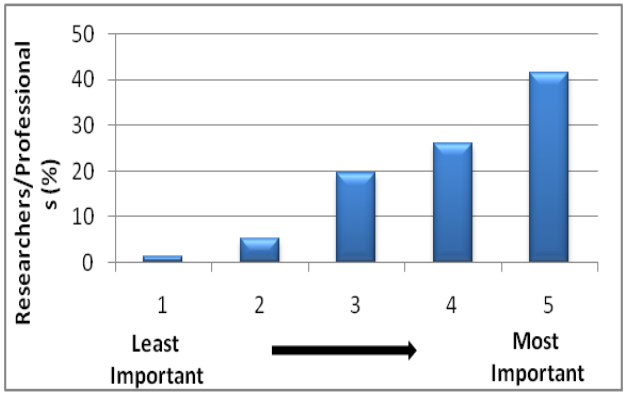
Required material is easily/locally available:

To propose a solution to enhance seismic safety of houses, local availability of required material is an important factor to be considered as, not only it helps to reduce construction time it also reduces the transportation charges and hence reduce the construction cost. Therefore to highlight the importance of easily/locally availability of required material in proposed method of seismically safe construction, we inquired the same from professionals and researchers. The results are presented here in Fig. 7(c).

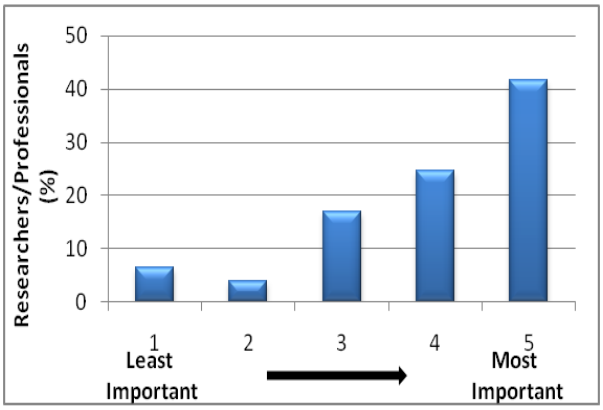
(a). Specialized instruments are not required



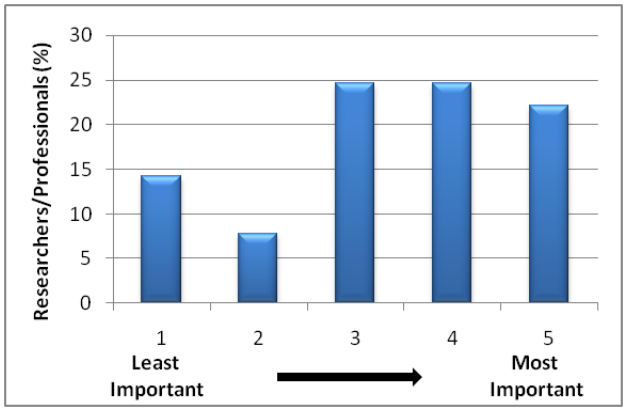
(b). Importance of aesthetics while formulating procedure for seismic safety of houses



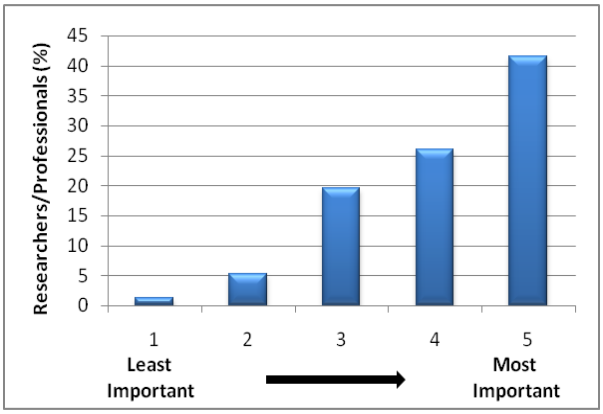
(c). Required material is easily/locally available



(d). No requirement of skilled labor



(e). The proposed method should be economical



(f) Acceptable increase in cost to incorporate seismic safety

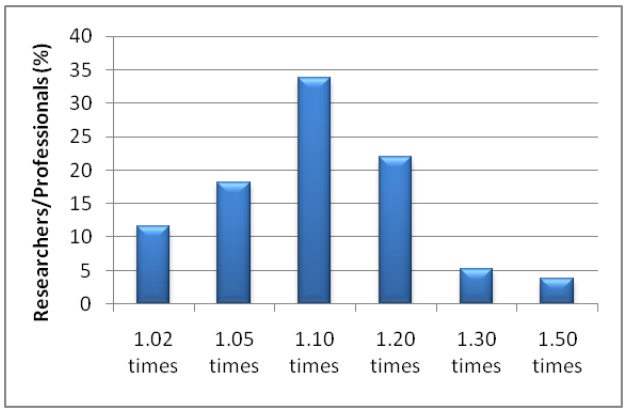


Figure 7(a to e) Importance of different factors to be considered while proposing future seismic mitigation strategies

A similar trend has been seen for this factor as was observed for the aesthetics of the structure. Peak response of 42% is obtained correspond to scale-5 and a cumulative response of 84% for scale-3, 4 and 5 is observed, which indicates that easy and local availability of required material is also one of the most important factor to be considered while proposing future seismic mitigation strategies.

Skilled labor is not required:

We asked the professionals and researchers that in formulating strategies for seismic enhancement of structures how important is it that skilled labor should not require in a proposed method?' The responses are summarized here in Fig. 7(d). The distribution shown in Fig. 7(d) depicts that cumulatively 75% of professionals and researchers are agree that no requirement of skilled labor for the proposed method

is most important factor while in view of 25% respondents it is not that important.

The proposed method should be economical:

Being economical of a proposed solution is one of the most important criteria which affect the acceptability and success of that method in local community. Therefore, we inquired about the importance of the fact that proposed method should be economical, from professionals and researchers and the responses are shown in Fig. 7(e).

Clear peak is observed corresponding to scale-5 which corresponds to most importance. It is also clear from the distribution shown in Fig. 7(e) that approximately 90% of responses correspond to scale-3, scale-4 and scale-5; depicting that researchers and professionals untidily agree that proposed method should be economical.

Realizing the importance of economical solution, it is necessary to decide about the acceptable limit in increase in cost to incorporate seismically safe construction. Therefore, we asked the professionals and researchers about the acceptable increase in construction cost to incorporate seismic safety of houses, and the responses are summarized here in Fig. 7(f).

Central bar in bar chart shown in Fig. 7(f) is highest among all and shows that a maximum percentage of response i.e. 34% is observed at increase in construction cost correspond to 1.10 times.

Cumulative percentage of responses corresponding to 1.02 times, 1.05 times and 1.10 times is 65% which indicate that in view of 65% of the professionals and researchers the increase in cost to incorporate seismic safety of houses should not be more than 10 percent of the original cost of construction.

Summary of above discussion is reproduced in Fig. 8. In Fig. 8, the factors which are required to be considered in deciding the future seismic mitigation strategies are presented on horizontal axis and their importance on a ranked scale of 1 to 5 is presented on vertical axis; scale-1 corresponds to least important and scale-5 corresponds to most important.

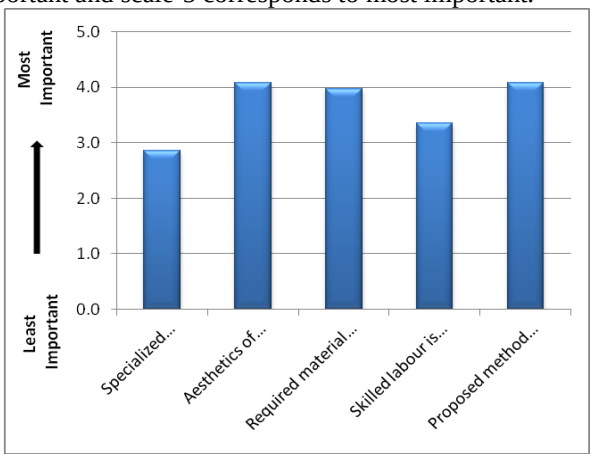


Figure 8. Importance of different factors to be considered while propose future seismic mitigation strategies in view of professionals and researchers

The results in Fig. 8 indicate that in deciding the future mitigation strategies, most importance is given by the professionals and researchers to following factors,

- Aesthetics of structures are not disturbed
- Required material is easily/locally available
- Proposed method should be economical

While relatively less importance is given by them, to the requirement of specialized instruments and skilled labor, in proposing the procedures for enhancement of seismic safety of houses.

Considering aforementioned analysis, it is required to invoke the awareness of seismically safe construction in local community of Pakistan. So the professionals were inquired about the most effective source to educate general public about safety of their houses against earthquake, the responses are discussed in the following section.

7. MOST CONVENIENCE SOURCE TO CONVEY INFORMATION ABOUT SEISMIC SAFETY

The gap between policies and their application in local community is challenged by a number of factors. Generally, financial conditions, coherence of new policies with culture and trends, and awareness of community regarding the importance of issues, etc play the effective role.

In the following discussion, the main interest of authors is to evaluate various sources to convey useful information regarding seismic safety of houses in Pakistan. In this discussion we relatively compare the following four options.

i. Print media (News paper, Magazines, etc)
ii. Electronic media (T.V, Radio, etc)
iii. Social networking sites (Facebook, Twitter, etc)
iv. Internet (Google, Wikipedia, etc)

We asked the following question to the professionals and researchers; *'In context of convenience of general public, how do you rank the following sources in conveying information about safety of houses against earthquakes?'*

Response for each source is collected on a scale of 1 to 5; scale-1 corresponds to least convenient source and scale-5 corresponds to most convenient source. The governing value of response for each source is analyzed by the authors and plotted for comparison in Fig. 9.

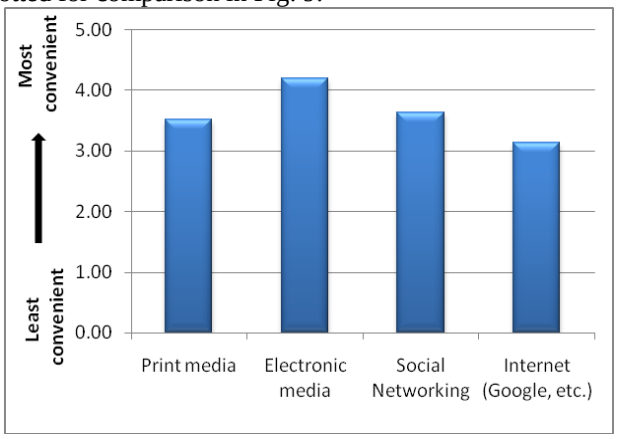


Figure 9. Comparison of different sources to convey information regarding seismic safety of houses

It is clear from the Fig. 9 that in view of professionals and researchers, among above mentioned sources, electronic media (T.V, Radio, etc) is the most convenience source to provide information regarding seismic safety of houses in general public, having governing value of scale 4. After that, with a minor difference in scale, social networking sites and print media (Newspaper, Magazines, etc) are relatively lesser

convenient and Internet (Google, Wikipedia, etc) is least convenient for general public to convey useful information about safety of houses against earthquakes.

8. CONCLUSIONS

2005 Kashmir earthquake was a devastating experience in the recent history of Pakistan. It resulted in a huge number of casualties and posed a serious question to the seismic safety of residential houses. The main focus of this study is the seismic safety of the residential houses. The analysis sequence was discretized into five parts (i) what is the percentage of seismically vulnerable houses in Pakistan? (ii) how the construction practices are modified after 2005 Kashmir earthquake? (iii) evaluation of expected damage if same magnitude of earthquake strikes again and importance of work out a plan to enhance seismic safety of houses during such events (iv) evaluation of important factors to be considered while proposing procedures to enhance seismic safety of houses (v) Comparison of different sources to convey useful information about seismic safety of houses in general public.

Owing to uncertainty of seismic events and diversity of structural response, it is difficult to answer the aforementioned queries. Therefore, an indirect and more practical approach was adopted to accomplish the goal. Using this approach 100 professionals (only qualified engineers and architects) and researchers working in local construction industry were contacted; and their responses were rationally analyzed.

The results of this study shows that more than 75% of houses in Pakistan are seismically vulnerable which indexes damageability of structures. After Kashmir earthquake, a modification in construction practices was expected. According to this study, however, approximately 60% of the professionals and researchers have opinion that the construction practices are either similar as practiced before Kashmir earthquake or are slightly improved.

To propose future mitigation strategies, importance of different factors is evaluated to be considered while proposing such strategies. In opinion of the professionals and researchers, aesthetics of structures, local availability of material and economics are most important to be considered, while the requirement of specialized instruments and skilled labor is relatively less important.

For conveying information about seismic safety of houses, various sources were compared in this study; such as print media, electronic media, social networking sites and internet (Google, etc). The results of the study has shown that electronic media is the most convenient source to convey useful information about seismic safety of houses and to enhance concern in general public. After electronic media, priority of other sources is as follows, social networking sites, print media.

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