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Original Research Article

Effective Criteria for Seismic Rehabilitation Planning of Road Transportation Infrastructures

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Abstract

While seismic rehabilitation process for road infrastructures has been traditionally based on seismic factors, consideration of non-seismic factors is necessary for reliable project ranking. Non-seismic factors include socioeconomic criteria, determining the value of a project to its users' community. Based on the information obtained from a questionnaire survey and literature review, this paper identifies a set of effective rehabilitation criteria (ERC) for seismic rehabilitation decision-making to develop a priority index that is applied to determine the rehabilitation priority. The identified RC will then be weighted for four types of road structures including bridges, tunnels, retaining walls, and buildings. The results can be generalized to provide valuable insights for policy makers concerned with transportation infrastructure planning, especially in developing countries where project prioritization is often an issue. To underline the value of the study, the weighted RC are applied in ranking road rehabilitation projects in an illustrative example.

Keywords: *Road Infrastructure, Seismic Rehabilitation Planning, Effective Criteria, Decision Making, Prioritization.*

1. Introduction

Pertaining to rehabilitation planning for risk mitigation in road network, the prioritization of road structures is a typical measure for government project managers for different purposes such as optimal budget allocation. The word "rehabilitation" in this study refers to a technical strategy or approach for developing rehabilitation measures for a structure to improve seismic performance before or after an earthquake. This process may include modifications of existing components or installation of new components to address the deficiencies identified during a seismic risk evaluation in order to achieve a selected rehabilitation objective. Rehabilitation strategy depends on selected criteria and may include a range of activities such as repairing, retrofitting, abandoning, replacing or even doing nothing.

Selecting the most effective criteria in order to evaluate the rehabilitation alternative has been always challenging. Such criteria must be considered from the perspectives of society, economy, manpower, environment, market and policy, etc. (Teng *et al.*, 2010). Moreover, the prioritization process for seismic rehabilitation purposes depends on the evaluation of in-service performance and economic criteria. These criteria are mainly related to the financial issues such as the amount of initial capital resources, the economic service life of the particular alternative, the predicted annual maintenance costs and the life cycle costs. To support this, Shohet & Perelstein (2004) evaluated the rehabilitation projects according to six quantitative criteria (e.g. level of performance, duration of the rehabilitation work and etc.) in order to find the best rehabilitation alternatives in buildings.

Whilst the seismic rehabilitation process of road infrastructures is extremely costly and time-consuming (Elhag & Wang, 2007; Gokey *et al.*, 2009), selecting appropriate criteria that maintain an advantageous contribution to rehabilitation priorities is important. The necessity of paying attention to choose appropriate criteria is due to three main reasons: First, in most cases, high numbers of road assets require rehabilitation. Second, limited financial and human resources are available to perform rehabilitation tasks; and, third, uncertainties about the weight factors can affect the rehabilitation process. In most cases, criteria selection and weighting is associated with conflict, mobility, comparability and relativity. Failure in reliable weighting of the criteria for seismic assessment may result in an increased risk of failure during an earthquake. In fact, engineering and societal judgment are the critical keys to this stage of the ranking process. Nevertheless, a prioritization method that solely relies on decision makers' instincts may be subject to failure and result in costly consequences.

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Furthermore, reliability of the solutions is sensitive to the decision makers' levels of experience and behavioural characteristics such as risk tolerance and foresight. An appropriate prioritization method should maximize the benefits of infrastructure owners (normally government agencies) with respect to the risk of failure of infrastructure systems. In the absence of reliable rehabilitation criteria (RC), transportation agencies have used subjective criteria and negotiations to identify priorities and decide how funding must be allocated across different projects. The evaluation criteria for infrastructure projects are all qualitative and cannot be easily measured with definite numerical values; so, it is necessary to survey the expert judgments. Each expert can make a judgment in accordance with the need grade of every project under each evaluation criterion (Huang *et al*., 2010).

To improve the prioritization process for seismic rehabilitation projects, this study introduces a set of weighted RC. In order to identify the weights of RC that directly affect the rehabilitation priority, a questionnaire survey was utilized. It is acknowledged that a questionnaire survey is an effective, convenient and economical investigation tool for obtaining data and sampling the experts' opinions in spatially diverse locations. The main purpose behind conducting the questionnaire survey was to find the RC and their pertinent weights.

2. Scope of the Study

In the present study, the RC for four categories of road infrastructures are evaluated; namely, bridges, tunnels, retaining walls and road buildings. Road buildings in this study include all buildings which are under the control of the Department of Transportation (or other similar departments) such as toll collection facilities, State or Federal Highway department office buildings and so on. These structures were selected from among Critical Transportation Infrastructures (CTI). CTI are comprised of those transportation facilities whose removal from service would seriously affect public safety, national security, economic activity or environmental quality (Fletcher, 2002). The results of this study effectively help the decision makers to identify the "non-seismic and other criteria" contributing to the seismic rating procedure, and also to calculate the weights of relative criteria in order to determine a final priority score.

3. Seismic Rehabilitation Priority Index

Several factors representing different perspectives of rehabilitation performance are involved in seismic rehabilitation decision-making. "Seismic Performance" is referred to the expected performance of a rehabilitated structure which is recommended for different levels of earthquake ground motion (FHWA, 2008). In order to prioritize the projects, a seismic rating procedure is needed. In seismic rating methods, different criteria contribute to the final priority score including non-seismic factors which make a qualitative part. While existing studies have proposed various methods for the prioritization of seismic rehabilitation projects, the lack of weighted criteria presents a barrier in that the seismic priority rating cannot be estimated effectively. The Seismic Retrofit Manual for Highway Structures (FHWA-Part 1, 2008) stipulates that the qualitative part modifies the rank in a subjective way which accounts for the importance, network redundancy, non-seismic deficiencies, remaining useful life, and similar issues to arrive at an overall priority index. According to this manual, the priority index is defined as follows:

$$P=f\left(R,\ \text{Importance, non-sesimic, and other factors}\ldots\right)=f(R,O) \tag{1}$$

In this equation, P is the priority index, R is the rank based on structural vulnerability and seismicity and O is the rank based on other factors. R includes the quantitative part which produces a seismic rating based on structural vulnerability and seismic hazard. According to the above equation, in order to calculate the priority index, P, for each project, R and O should be determined in advance. In light of the judgments and weighting made by the evaluation of experts, the evaluation matrix (Perng *et al*., 2007 and Teng *et al*., 2010) S_i for each project A_i under the evaluation criteria C_j can be formulated as follows:

$$S_i=\left[s_{ijk}\right] \tag{2}$$

where S_{ijk} indicates the priority score of project A_i at the j^{th} category under the evaluation criteria C_k. When considering m evaluation criteria for n distinct project and under t categories simultaneously, the following evaluation vector P_i is determined after the weighting:

$$P_i=\{P_{ijk}\}=W\otimes S \tag{3}$$

In this formula,

$$P_{ijk}=W_{kj}.S_{ji};\ \begin{cases} i=1,2,\ldots,n\ ;(n\geq 1) \\ j=1,2,\ldots,m\ ;(m\geq 1) \\ k=1,2,\ldots,t\ ;(k\geq 1) \end{cases} \tag{4}$$

$$P_i=\frac{\sum_{j=1}^{m} W_{kj}S_{ji}}{\sum_{j=1}^{m} W_{kj}} \tag{5}$$

where W_{kj} is the relative weight of j^{th} criterion in k^{th} category of infrastructures. It is to be noted that the ratings in this scale indicate only a rank order of importance of the criteria, rather than how much more important each rating is than the other.

4. Literature Review

A comprehensive literature review to identify the RC for seismic rehabilitation in road infrastructures, including definitions, subjective importance as well as classification methodologies was carried out. This part is planning to identify RC in relevant standards, codes and guides as well as the studies of other researchers. These criteria are varied and can be evaluated from different viewpoints such as vulnerability, reliability and criticality of road structures. Two main categories of references were reviewed which are presented as follows;

4.1RC Identification in Relative Manuals, Guides and Codes

According to Parts 1 and 2 of the FHWA (2008), the objective of a screening and prioritization program is to determine what structure (or set of structures) should be rehabilitated first. This manual introduces different rehabilitation factors for bridges, tunnels, retaining walls, culverts, slopes and roadways. It has been stipulated that the introduced criteria do not represent an exhaustive list, but illustrate some of the principles involved in assigning priorities. In addition, FEMA 366 (2008) states that the ability to correlate population density and annualized loss are two useful factors for developing policies, programs and strategies to minimize socio-economic loss from earthquakes. Hence, the ability to examine annualized loss in terms of demographic parameters such as ethnicity, age, and income are other important issues.

Furthermore, FEMA 154 (Edition 2, 2002) presents seismic performance attributes for seismic rehabilitation of buildings. Likewise, FEMA 356 (Pre-standard, 2000) presents all RC for buildings when detailed evaluation is needed. This Standard defines rehabilitation objectives as rehabilitation goals which consist of the selection of a target performance level and a seismic hazard level. Some of the other hazards that may affect the seismic rehabilitation priority index are discussed in FEMA 433 (2004) including floods, hurricanes, landslides, tornados, tsunami and wildfires. The NEHRP Guideline (2007) for the seismic rehabilitation of buildings also contains the criteria for seismic rehabilitation of buildings.

PIARC-C18 (2003) introduces some criteria for risk evaluation that are categorized as operational, technical/engineering, financial, legal, social/political and environmental. Architectural, historical and cultural issues of road structures are other criteria which may occasionally be taken into account in decision making, particularly in the most developed societies. In fact, this is the result of recognizing the importance of architectural heritage conservation, as well as the need to improve existing structures for new purposes of use. In this regard, "Guide for the Structural Rehabilitation of Heritage Buildings" (2010) focuses on the masonry buildings with their significant cultural value.

4.2RC Identification from the standpoint of Researchers

Much research has been in progress to probe into the development of the subject of the seismic rehabilitation for road infrastructures over the past few decades. However, among all these studies, only some of them introduced new criteria for seismic rehabilitation rating procedure. Vieira *et al.* (2000) defined the importance of tunnels and bridges as a function of public safety, emergency response, long-term economic impacts and interference with other lifelines. In general, the selection and prioritization of projects for seismic rehabilitation must be addressed with a systematic method for the optimal allocation of budget and other resources (Yadollahi & Zin, 2012). Moore (1994) prioritized the RC and provided technical information and methodologies to help in planning and organizing resources for road rehabilitation projects.

A few studies also presented other criteria in their budget optimization models (Teng *et al.*, 2007; Gokey *et al.*, 2009; Huang *et al.*, 2010 and Augeri *et al.*, 2010). Financial consideration and direct rehabilitation costs are important issues among transportation asset managers when they decide upon the allocation of available budget across infrastructure classes (e.g., bridges, Tunnels) or programs (e.g., maintenance, construction). In addition to direct costs, some studies investigated the indirect social and economic impacts of earthquakes which can be attributed to inhibited emergency response efforts, increased travel time in the transportation network, business disruption, and etc. (Padgett *et al.*, 2010). In addition, Egbelakin *et al.* (2011) discussed about the social and perceptual factors relating to the seismic retrofit implementation in New Zealand. Similar objectives were also investigated by other researchers which can be divided into three distinct areas: maintenance, economic, and political issues (Reilly & Brown 2004; Frangopol *et al.*, 2001; Gharaibeh *et al.*, 2006).

Other than financial or economic considerations, infrastructure planning involves a multitude of concerns, where safety considerations generally range behind economic issues. Some researchers believe that safety issues are insufficiently considered in infrastructure planning due to the lack of a shared view amongst the different safety experts (Rosmuller & Beroggi, 2004). To support this, a research study was conducted by Sharma *et al.* (2008) related to safety considerations. Furthermore, Zayed *et al.* (2004) introduced some factors that contribute to the safety risk for bridges with unknown foundations. Physical structural defects of bridges (Such as corrosion, durability, environment, materials, ductility and seismic loads) were also taken into account by Pellegrino *et al.* (2011) as evaluation criteria of bridges.

Past disaster experiences have demonstrated that damage to road or highway structures such as bridges, roadways, tunnels, and retaining walls can severely disrupt the whole network performance level including traffic flow. Any disruption in traffic flow at the network level subsequently affects the economy of the region as well as the post-earthquake emergency response and recovery. Hence, traffic issues are another criterion considered by some researchers (Werner *et al.* 1995; Shiraki *et al.* 2007). In addition, Salem *et al.* (2003) identified other factors affecting life-cycle performance of civil infrastructure and believed that identifying these factors is the first step toward predicting its service life.

Since the effects of other natural disasters (e.g. floods, landslides, soil liquefactions) on road structures are comprehensive and seriously disruptive, environmental, hydraulic, geotechnical and other required vulnerability assessment has brought about a significant amount of research in recent decades. In the case of a disaster event, Mechler (2002) discussed the rehabilitation project effects, including the loss of life or injuries, economic and ecological consequences that cause damage to ecosystems. Moreover, liquefaction potential, geological and physical conditions are three important factors which were evaluated in a study by Zatar *et al*. (2008). The methodology suggested that it is necessary to quickly conduct seismic assessment and ranking of bridge embankments in order to identify and prioritize those embankments that are highly susceptible to failure.

In addition, Croope (2009) reviewed the RC contributed as mitigation measures to capture opportunities and constraints for mitigation measures. These criteria included social, technical, administrative, political, legal, economic and environmental issues. In this regard, Shrestha (2004) and Ziderer (2006) considered environmental issues and their socio-economic consequences for road network planning and prioritization in Nepal and Tajikistan respectively. Based on the model and analyses of Hellstrom (2007), technological change is an important factor in the development of critical infrastructures. He stated that the dynamics of technological change must be taken into account when assessing how such structures advance into a state of vulnerability over time.

Multi criteria (or multi attribute) decision-making has been widely implemented by researchers to tackle the budget allocation problem for rehabilitation projects in a road network. In order to optimize the budget, various criteria were defined to establish the objective functions. Different criteria, such as the safety factor, were proposed in this regard by Augeri *et al*. (2010). Likewise, a multi-criteria optimality index was proposed by Elhag & Wang (2007) introducing the minimization of risk of failure, minimization of maintenance costs, and minimization of traffic disruption as three conflicting criteria to achieve the optimal maintenance strategy.

In summary, this section shows the authors' efforts to introduce and identify factors or criteria that cause the most wear and tear on seismic rehabilitation procedure for road infrastructures. These factors were always selected based on the rehabilitation goals and aims of the researcher. In this study, these factors are classified and summarized into larger groups. The identified RC from the previous studies are summarized in Table 1.

5. Problem Statement

The wide scope of literature review revealed that there was no comprehensive list of RC developed specifically for the seismic rehabilitation. It can be seen that the identified criteria are fragmental, not well-defined and cannot be applied for determining a seismic priority score. A rehabilitation criterion may be evaluated in the work scope of a manual, guide or study of researchers from different viewpoints. For example, social criteria look into developing a community consensus for implementing the mitigation measures; while technical criteria would take care of technical feasibility, which includes effectiveness, secondary impacts, implementation and sustaining technical capabilities.

Despite the wide studies on seismic rehabilitation process, there is not a comprehensive list of RC in the form of quantitative values for real decision making in the seismic rating procedure. This is because the vulnerability assessment of the road structures is not a rapidly quantifiable concept and such structures are vulnerable to many events. Hence, the problem here is the lack of a comprehensive list of weighted RC for responsible managers in order to prioritize the seismic rehabilitation projects.

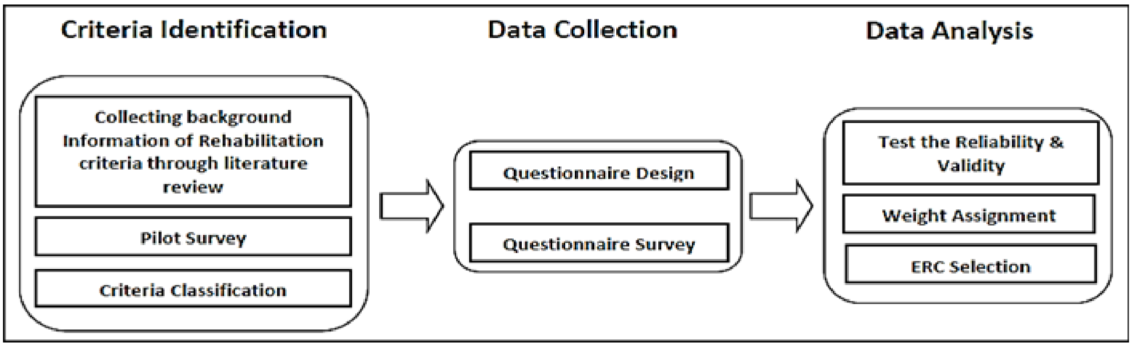

Figure 1: Methodology to Identify the Weighted RC

6. Research Method

This section develops a methodology to identify the RC for the seismic rating of road structures. The research methodology included three main parts: criteria identification, data collection and data analysis. The following subsections describe the methods applied in these three parts. The research framework to identify the weighted RC for the seismic rehabilitation of road structures is illustrated in Figure 1.

6.1Pilot Survey

A comprehensive literature review including a pilot survey was conducted to identify and classify the RC. The pilot survey was conducted with the help of selected experts to classify the identified criteria and ask for introducing other new criteria. A content analysis method (Holsti, 1969) was used for conducting the pilot survey. The method is considered effective and has been widely utilized in social science (Rattleff, 2007 & Shen *et al*., 2011). The adoption of the content analysis method in this section led to the generation of a list of criteria for rehabilitation purposes. Three main conclusions obtained from pilot survey for selecting four categories of road infrastructures in this study; including: First, the costs associated with the collapse of these structures are extremely high. Previous studies and reports in this area have demonstrated that the retrofit cost for only a small part of a bridge, tunnel or road building is much higher than other facilities such as drainage, illumination or road safety equipments (Gokey *et al*., 2009; Khan, 2010). Second, rehabilitation process for these structures after an earthquake requires high amounts of energy, human resources and time; and third, returning these structures to service is of crucial importance for improvement and reviving the society. Finally, the Factor Analysis implemented to classify all identified criteria into larger groups.

6.2 Research Data

Research data used for analysis were collected from a questionnaire survey completed by groups of experts including seismic rehabilitation specialists from the participants of disaster management conferences (International Disaster and Risk Conference, Davos, Swiss, 2008 and 2010). This was conducted by email questionnaire and unstructured interviews with the related experts and professionals. The data for this study was the result of analysis of 65 valid responses that were selected from more than 500 administered email questionnaires.

6.3Sampling Method

Rehabilitation activities for road infrastructures can be done for different purposes such as upgrading the structural or seismic performance, improvement in network functionality, historical or aesthetic issues and so on. In this regard, seismic rehabilitation process is comprised of a variety of associated civil engineering disciplines and tasks depending upon the complexity of the project. Therefore, the data in this step should be included the opinions of different experts. Since it is not always possible to collect the opinions of all related experts, sampling through questionnaire survey is an effective method to collect the opinion of selected related experts.

When the respondents are in divers location, data gathering through the questionnaire survey is an effective, convenient and economical approach (Zhang, 2007).

Hence, a close-end questionnaire was designed to find and assign weights to RC. The designed questionnaire asked the selected experts to decide which criteria would be the most important and what rank would they assign to these criteria if they were the principal decision maker (or a project manager). A combination of purposive and random sampling was used in this research to select the experts (Cohen *et al*., 2004). The sampling here is mainly based on the knowledge and experiences of a selected group of respondents who have been targeted according to the goal of the survey. The population for this purpose was too large to attempt to survey. Random sampling is a common method applied by researchers in this type of situation (Guo, 2010, Islam *et al*., 2011). The probability of selecting each member amongst the population is equal to each other. The formula for simple random sampling is presented in the following (Guo, 2010):

$$n=\frac{Z^2\,\Theta(1-\Theta)}{S^2} \qquad (6)$$

where n is the required number of respondents, z is the score associated with the confidence level required, S is the required precision, and Θ is the occurrence rate within the population.

The data for this part was the results of valid questionnaires administered to. Mail survey questionnaire sent to selected conference attendees (a combination of purposive and random sampling), which produces substantial findings regarding the importance of criteria, their estimated weights and inferences for rehabilitation of road infrastructures. Whilst the questionnaire survey form was designed to find and assign weights for classified RC, it also asked the respondents to add any other criterion that contributes to rehabilitation decision-making that was not mentioned in the questionnaire form according to their experiences.

6.4Scaling Method and Data Analysis Instrument

Computer-based statistical analysis was selected in this study because of available and appropriate statistical methods and also easiness of testing process. SPSS-PASW 18 (Statistical Package for Social Science) is a software package for analyzing data. The data collected for this questionnaire survey was analyzed using the "Average Index Method" (Wahida, 2010). In addition, the measurement method used to rank the criteria for this study was the ordinal or ranking scale. This is because, firstly, the vulnerability score assignment (in order to find the seismic rating) is more compatible with ranking scale (Zayed *et al*., 2007; Shen *et al*., 2011) and secondly, this

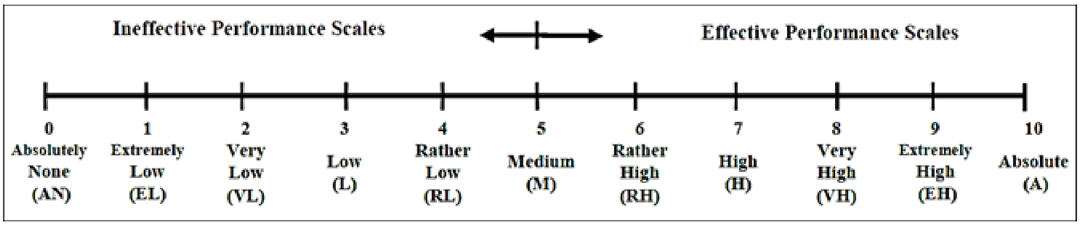

Figure 2: Subjective Performance Scales (IOE Categories)

type of scaling is more precise and familiar for experts according to professional opinions in the pilot survey.

The importance level is also compatible with 10-point Likert scale. In this study, rate zero means that the mentioned criterion is absolutely not relevant as a criterion in decision making for the specific infrastructure category; while rate 10 means that the criterion is absolutely relevant in decision making. Ten scale rating and their relative abbreviation codes used are classified as below. To convert the continuous index (average index) into discrete scale, discrete categories are classified and proposed as follows:

a.	Absolutely None (AN)	$0.0 \leq MS < 0.5$
b.	Extremely Low (EL)	$0.5 \leq MS < 1.5$
c.	Very Low (VL)	$1.5 \leq MS < 2.5$
d.	Low (L)	$2.5 \leq MS < 3.5$
e.	Rather Low (RL)	$3.5 \leq MS < 4.5$
f.	Medium (M)	$4.5 \leq MS < 5.5$
g.	Rather High (RH)	$5.5 \leq MS < 6.5$
h.	High (H)	$6.5 \leq MS < 7.5$
i.	Very High (VH)	$7.5 \leq MS < 8.5$
j.	Extremely High (EH)	$8.5 \leq MS < 9.5$
k.	Absolute (A)	$9.5 \leq MS \leq 10$

where MS represents the mean score. The mean score statistic is one common way to generalize the data (Guo, 2010; Islam *et al*., 2011). It is applicable when the response levels are measured at an ordinal scale. MS can be defended as follows:

$$\text{Mean Score (MS)}= \frac{\sum_{i=1}^{10} a_i x_i}{10\sum_{1}^{10} x_i} \qquad (7)$$

where a_i is a constant expressing the weight given to i and x_i are variable expressing the frequency of the response for i=1,2,…,10. A rating system was used to describe the Intensity of Effectiveness (IOE) for each criterion which leads to subjective performance scales of RC. The IOE represents a general category regarding the opinions of decision makers for one single criterion in a specific category of infrastructures. The subjective performance scales of these ranges are schematically presented in Figure 2.

By feeding the survey results into PASW 18, MS and standard deviation (SD) values for all criteria were calculated. Moreover, based on the magnitude of the MS, the ranking results for each criterion were estimated. The results were finally validated using a holistic evaluation method, which proved the robustness of this survey in infrastructure rehabilitation procedure.

7. Findings

The previous sections outlined the methodology applied to identify factors or criteria contributing to the seismic rehabilitation procedure for road infrastructures. A large number of 64 RC were identified through literature review, interviews and the email questionnaire. These RC were then classified and incorporated into the main questionnaire to set a comprehensive scene for respondents to indicate their relative importance.

7.1Criteria Classification

The aim here was to reduce the number of criteria by grouping together related ones. The criteria were classified by Factor Analysis and incorporated into the main questionnaire to set a comprehensive scene for respondents to indicate their relative importance. Table 2 shows the result of criteria classification. Although the criteria were varied and covered different areas, they categorized in much more simple classes; such that all 64 criteria were classified into 20. Studies of the RC in different references and countries have demonstrated their different focuses of interest.

7.2Reliability Analysis

Reliability analysis allows study of the properties of measurement scales and the items that compose those scales. The reliability analysis procedure calculates a number of commonly used measures of scale reliability and also provides information about the relationships between individual items in the scale. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. With the help of PASW 18, the Cronbach’s alpha coefficients were calculated for four categories of road infrastructures based on the information provided by 65 valid respondents. The alpha reliability coefficient normally ranges between 0 and 1, the closer alpha to 1, the greater the internal consistency reliability of the criteria in the scale. It is to be noted that a reliability coefficient of 0.70 or higher is considered “acceptable” in most social science research situations (Chen *et al*., 2010). The calculated Cronbach’s Alpha Coefficient for all 65 respondents was 0.914. Cronbach’s alpha coefficients for all RC across the four categories are more than 0.7. Therefore, the information from questionnaire survey is considered reliable. All alpha values were greater than 0.7, indicating that all reliability coefficients are acceptable and internal consistency of the criteria included in the scale is excellent. The calculation results are shown in Table 3.

Table 1: List of identified RC

Name	**Related Criteria** **Sub-Criteria** **Other names**	FHWA (2008)	FEMA 366 (2008)	FEMA 154	FEMA 356	FEMA 433	FEMA 273 (NEHRP)	PIARC – C18	Structural Rehabilitation of Heritage Buildings (2010)	Salem et al. (2003)	Flores-Colen et al. (2009)	Karydas and Gifun (2006)	Moore (1994)	Gokey et al. (2009)	Gharaibeh et al. (2006)	Reilly and Brown (2004)	Cheng et al. 2009)	Rosmuller and Beroggi (2004)	Sharma et al. (2008)	Zayed et al. (2007)	Vieira et al. (2000)	Shohet and Perelstein (2004)	Cheng et al. (2009)	Werner et al. (1997)	Shiraki et al. (2007)	Mechler (2002)	Croope (2009)	Hastak et al. (2005)	Ziderer (2006)	Hellstrom (2006)	Interviews & Respondents Feedback
Safety (C1)	- Fire Safety - Public safety - Humanitarian effects - Loss of life - Persons injured											*						*	*	*	*	*				*					*
Functionality (C2)	- Traffic Disruption - Traffic flows - Network redundancy - Detour length - Emergency response - Interference with other lifelines - Average Daily Traffic (ADT) - Average Annual Daily Traffic (AADT) - Post-earthquake emergency response - Logistics	*									*									*	*	*	*								*
Sustainability (C3)	- Materials availability - Past experiences - Technical Factors - Engineering factors									*			*														*			*	*
Environmental Issues (C4)	- Ecological effects among other damage to ecosystems	*						*				*														*	*		*		*
Political Restrictions (C5)	- Policies, programs and strategies - Administrative factors - Legal considerations - National Security	*	*					*		*		*			*	*	*										*	*			*

Historical Aspects (C6)		*							*																						*
Architectural Aspects (C7)	- Aesthetic issues - Symbolic value	*							*																						*
Economic Issues (C8)	- Annualized loss - Financial issues - Economic effects - Available budgets - Long term economic impacts - Life cycle costs - Annual maintenance costs - Initial capital resources - Economic service life		*					*		*	*	*	*	*	*	*	*			*	*	*	*				*	*	*		*
Social Issues (C9)	- Population density - Demographic parameters (ethnicity, age, and income)	*	*					*																			*	*	*		*
Anticipated Service Life (C10)	- Remaining (design) life - Value of lost time - Age of structure	*			*					*										*											*
Operational Considerations (C11)	- Human resources availability							*				*																*			*
Rehabilitation Duration (C12)																						*									*
Constructability (C13)		*																													*
Cost of New Construction C(14)																												*			*
Cost of Repair or Rehabilitation (C15)											*																				*
Weather Conditions (C16)	- Climate change adaptation																														*

Hydraulic Vulnerability (C17)	- Scour																		*												*
Physical Condition (C18)	- Physical performance - Importance and type of structure - Substructure system - Structural Conditions - Types of foundation - Soil characteristics - Geometry - Geotechnical factors - Geological conditions	*			*						*								*												*
Seismic Vulnerability (C19)	- Region seismicity - Seismic performance attributes	*		*	*														*												*
Other Hazards Vulnerability (C20)	- Risk - Liquefaction potential - Flood potential - Other hazards (hurricane, landslide, tornado, tsunami and wildfires)	*				*	*				*	*																			*

Table 2: List of Identified Rehabilitation Criteria

No.	Rehabilitation Criterion	Code	No.	Rehabilitation Criterion	Code
1	Region seismicity	C19	33	Cost of new structures	C14
2	Importance and type of structure	C2	34	Substructure system	C18
3	Network redundancy	C2	35	Remaining (design) life	C10
4	Age of structure	C10	36	Types of foundation	C18
5	Physical conditions	C18	37	Structural Conditions	C18
6	Traffic disruption	C2	38	Geometry	C18
7	Political restrictions	C5	39	Loss of life (injured persons)	C1
8	Constructability	C13	40	Soil characteristics	C18
9	Environmental issues	C4	41	Average Daily Traffic (ADT)	C2
10	Anticipated service life	C10	42	Average Annual Daily Traffic	C2
11	Aesthetic/architectural issues	C7	43	Scour	C17
12	Historical issues	C6	44	Seismic vulnerability	C19
13	Detour length	C2	45	Value of lost time	C12
14	Geotechnical factors	C18	46	Available budgets	C8
15	Social issues	C9	47	Materials availability	C3
16	Liquefaction potential	C20	48	Past experiences	C3
17	Flood potential	C20	49	Traffic flows	C2
18	Geological conditions	C18	50	Post-earthquake emergency response and recovery	C2
19	Population density	C9	51	Physical performance	C18
20	Annualized loss	C8	52	Risk	C20
21	Policies, programs and strategies	C5	53	Humanitarian effects, including the loss of life and persons injured	C1
22	Demographic parameters (ethnicity, age, and income)	C9	54	Ecological effects among other damage to ecosystems	C4
23	Other hazards (hurricane, landslide, tornado, tsunami and wildfires)	C20	55	Economic effects	C8
24	Seismic performance attributes	C19	56	Administrative factors	C5
25	Operational factors	C11	57	Rehabilitation duration	C12
26	Technical/engineering factors	C3	58	Cost of repair/rehabilitation	C15
27	Financial issues	C8	59	Weather conditions	C16
28	Legal considerations	C5	60	Hydraulic vulnerability	C17
29	Public safety	C1	61	Fire safety	C1
30	Emergency response (immediately after the earthquake)	C2	62	Climate change adaptation	C16
31	Long term economic impacts (during the reposition of normality)	C8	63	Symbolic value	C7
32	Interference with other lifelines	C2	64	Human resources availability	C11

Table 3: The Cronbach's alpha values

Item Statistics	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items
Number of items	20	
Bridges	.802	.801
Tunnels	.792	.802
Retaining Walls	.858	.856
Buildings	.888	.890
all	.914	.914

8. Discussion about the Criteria and Ranking Analysis

It is worth mentioning that although the identified weighted RC in this study helps the decision makers to evaluate the seismic priority index for a better seismic rating of road infrastructures, management policy will always be above any other factors in prioritization for considering whether a rehabilitation project should be implemented. In real situations, the selection of a road infrastructure for rehabilitation purposes usually consists of multi-criteria decision making, because so many factors such as identified RC influence our decisions. During the interview discussion, the respondents also asserted that the criteria they rated lower did not mean they are not important for selecting rehabilitation decision making, but rather they wanted to highlight the relative importance of criteria from their vantage point.

The IOE index then evaluated for each criterion. The RC subjective performance scales show that the intensity of effectiveness for all criteria range from rather low (RL) to extremely high (EH). This fact implies that almost all of the classified criteria contribute to the rehabilitation decision-making process. Moreover, only the "seismic vulnerability" of bridges received an extremely high (EH) importance level among all others. The scores in this table show the first important criterion for bridges, retaining walls and buildings is "seismic vulnerability", while the first important criterion in tunnels is "safety". "Seismic vulnerability" is the second priority for tunnels. This indicates that, according to experts' judgments, tunnels are more reliable structures against earthquakes than the other three structures. Moreover, the rank of this criterion (C19) confirms the importance of C19 as an effective factor in calculating the seismic rating of a structure (such as a bridge) for prioritization.

Among the criteria with "Very–High" (VH) importance levels, "safety" and "other hazards vulnerability" of bridges with mean scores of 8.45 and 8.18 have the highest importance levels. Supporting this, all criteria with very high importance level are counted with bridges and tunnels. From the results in Table 4, it is clearly seen that most of the RC rated with "Rather Low" importance level are corresponding to retaining walls and buildings. The valid percentage of scores demonstrates that only a small percentage of respondents voted "zero" to "political restrictions", "weather conditions", "historical" and "architectural aspects".

Table 4: Data analysis for RC based on Mean Scores and Standard Deviation Values

Code	Building			Retaining wall			Tunnel			Bridge		
	MS	SD	IOE	MS	SD	IOE	MS	SD	IOE	MS	SD	IOE
C1	5.57	2.43	RH	6.71	2.58	H	8.11	1.88	VH	8.45	1.50	VH
C2	5.42	2.39	M	4.63	2.29	M	7.52	1.92	VH	7.72	1.81	VH
C3	5.49	1.88	M	5.42	1.92	M	6.49	1.88	RH	6.68	1.96	H
C4	4.49	2.10	RL	4.52	2.22	M	5.77	2.25	RH	5.46	2.08	M
C5	4.78	2.17	M	4.43	2.09	RL	6.68	2.56	H	7.25	2.35	H
C6	4.88	2.36	M	3.97	2.27	RL	4.68	2.13	M	5.72	2.09	RH
C7	4.66	1.93	M	4.17	1.73	RL	4.86	2.45	M	6.32	2.23	RH
C8	5.54	2.25	RH	5.54	2.22	RH	7.02	1.83	H	7.28	1.82	H
C9	4.94	2.12	M	4.43	2.13	RL	5.85	2.13	RH	6.45	1.96	RH
C10	5.80	2.45	RH	6.09	2.37	RH	7.38	2.01	H	7.65	1.70	VH
C11	5.18	2.23	M	5.46	2.05	M	7.25	2.11	H	7.35	1.97	H
C12	4.58	1.99	M	4.78	2.19	M	7.11	1.91	H	6.68	2.15	H
C13	4.83	1.62	M	4.74	1.85	M	7.03	1.88	H	7.55	1.82	VH
C14	5.11	2.05	M	4.92	2.16	M	7.88	2.10	VH	7.37	2.05	H
C15	4.71	2.06	M	5.08	2.41	M	7.42	2.03	H	7.65	1.83	VH
C16	4.00	2.08	RL	5.12	2.74	M	5.29	2.68	M	6.42	2.29	RH
C17	4.22	2.23	RL	5.98	2.72	RH	6.89	2.23	H	7.69	1.76	VH
C18	5.55	2.36	RH	6.58	1.77	H	7.48	1.65	H	7.72	1.36	VH
C19	6.34	2.12	RH	6.89	2.25	H	7.89	1.92	VH	8.74	1.54	EH
C20	5.52	2.31	RH	6.08	2.23	RH	7.12	1.78	H	8.18	1.40	VH

MS: Mean Score, SD: Standard Deviation, IOE: Intensity of Effectiveness

Based on the magnitude of the MS values, the ranking results for each criterion are presented in Table 5. Criteria C2, C18, C17 and C9 in bridges and tunnels have exactly the same ranking positions. Likewise, criteria C1, C19, C15, C10, C8, C3, C16, C17, C11 and C6 are almost the same in position rankings (only one position difference). The similarity in the ranking of criteria for tunnels and bridges signifies that these two structures have almost the same functionality in road performance.

Table 5: Overall ranking of criteria for road infrastructures

Ranking	Bridge	Tunnel	Retaining Wall	Building
1	C19	C1	C19	C19
2	C1	C19	C1	C1
3	C20	C14	C18	C10
4	C2	C2	C10	C8
5	C18	C18	C20	C20
6	C10	C15	C17	C3
7	C15	C10	C8	C2
8	C13	C11	C11	C11
9	C14	C20	C3	C14
10	C11	C12	C16	C9
11	C8	C13	C15	C6
12	C5	C8	C14	C13
13	C17	C17	C12	C5
14	C3	C5	C13	C15
15	C12	C3	C2	C7
16	C9	C9	C4	C12
17	C16	C4	C5	C18
18	C7	C16	C9	C4
19	C6	C7	C7	C17
20	C4	C6	C6	C16

The ranking of the criteria, "historical", "architectural" and "social issues" (C6, C7 and C9) indicates that these are more important factors in buildings than other infrastructures. On the other hand, "hydraulic vulnerability" and "physical conditions" (C17 and C18) seem less important in the buildings category. Furthermore, weather conditions (C16) has more effect on the rehabilitation process for retaining walls than other infrastructures. Figure 3 shows the ranking positions of all 20 RC separately.

"Social Issues" (C9), "Weather Conditions" (C16), "Environmental Issues" (C8), "Architectural" (C7) and "Historical Aspects" (C6) were recognized as the five least important RC in seismic rehabilitation decision making for road infrastructures. As Figure 3 depicts, the bridges have the highest rating score among other categories. This indicates bridges can play a more significant role in road network performance than other infrastructures. It can also be emphasized in another way by looking at the General Score (GS) in the questionnaire forms, which were derived based on expert judgments. GS values are defined in the next section.

It must be appreciated that different group of experts have different perceptions of the priorities to be considered in assessing RC and this is demonstrated in that they allocate different weighted values to individual criteria. 77 percent of all respondents were not engineers in the fields of transportation, infrastructure and earthquake. However, the majority of respondents believe that "seismic vulnerability" and "safety" are the two most important criteria in seismic rehabilitation decision making. Prioritization for retrofit or rehabilitation purposes is not limited to specific regions or countries. Screening an inventory of road infrastructures can be done at any level of road and transportation departments, including local, provincial, and network or national level. However, it is to be noted that the collected RC are general, though local experts can quantify the weights more precisely for a specific region.

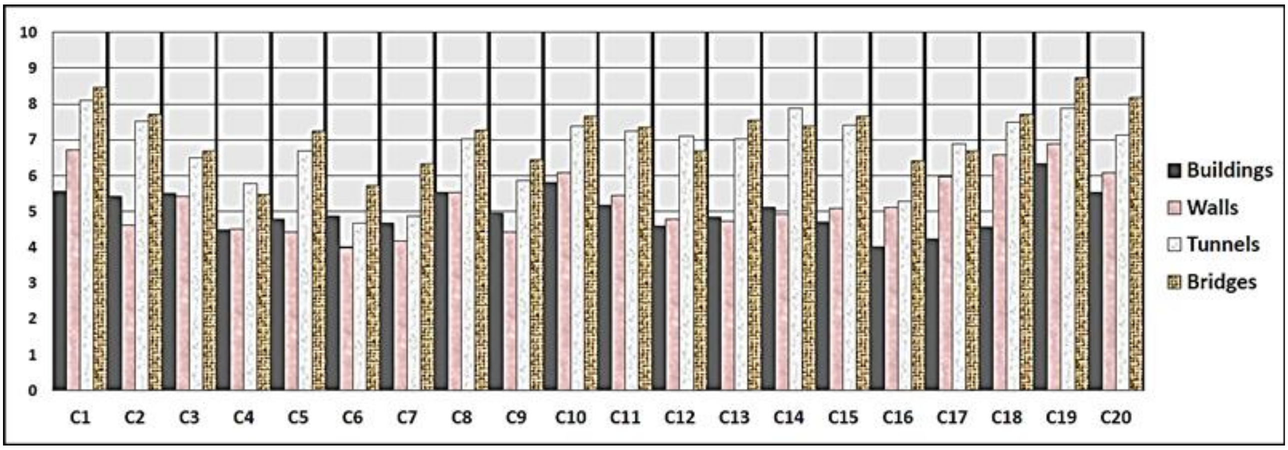

Figure 3: RC Weighting Comparison for four Categories of Road Infrastructures

9. Validation Process

Convergent validation was used to validate the whole process and verify its robustness in assigning weights for non-seismic rehabilitation criteria. The respondents holistically evaluated the weight of each infrastructure on a scale from zero to ten. This evaluation consisted of using their experience and knowledge of the individual infrastructure. The overall evaluation was called the General Score (GS) in the questionnaire forms (Figure 4). According to expert judgments, the average mean of "General Score" was 4.40, 4.91, 8.09 and 8.54 for road buildings, retaining walls, tunnels and bridges respectively.

This evaluation was then compared to the results obtained by the analysis process using the validation factor as follows:

$$VF = \frac{AMC}{GS} \tag{8}$$

where VF is the validation factor; AMC is the average mean of RC for each category and GS is the general score. The results of the holistic and quantitative evaluations of the two methods are shown in Table 6 along with the VF for the four categories of infrastructures. The results demonstrate that the weight assignment for non-seismic RC for road infrastructures was robust in ranking and prioritizing different infrastructures.

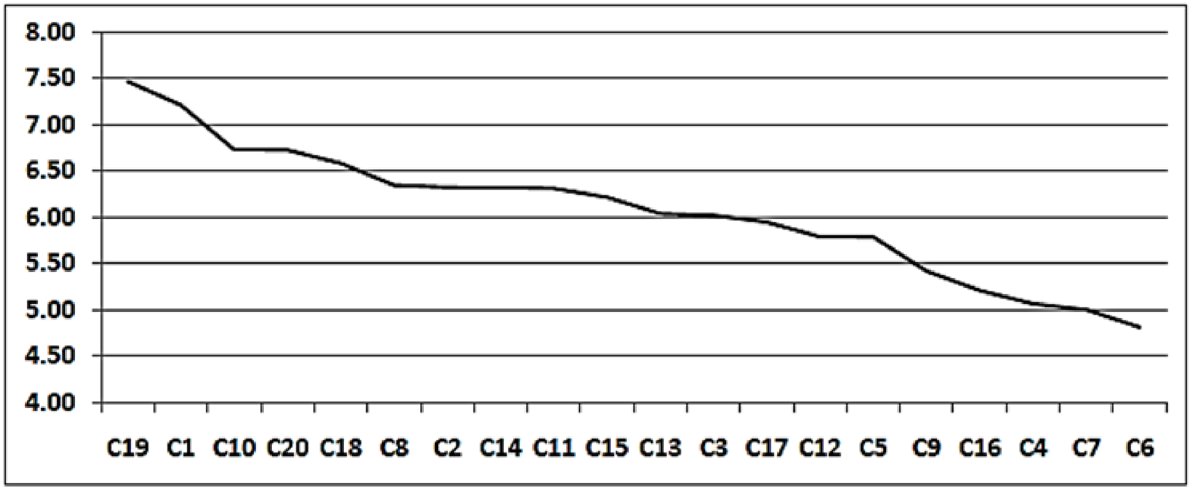

Figure 4: Average Mean of Criteria

Table 6: Rehabilitation Criteria Validation

Infrastructure	Holistic Evaluation General Score (GS)	Average mean of criteria for each infrastructure (AMC)	Validation Factor (%)	Absolute value Error (%)
Bridges	8.54	7.17	83.95	16.05
Tunnels	8.09	6.79	83.93	16.67
Retaining Walls	4.91	5.28	92.99	-7.01
Buildings	4.40	5.03	85.68	-14.32
Average	-	-	86.64	11.39

10. Numerical Example and Discussion

In this section, a problem to prioritize hypothetical road structures is developed to demonstrate the mathematical process of the seismic rating procedure. It is assumed that the Ministry of Road and Transportation is planning to evaluate 20 rehabilitation projects including 5 bridges, 5 tunnels, 5 walls and 5 buildings which are symbolized with Br, Tu, Wa and Bu, respectively. The seismic and structural scores with the relative weighted RC for each category is listed in Table 7. In this situation, the Ministry is faced with the prioritization decision-making problem of how to rank the structures and how to decide which projects ought to be executed. For the sake of conciseness, the decision-making judgment of experts is illustrated with non-fuzzy numbers in this numerical example. It was decided to adopt the multi-criteria model (Weighted Sum Model) to prioritize the rehabilitation projects and under the 20 evaluation criteria and assign the appropriate scores, according to the field surveys and briefings An evaluation committee should be constituted to make their judgments based on the need priorities of projects submitted by each unit. In order to simplify the evaluation work in this case, the scores (S_{ijk}) are assumed for each determine their final priority scores (Huang *et al*., 2010). structure. In the score assignment under each criterion, the 10-points Likert scale was applied.

In the below table, C19 represents the "Seismic Vulnerability" of structures which is the rank based on structural vulnerability and seismicity and can be calculated for bridges based on "Seismic Rating Method using Indices" (Seismic Retrofit Manual for Highways Bridges, Part 1: Section 4.3). This method can be developed for other infrastructures as well. According to the results of the evaluation process for the rehabilitation projects submitted by the Ministry, the final priority scores for each project are determined, as shown in Table 8. In this table, column $\mathbf{P}_i$ represents the priority scores of the projects. The results will give a clear view to the decision makers for a better understanding of the ranking and urgency of the projects at road network level.

Table 7: Results of expert's evaluation for score determination of each infrastructure

S_{ijk}																					
RC		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
Bridges	Br-1	4	6	6	7	5	6	3	3	1	9	8	5	7	4	5	6	7	7	4	4
	Br-2	5	6	7	8	5	4	9	8	4	2	3	4	6	5	4	8	7	6	5	4
	Br-3	9	8	9	7	4	5	7	3	8	7	6	5	6	4	8	7	6	9	6	3
	Br-4	8	9	6	7	4	5	3	8	7	4	1	3	2	4	3	5	4	3	1	6
	Br-5	8	9	6	4	3	5	7	4	2	8	1	2	6	5	4	3	2	6	5	7
Tunnels	Tu-1	4	5	4	3	7	6	5	7	6	7	6	8	7	9	8	8	7	9	4	10
	Tu-2	10	7	8	9	4	3	2	8	1	2	3	2	5	4	7	6	1	1	4	5
	Tu-3	4	3	5	6	8	7	3	9	8	2	3	5	4	6	7	1	8	7	4	9
	Tu-4	2	3	4	3	2	1	1	1	3	4	5	4	3	2	4	3	4	3	5	4
	Tu-5	2	1	3	4	3	5	4	6	9	7	4	3	4	7	5	6	3	1	3	4
Walls	Wa-1	10	8	9	5	8	7	6	8	9	1	2	5	8	7	9	6	8	6	9	8
	Wa-2	5	4	6	8	7	9	8	7	2	4	6	2	5	3	5	8	7	8	7	9
	Wa-3	2	4	5	6	8	7	8	4	5	2	1	10	9	10	9	5	4	8	8	9
	Wa-4	1	2	5	8	9	8	7	6	5	8	4	9	5	8	9	10	2	8	7	9
	Wa-5	2	5	4	5	4	5	8	9	8	7	8	9	8	7	8	9	8	7	8	9
Buildings	Bu-1	10	8	9	8	10	9	8	5	7	8	8	8	9	8	7	4	5	6	9	8
	Bu-2	2	5	4	2	6	5	3	5	4	7	8	9	5	1	2	5	4	5	8	7
	Bu-3	3	3	2	5	4	2	1	2	5	3	6	2	4	2	3	2	1	5	3	2
	Bu-4	9	9	8	9	10	10	5	8	10	4	10	7	8	6	6	7	8	10	9	10
	Bu-5	8	7	4	5	6	2	5	7	8	9	5	4	8	5	6	9	5	8	4	8

Table 8: Results of the priority scores and ranking for selected projects

Infrastructures		P_i	Priority Grade
Bridges	Br-1	53.37	13
	Br-2	54.20	12
	Br-3	63.49	7
	Br-4	46.10	17
	Br-5	49.55	14
Tunnels	Tu-1	65.49	5
	Tu-2	46.62	16
	Tu-3	54.57	11
	Tu-4	31.25	19
	Tu-5	41.14	18
Walls	Wa-1	69.70	3
	Wa-2	60.40	10
	Wa-3	60.84	9
	Wa-4	64.10	6
	Wa-5	69.10	4
Buildings	Bu-1	77.68	2
	Bu-2	49.16	15
	Bu-3	30.23	20
	Bu-4	81.78	1
	Bu-5	61.67	8

Conclusions

It is important to develop measures to help to mitigate probable risks and consequences of the seismic damages to road infrastructures. Finding the most critical and important structures in road network for repair or rehabilitation tasks has been one significant challenge facing transportation managers and practitioners. This is mostly because of a variety of factors and criteria that affect the rehabilitation decision-making process. The qualitative part of the proposed seismic rating method modifies the rank in a subjective way that takes into account different factors for inclusion in an overall priority index. Hence, the priority index is a function of rank, importance, and other factors.

This study describes the writers' efforts in identify the most effective rehabilitation criteria for the seismic rehabilitation of road infrastructures in terms of numeric weighted values. Accordingly, through relevant references and documents, 20 weighted criteria were identified that are effective on seismic rehabilitation decision-making. Experienced risk practitioners including managers, supervisors, designers, engineers and other experts in related areas were surveyed. Ranking analysis revealed that all criteria had a mean score between 4.0 and 8.0 and were mostly highlighted as being of "high", "rather–high", or "medium" importance levels. It is important to mention that "safety" and "seismic vulnerability" were identified as the two most important criteria in all road infrastructures. According to ranking results in four categories of road infrastructures, only one criterion in bridges was recognized as being of an "extremely high" importance level. This criterion is the "seismic vulnerability" which embraces the seismic-structural part the priority index. Meanwhile, the results indicate that "seismic vulnerability" (C19) is the second most important factor in other infrastructures. Moreover, bridges have the highest importance values in comparison to tunnels, walls and buildings. The results also indicate that "historical" and "architectural aspects" of these infrastructures seem to be the least important criteria.

Determining the weights of criteria, the priority index for each project can be calculated. It is to be noted that the identified criteria can be generalized and applied for prioritization at any level of road network. However, the limitations of the study are appreciated, particularly, (1) the fact that the weights need to be scrutinized and modified in any specific region by their local experts and for any specific purpose; (2) some other factors may have not been included in the study which is due to the number of disciplines of the respondents in the sample population. The introduced weighted criteria may help the road infrastructure decision makers in transportation departments to determine the final priority index of rehabilitation projects.

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References

Augeri, M.G., Colombrita, R., Greco, S., Lo Certo, A., Matarazzo, B., & Slowinski, R. (2010). Dominancebased rough set approach to budget allocation in highway maintenance activities. *Journal of Infrastructure Systems*, 17(2), 75–78.

Chen, Y., Okudan, G.E. & Riley, D.R. (2010). Sustainable performance criteria for construction method selection in concrete buildings, *Journal of Automation in Construction*, 19, 235-244.

Cohen, D.P.L. (2004). Maintenance and Repair Decision Making for Infrastructure Facilities without a Deterioration Model, *Journal of Infrastructure Systems*, 10(1), 1-8.

Croope, S.V. (2009). Working with HAZUS-MH, *A working paper submitted to the University of Delaware University Transportation Centre* (UD-UTC), UDUTC Working Paper.

Egbelakin, T.K. Wilkinson, S., Potangaroa, R. & Ingham, J. (2011). Challenges to successful seismic retrofit implementation: a socio-behavioural perspective, *Building Research & Information*, 39(3), 286–300.

Elhag, T.M.S. & Wang, Y. (2007). Risk Assessment for Bridge Maintenance Projects: Neural Networks versus Regression Techniques, *Journal of Computing in Civil Engineering*, 21(6), 402-409.

Federal Highway Administration. (2008). *Seismic retrofitting manual for highway structures* (MCEER-08-SP02). Part 1: Bridges. Washington, DC: FHWA.

FEMA 154, Edition 2. (March 2002). *Rapid Visual Screening of Buildings for Potential Seismic Hazards*, A Handbook, Applied Technology Council, Washington, DC.

FEMA 356, Prestandard (2000). *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, American Society of Civil Engineers (ACSE), Federal Emergency Management Agency, Washington D.C., November 2000.

FEMA 366 (April 2008), *Estimated Annualized Earthquake Losses for the United States*, HAZUS MH, http://www.fema.gov/plan/prevent/hazus.

FEMA 433 (August 2004), *Risk Assessment and User Group Series*, Using HAZUS-MH for Risk Assessment, How-To Guide, HAZUS-MH.

Fletcher, D.R. (2002). The Role of Geospatial Technology in Critical Transportation Infrastructure Protection, A Research Agenda, National Consortium on Remote Sensing in Transportation Management Spatial Information Technologies in Critical Infrastructure Protection, *NCRST*, U.S. Department of Transportation.

Frangopol, D.M., Kong, J.S., & Gharaibeh, E.S. (2001). Reliability based life-cycle management of highway bridges. *Journal Computing Civil Engineering*,
15, 27–34.

Gharaibeh, N.G., Yi-Chang, C., & Gurian, P.L. (2006). Decision methodology for allocating funds across transportation infrastructure assets. *Journal of Infrastructure Systems*, 12(1), 1–9.

Gokey, J., Klein, N. & Mackey, C. (2009). Development of a Prioritization Methodology for Maintaining Virginia's Bridge Infrastructure Systems, *IEEE Systems and Information Engineering Design Symposium*, University of Virginia, Charlottesville, April 24, VA, USA.

Guide for the Structural Rehabilitation of Heritage Buildings, Prepared by CIB Commission, W023– Wall Structures, CIB Publication 335, 2010.

Guo, H. (2010). The Reform and Pilot Study of Survey Methodology for Road Freight Transport, ICLEM 2010, *Logistics for Sustained Economic Development*, ASCE, 27-34.

Hellstrom, T. (2007). Critical infrastructure and systemic vulnerability: Towards a planning framework, *Journal of Safety Science*, 45, 415–430.

Holsti, O.R. (1969). Content Analysis for the Social Sciences and Humanities, Addison-Wesley Publishing Company, Massachusetts, 14-20.

Huang, W.C., Teng, J.Y., & Lin, M.C. (2010). The budget allocation model of public infrastructure projects. *Journal of Marine Science and Technology*, 18(5), 697–708.

Islam, M.A., Sakakibara, H., Karim, M. R. & Sekine, M. (2011). *Rural water consumption behavior: A case study in southwest coastal area*, Bangladesh World Environmental and Water Resources Congress 2011, Bearing Knowledge for Sustainability, ASCE 2011, 4403–4412.

Khan, M.A., Bridge and Highway Structure Rehabilitation and Repair, The McGraw–Hill Companies, Mc Graw Hill, 2010.

Mechler, R. (2002). Natural Disaster Risk and Cost–Benefit Analysis, *Building Safer Cities*: The Future of Disaster Risk, Chapter 3.

Moore, G.D. (1994). Resource Road Rehabilitation Handbook: Planning and Implementation Guidelines (Interim Methods), *Watershed Restoration Technical Circular*, 3, July 1994.

NEHRP, Annual Report of the National Earthquake Hazards Reduction Program to accompany the President's Budget Request to Congress for Fiscal Year 2008, March 2007.

Padgett, J.E., Dennemann, K. and Ghosh, J. (2010). Risk-based seismic life-cycle cost–benefit analysis for bridge retrofit assessment, *Journal of Structural Safety*, 32, 165–173.

Pellegrino, C., Pipinato, A. & Modena, C. (2011). A simplified management procedure for bridge network maintenance, *Structure and Infrastructure Engineering*, 7(5), 341–351.

Perng, Y.H., Juan, Y.K., & Hsu, H.S. (2007). Genetic algorithm-based decision support for the restoration budget allocation of historical buildings. *Building and Environment*, 42, 770–778.

PIARC – C18 (2003). Risk Management for Roads, Introductory Report, PIARC 2 . 22.18. E.

Rattleff, P. (2007). The Reliability of Content Analysis of Computer Conference Communication, *Journal of Computers & Education*, 49(2), 230–242.

Reilly, J. & Brown, J. (2004). Management and control of cost and risk for tunneling and infrastructure projects, *Tunneling and Underground Space Technology*, 19, 4–5, 330.

Rosmuller, N. & Beroggi G. E. G. (2004). Group decision making in infrastructure safety planning, *Safety Science*, 42, 325–349.

Salem, O., AbouRizk, S. & Ariaratnam, S. (2003). Risk–based Life-cycle Costing of Infrastructure Rehabilitation and Construction Alternatives, *Journal of Infrastructure System*, 9(1), 6–15.

Sharma, A. K. & Vohra, E. (2008). Critical evaluation of road infrastructure in India: a cross-country view, *Journal of Road infrastructure in India*, 12, 69–76.

Shen, L., Wu, Y., & Zhang, X. (2011). Key assessment indicators (KAIs) for the sustainability of infrastructure project. *Journal of Construction Engineering and Management*, 137(6), 441–451.

Shiraki, N., Shinozuka, M., Hon, M., Moore, J. E., Chang, S. E., Kameda, H. & Tanaka, S. (2007). System Risk Curves: Probabilistic Performance Scenarios for Highway Networks Subject to Earthquake Damage, *Journal of Infrastructure Systems*, 13, 43–54.

Shohet, I.M., & Perelstein, E. (2004). Decision support model for the allocation of resources in rehabilitation projects. *Journal of Construction Engineering and Management*, 130(2), 249–257.

Shrestha, C.B. (2004). Developing a Computer-Aided Methodology for District Road Network Planning and Prioritization in Nepal, *International Journal of Transport Management*, 1, 157–174.

Teng, J.Y., Huang, W.C., & Lin, M.C. (2010). Systematic budget allocation for transportation construction projects: A case in Taiwan. *Transportation*, 37, 331–361.

Teng, J.Y., Yeh, R.C., Lin, M.C., & Huang, W.C. (2007), The budget allocation of transportation construction projects by fuzzy multicriteria grade classification model. *Journal of the Eastern Asia Society for Transportation Studies*, 7, 415–426.

Vieira, V., Oliveira, C.S. & Costa, C.B. (2000). *A Methodology to Evaluate Strategic Importance of Bridges and Tunnels Considering Seismic Vulnerability*: Application to Lisbon, Euro-Conference on Global Change and Catastrophe Risk Management: Earthquake Risks in Europe, IIASA, 6–9 July, Luxemburg, Austria.

Wahida, B.M. (2010). *Road Maintenance Management System: A case study at Public Work Department,* Master of

Science (Construction Management), Faculty of Civil Engineering, Universiti Teknologi Malaysia, April 2010.

Werner, S.D., Jernigan, J.B., Taylor, C.E. & Hwang, H.H. M. (1995). Seismic Vulnerability Assessment of Highway Systems, *NCEER Bulletin*, 9(4) 4.

Yadollahi, M. & Zin, M.R. (2012). Multi-Strategy Budget Allocation Decision Support System for Seismic Rehabilitation of Road Infrastructure, *Journal of Structure and Infrastructure Engineering*, 1–22.

Zatar, W.A., Harik, I.E., Sutterer, K.G. & Dodds, A. (2008). Bridge Embankments. I: Seismic Risk Assessment and Ranking, *Journal of Performance Constructed Facilities*, 22(3), 171–180.

Zayed, T.M. (2004). Budget Allocation for steel bridge paint maintenance. *Journal of Performance of Constructed Facilities*, ASCE, 18(1).

Zhang, G. & Zou, P.X.W. (2007). Fuzzy Analytical Hierarchy Process Risk Assessment Approach for Joint Venture Construction Projects in China, *Journal of Construction Engineering and Management*, 133(10), 771–779.

Ziderer, I. (2006). TAJ: *Road Rehabilitation Project*, Social Monitoring Report, Asian Development Bank (ADB), Project Completion Monitoring and Evaluation Report.

Appendix

Profile of Respondents

After the questionnaire was delivered and a follow-up reminder email was sent to the respondents who had not returned the survey, a total of 65 accurate and valid responses were collected. Some of the questionnaires were not properly completed. Only valid questionnaires were selected for analysis. Invalid forms include the ones that weren't returned or filled out completely. Some respondents returned the questionnaire but responded to only one or two criteria and were therefore considered as invalid. The profile of the questionnaire respondents is shown in following figure.

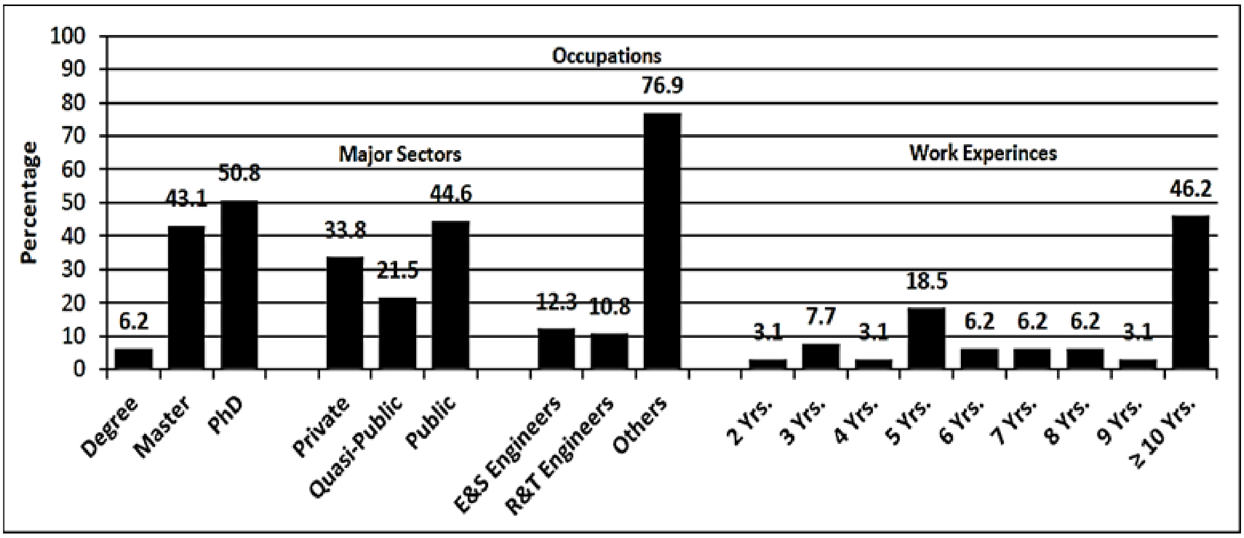

Figure 5: Profile of the questionnaire respondents

In this figure, (R&T) and (E&S) represents the road/transportation and earthquake/structural engineers respectively. The participants were selected from amongst the experts in different area of disaster management who attended the related conferences. The respondents were of the following nationalities: German, Italian, Iranian, Korean, Turkish, Austrian, Chinese, American, Swiss, Australian, Danish, Malaysian, Japanese, etc. The respondents' expertise including the following:

Structural Engineering, Earthquake Engineering, Road/Transportation Engineering, Construction Management, Architectures, Environmental Geology, Risk Management, Intelligent Systems, Risk Quantification, Fire Protection Engineering, Business Continuity Management, Traffic Safety, Geo-information, Economics, Nuclear Engineering, Disaster Management, Natural Disaster, Urban Planning, Water Management, Operations Research, Coastal Risks, Environmental Engineering (Ecology- water resources) and Meteorology (Climatology).