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Research Article

COST MANAGEMENT AND IMPLEMENTATION IN SEISMIC RETROFITTING OF HIGHWAY BRIDGES

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ABSTRACT
Seismic retrofitting of the bridges is one of the methods for reduction of seismic hazard. The study of seismic retrofitting of bridges includes the study of bridge susceptibility through qualitative and quantitative approaches and the study of the strategies for retrofitting and design of retrofitting. This study aims at detailed evaluation of the elements of one of the bridges of Tehran through the most recent evaluation methods of seismic susceptibility including the instruction of seismic retrofitting of existing buildings and the instruction of seismic retrofitting of the existing bridges and FHWA. It also aims at proposing various options and introducing the best option in terms of technical and economic aspects.

Keywords: *Cost Management, Seismic Retrofitting, Highway Bridges*

INTRODUCTION
Since our country has been located on Alp-Himalaya seismic belt that has high seismicity potential. For constant utilization of communication ways at the time of earthquake, the necessity for evaluation of seismic nature of these structures becomes very significant, while in previous bylaws, most of the main seismic points had not been considered. Seismic retrofitting of the constructed bridges is one of the seismic retrofitting methods. The main bridges with high susceptibility risk in severe seismic areas should be considered as the first priority for seismic retrofitting. The implementation problems and high cost of bridge retrofitting with the use of new designing standards usually make retrofitting unjustifiable. To this end, the aim of retrofitting has been limited to prevention of unacceptable failure. Thus, when dealing with bridge retrofitting, it is possible to accept one method among lack of retrofitting and acceptance of bridge fall risk, construction of alternative bridge and bridge retrofitting that requires the evaluation of significance and level of bridge susceptibility. In other words, the economic aspects of seismic retrofitting of existing bridges will be compared with those of construction of new bridge.
Since seismic retrofitting is usually done based on evaluation of unacceptable damage by earthquake, the engineering judgment plays significant role in seismic retrofitting due to the complexities and intangible decisions on seismic retrofitting and various non-engineering factors that are involved. Concerning the significance of cost in areas with low to mid seismicity risk, seismic retrofitting is justifiable when non-seismic retrofitting is also done on the bridge, then the value of traffic control and its reduction compensate a great part of seismic retrofitting cost. Concerning the experiences on America highway bridges, more than 80% of which are evaluated at least once within two years, it becomes necessary to be seriously sensitive on the occurrence of similar events in the bridges of our country. During past 8 years in Tehran city, bridge retrofitting and the maintenance of these capitals was taken into account. Technical inspection of all bridges of Tehran and preparation of their technical identification card lead to repair and maintenance plan for 140 damaged bridges. Out of which 33 ones have been essentially repaired and 6 km expansion joints have been replaced. On the other hand, through evaluation of seismic susceptibility of 106 bridges of Tehran city, retrofitting of 8 bridges including *Seyed Khandan*, *Chamran* and *Azmayesh* becomes operational and the material strength and geotechnical tests of 35 bridges become finalized. Future plans of technical and civil deputy of Tehran municipality in this regard include completion of the second stage of retrofitting studies of 59 bridges, implementation of retrofitting operation of 89 bridges and constant maintenance of all bridges all over the city. Currently, the study of the second stage of seismic and non-seismic retrofitting plant on 13 bridges of the main sections of Tehran is at hand.

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In recent years, seismic retrofitting of buildings has significantly developed; yet, concerning the infrastructural structures such as bridges that are the most sensitive and susceptible element of the country, no complete and comprehensive collection has been presented. The present study is new and significant due to its attention to these vital structures and seismic retrofitting of them. The study of seismic retrofitting of brides includes the study of bridge susceptibility through quantitative and qualitative approach and the study of strategies for retrofitting and retrofitting design.

Economic Consideration of Seismicretro Fitting

Cost is one of the main factors in retrofitting design. Table 1 includes collected data on the seismic retrofitting costs of 165 bridges in California State by Caltrans during 1993 and 1994 where the retrofitting costs have been expressed as a percentage of construction of new bridge. In average, the retrofitting cost is almost 15% of the cost of construction of new bridge in the same time period. Retrofitting costs extremely depend on the used strategy. When just the surface structure is retrofitted (cable binding and seat width expanders, the retrofitting cost is just 3.1% of the cost of constructing new bridge. When the deep structure except foundation is retrofitted, this value will be 15.4. When the foundation is retrofitted with other sections, this value will increased by 28.8. This indicates cost variation of the same strategy is used for various bridges. In addition, it should be taken into account that this data is related to the condition of bridge reconstruction in California and this condition is different in other countries. Table1 presents Caltrans data for 165 retrofitted bridges in 1993 and 1994 where the costs have been expressed as a percentage of construction cost of new structure and the retrofitting of the surface structure includes longitude bounds and expansion instruments. Engineering costs for retrofitting design is usually higher than new structures. This is due to the fact that most bridges are unique and usually require special retrofitting strategies. Thus, achieving the standardization of design details and retrofitting will be problematic. In addition, detailed seismic evaluation of a bridge and defining of the most proper retrofitting strategy is a timely process that includes precise dynamic analysis and trial and test in investigation of possible strategies. In addition to higher initial costs, it is required that the life of a retrofitting plan should not exceed the remaining life of bridge servicing. Thus, it is required that the weight of the benefits of retrofitting strategies to be compared with the higher cost of choosing other strategies to prevent damage of bridge at the time of earthquake (Mahdavi and Azadi, 2014).

Table 1: The cost of various retrofitting strategies as a percentage of new bridge construction cost (Caltrans (2004)

Retrofitting area	**Retrofitting strategy**			**Sum**
	Surface structure	**Surface and deep structure**	**Surface and deep structure and foundation**	
Low	1.3	0.7	2.3	0.7
Mid	3.1	15.4	28.8	15.1
High	13.2	64.8	232.9	232.9

Retrofitting and its Objectives

The physical structure of an element of a bridge with the aim of overall elevation of its seismic function is called retrofitting. For example, adding a steel sheet to a concrete column is considered as retrofitting method. The decision to retrofit the bridge depends on some non-engineering factors including political, social and economic considerations such that one can say that the issue of cost for retrofitting is the most important and prior issue. The main aim of retrofitting is to reduce the hazard due to unacceptable damage during earthquake at design level. Those damages are called unacceptable that lead to one or all of the following items:

- ✓ Overall or partial collapse of bridge
- ✓ Failure to use the accessibility path in main transportation ways
- ✓ Serious life threats and losses

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At the time of seismic retrofitting of susceptible members of structure, new design standards should be used that are plausible. However, complete retrofitting of the bridge and all its members based on new structural standards is not possible due to economic issues and failure phenomenon in constituting materials and members of bridge during its life. Thus, retrofitting depends on the demand of bridge structure and its cost is determined based on details and required level. Furthermore, seismic retrofitting of bridge should be planned to achieve the least demand level in respect to force strength or structure displacement concerning effective environmental and non-environmental factors.

Retrofitting Process

The study of bridge susceptibility is usually done through qualitative approach or qualitative evaluation of bridge susceptibility based on field study and visit of the bridge, the investigation of presence or absence of technical documents including design and implementation maps of the bridge, the calculation notebook, the seismicity studies, soil mechanic and dynamic studies, completion of technical identification cards of the bridge, preparation of qualitative evaluation report of bridge susceptibility and presenting the proposal of continuing studies in quantitative phase, complementary studies by performing sondage for identification of structural elements for drawing structural map and sampling of the structural elements for material strength test to determine the steel rate, concrete strength and documentation of complementary data. Furthermore, quantitative evaluation studies of bridge susceptibility include structural modeling of the bridge based on the existing data and documents, performing loading and structural analyses, detailed evaluation of bridge structural elements, the investigation of the status of susceptibility of bridge non-structural elements and determination of the need to retrofitting or lack of it.

After performing qualitative and quantitative evaluation studies, the retrofitting strategies and design will be investigated that includes presenting bridge retrofitting options and selection of the best option, detailed design of retrofitting, preparation of operational maps for retrofitting structural and non-structural elements and the economic study of retrofitting.

Introducing the Studied Bridges

The studied bridge is shown in figure 1.

Figure 1: The view of studied bridge

Concerning the existing maps and the visits of the bridge and the studies, the concrete bridge has been formed from two separate tableaus. Each tableau has 6 openings with 32 meter diameter. This bridge is

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among concrete bridge with constant/ in-situ deck and I-shape girders and reinforced concrete columns. The bridge openings are all simple and there are 7 expansion joints on the deck. Each deck has 5 grinders with 3.20 cm distance. The southern and northern deck width is 16 meters and the height of columns is 15-18 m. An approximate area of 1-4 m around the columns has been embanked. Moreover, the total length of the bridge is 192 meters. The transverse concrete diaphragms support the concrete girders at intervals of 6.40 m. Three passing routes and three return routes direct the traffic. The studied bridge has been located on the way of Resalat highway. The traffic of the bridge is not the same as other urban bridges of Tehran that are usually full of automobile at all times of day (such as *Modarres* bridge) and usually guides slow flow.

The Qualities Evaluation of the Studied Bridge

In this section, after performing the initial study of the intended bridge, concerning the efflorescence on the back, deck and grinders, it was required to do required corrections on wastage system. The status of embankment of backfills was inappropriate since the backfill concrete wall was hollow and caved; even part of the soil in front of backfill wall was collapsed that made it necessary to study the pressure of soil on the backfill wall. On the other hand, around some columns, embankment had been done that can lead to change in column stiffness.

The intervals between expansion joints in the deck are inappropriate; however, some joints are completely filled that can make the thermal deformation of deck problematic. In some transverse diaphragms, big holes have been created that reduce the stiffness of diaphragm; while, there is no necessity for the presence of these holes and on the other hand, in some diaphragms, the rusty steel wires came out that can lead to entrance of corrosive materials inside the concrete.

Since the bridge has been located on the bed of Kan River, there is the possibility of river bed overflow at the time of raining and it is required to perform hydraulic calculations and calculate the pressures on the basis and columns due to water. In addition, in the bed river, a 4-meter wall has been constituted that can lead to flood and damage to structural members of bridge at the time of raining. In one hand, this issue can be environmentally problematic. At the end, concerning the mentioned issues, the retrofitting of the bridge seems to be necessary. In this regard, due to lack of sufficient technical maps and documents of the studied structure, the additional services of the study include performing field studies, identification sondage, armature tracking, material sampling, soil mechanic test and geo-radar tests. After identification procedures and tests and some material strength tests, structural maps of the current status of bridge were prepared.

The Quantities Evaluation of the Studied Bridge

The main aim of the analytical studies on the finite element model of existing bridges is to evaluate the main structural elements and investigate the fulfillment of the inclusion criteria for retrofitting aim, risk level and their certain structural performance. Analytical evaluations of the structure have been done based on the information obtained in previous stage. The finite element model that was prepared due to lack of least data in qualitative studies was precisely prepared in this section based on the obtained information. The evaluation method has been selected based on the introduced models in FHWA journal (FHWA, 2006).

Concerning the concrete foundation of the bridge, capacity to demand method was used for evaluation. According to the instruction, the most common method for detailed evaluation of seismic performance is to use resilience modal analysis and the estimation of loading capacity and components' strength. It is required to calculate D/C ratio for each component, individually.

The ratio smaller than 1 indicates the necessity to do retrofitting; the seismic D/C ratios of bridge components are the indices that indicate the performance of the structure under certain earthquake. These figures are indicative of the susceptibility of structural components of the bridge exposed to earthquake and are used to provide retrofitting methods for various components of the bridge. The modeling of the studied bridge (Chen and Duan, 1999), the evaluation method, the analyses and their results will be discussed and it is tried to prepare the retrofitting designs in the next steps and implement the immunization plan.

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Concerning *Resalat* bride-Kan River, the investigations and evaluations of the bridge showed that the structure has some problems and weaknesses. Thus, one of the intermediate frames (axis P3) was selected as test frame and evaluations were performed on it. The frame has three columns and one reinforced concrete head. The lateral and intermediate columns were separately investigated, the demand on the pile caps was calculated and the piles were evaluated.
In the analyses of susceptibility on shear and moment strength of columns (AASHTO, 2010) and heads of foundation, the loading capacity of piles, bending and shear strength of grinders, control of longitudinal reinforcement of column in the head and foundation, lateral locking of column concrete around the plastic joint (Priestley and Calvi, 1996), the length of armature joint and the position of them, the width of seat, the strength of the elastomeric seats, the status of backpack and its pile foundations have been considered. The status of the components has been sorted in table 2.

Table 2: The summary of the C/D ratio of Resalat-Kan Bridge

Row	**Structural component**	**C/D ratio**		
		Bending	**Shear**	**Axial**
1	The column of intermediate frame	0.54	5.70	N.A.
2	Head of intermediate frame	1.25	0.55	N.A.
3	Backpack column	N.A.	0.86	N.A.
4	Head of backpack	2.10	1.10	N.A.
5	Control of longitudinal armature of intermediate frame column in the head	1.00		
6	Control of longitudinal armature of the column of intermediate frame in the foundation	0.79		
7	Patching of longitudinal armatures of intermediate frame column	0.79		
8	Imprisoning of concrete in intermediate frame column	3.13		
9	The width of seat in the head of intermediate frame and backpack	1.10		
10	The strength of the seats of head of intermediate frame	N.A.	0.06	N.A.
11	The strength of seats of head of backpack	N.A.	0.10	N.A.
12	The lateral pre-constructed girders of deck	0.42	1.10	N.A.
13	The internal pre-constructed girders of deck	0.44	1.08	N.A.
14	The transverse diagram of the end of openings	N.A.	N.A.	7.40

Based on the studies, it was specified that the main retrofitting cost is related to the bending retrofitting of the column of intermediate frame, shear retrofitting of the column heads of intermediate frames and backpack columns, bending reinforcement of girders, replacement of seats with proper types and embedding of longitudinal bindings. The analysis shows that relative displacement of the openings during earthquake is high and although the width of seat is bigger than what is determined in the standards, there is the possibility of the collapse of opening from the support. Thus, installation of bindings is seriously recommended. The status of pile foundations is appropriate; however, unfortunately there is no precise information of the status of backpack foundation. It worth noting that the bridge needs fixing in addition to seismic retrofitting. The quality of the concrete of most structural components is not proper and in some areas, the concrete coverage of armature and reinforcement has broken and the armatures become visible.

Efflorescence is widely seen under deck. The bridge lack proper drainage system. Expansion joints need to be replaced. It is required to fill the cubic holes on the top of the columns (exactly at the place of plastic hinges formation) and the circular holes in diaphragms that are embedded for passing of the facilities with proper materials. It is useful to organize the retrofitting processes and build canals for passing of flood under the bridge to prevent the probability damage to intermediate bases.

The Presentation of Preliminary Plan for Retrofitting of the Studied Bridge

In this section, it was tried to study at least three options for retrofitting of the bridge through technical approach. In case of this bridge, the main focus is on retrofitting of the columns of the intermediate frames. First, as an overall recommendation of FHWA instruction (FHWA,1995), it was tried to direct the elastic hinges of the intermediate frames of the bridge toward the body of the column and not pile through installation of a concrete rectangular pile on the top of the balance of vase shape pile of the column base. Then, to compensate the weakness of longitudinal armature patch of columns, three steel casings, concrete casing and FRP fiber were investigated. For shear retrofitting of the head, FRP fiber method and joint concrete element on the sides of head were recommended and it was shown that these methods can reduce the shear susceptibility of the column head with the mentioned specifications. At the end, it was recommended that concerning inefficiency of the elastomer seats in the bridge, the new seats (GUMBA, 2003) with presented technical specification to be replaced for weak seats. At the following, the various options of retrofitting have been fully explained:

Concrete Casing for Column Retrofitting

The use of concrete casing for reinforcement of the bases requires lower technology and workforces with less expertise compared to reinforcement method with FRP. While, this method has some problems in the intended area, this method requires more precise processing of the concrete. Moreover, the concrete casing leads to considerable change of stiffness in the column that changes the dynamic behavior of the structure. the experience has shown that in case of lack of linking of new concrete and the old concrete, the concrete coverage will break down. Thus, to link new and old concrete, the embedded shear lug in the old concrete is used. However, concerning the bridge bases with low pressure strength concrete, the embedding of shear lugs can aggregate the existing concrete that is one of the other deficiencies of the concrete casing method. In terms of the speed of implementation, concerning the required time for molding, reinforcing and concreting of this option is in the third rank. From this approach, the cost of this option is in the first rank.

Steel Casing for Column Reinforcement

The use of steel casing for reinforcement of bases requires higher technology compared to reinforcement by concrete casing; yet, this method has to some extent the problems of concrete casing. This method requires precise shearing of casings. In addition, the imbedding of casing leads to considerable change of stiffness in columns that change the dynamic behavior of the structure. The need for next measures for prevention of steel corrosion and continuous rusting of casing surface are among the problems of this method. In terms of appearance, this method is at the next rank of FRP method. In terms of implementation time, this method is quicker than concrete jacket; however, it is slower than reinforcement with FRP. In terms of cost, this option has the highest cost among three options and is in the third rank.

FRP Fiber for Reinforcement of the Column

FRP materials are light, resistant against corrosion and have high tensile strength. These materials are accessible in different forms and in wide range of multi-layer sheets of factories to inflexible sheets on various structural forms before adding resin, especially, when the appearance of the work seems to be finished or when the possibility of accessibility is intended.

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One of the main advantageous of this method is lack of considerable change in column stiffness and thus, lack of variation in dynamic behavior of the bridge. The fiber of the used resins in FRP systems compared to other common materials such as concrete and steel is a bit more expensive. However, mostly the costs related to wage and installation equipment of FRP are cheaper such that this option is the cheapest option with a bit difference with that of concrete casing in the second rank. The implementation time of this option is less than other options. In addition, the strength and durability of this option is more than others after implementation. Aesthetically, this option has better appearance than two other options. The precision in sticking FRP sheets and preparation of the surface before sticking of the sheets are among the problems of this method.

FRP Fiber for Reinforcement of Column Head

FRP fiber is prior for reinforcement of the head compared to concrete through technical and financial approach; however, the only problem of this method is that since the heads are located in the expansion joint areas, if the drainage system doesn't act properly when these fibers become wet or polluted, they might lose their properties and are effective just when they are properly protected against the penetration of water and environmental pollutants. Furthermore, they are required to be effectively controlled to be able to create shear reinforcement for head. The implementation time of this method is significantly less that joint concrete element. Precision in sticking FRP sheets and preparation of the surface before sticking of the sheets are among the problems of this method.

Joint Concrete Element Method for Reinforcement of the Head

This method is relatively more traditional that FRP composites, its advantages include longer life time and no need to precise protection of the reinforced members. Its problems include the need for concrete molding, using reinforcement and reinforcing the sides of head that make the implementation time more than previous method, it has higher cost that the previous method and requires supervision of the quality of concreting and care after concreting.

Its other advantages include increased width of head that increases the shear and bending stiffness of the head higher than previous method that might not appear to be desired due to more energy absorption. The other problem of using this method is the necessity for creation of abrasions and ridged on the sides of concrete head.

Investigation and Comparison of Options

In this section, concerning the effective factors in selection, various reinforcement options of the bridge have been compared and studied. It worth noting that concerning the local properties and the project type, also the type of the studied options, some of the criteria are not significant or the studied options have not certain relative advantage in relation with its agent.

In this study, some recommendations were proposed for reinforcement of the susceptible components of the bridge that are briefly referred in following:

For reinforcement of the columns three options of concrete casing, steel casing and composite fiber were recommended due to lack of patch length and compensation of improper place of casing patches.

To insure that at the time of earthquake, all hinges are formed in the base of columns and not on the body of pile, one strategy is to install a stiff rectangular cubic concrete foundation at the beginning of the columns and on the vase balance. By this, the side motion of column base will be bounded and it is possible to easily reinforce the columns without the need to reinforce the body of piles.

For reinforcement of the existing seats, it is required to replace these seats with new reinforced elastomer types.

To reinforce the heads of the frames under the structure, FRP fiber and joint element methods were proposed. Concerning the above explanation and by consideration of special condition of the project, economic considerations and other scientific and technical arguments and implementation facilities of the country, concrete casing was selected as the optimum method for supplying bending strength of the columns and shear strength of the heads of axes 3 and 4 and at the end, the reinforcement option was selected concerning higher score. The selection of the best option has been done using Analytical Hierarchy Procedure (AHP Method) and according to the studies as presented in table3.

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Table 3: The scoring and weighting of decision making criteria for selection of the best choice of reinforcement of bridge head

Row	Criteria	Cost		Technical		Implementation		Maintenance		Expertise		Time		Sum of coefficients
	Weight percentage	35		30		8		15		5		7		100
1	Reinforced concrete casing	9	315	5	150	5	40	9	135	5	25	3	21	686
2	Steel casing	1	35	3	90	3	24	7	105	3	15	5	35	304
3	Composite fiber	5	175	5	150	5	40	3	45	1	5	9	63	478

Concerning the studies based on cost and condition of implementation of various options of seismic reinforcement of the studied bridge, the options of bridge reinforcement along with their economic comparison of items have been presented in table4. Furthermore, it should be reminded that for implementation of reinforcement plan, consideration of annual inflation coefficient on the price of mentioned table are necessary.

Table 4: The costs of reinforcement options of the bridge

Row	Reinforcement	Explanation of operation	Total price ($)
1	Column	The use of composite fiber (FRP)	320,650
2		The use of steel jacketing	610,000
3		The use of concrete jacketing	176,010
4	Head	The use of FRP for shear reinforcement of the head	23,700
5		The use of bolster concrete element for shear reinforcement	144,666
6	Seat	Preparation and installation of reinforced elastomer	181,200
7	New pile	Construction of pile of column basis of axes 3 and 4 of intermediate frames	33,226

RESULTS AND DISCUSSION

In this study, a comprehensive study on proposing bridge reinforcing options, selection of the best option, detailed design of reinforcement, preparation of executive maps, reinforcement of structural and non-structural components and at the end the economic study of reinforcement was carried out. In the first stage, it was determined that the proposed damages can be removed by performing related reinforcement and fortunately, the bridge is not in a condition such that seismic reinforcement is not economic for it and the proposition of destruction and renewal to be proposed for it. Furthermore, by comparison of all proposed options in technical, economical and executive terms for reinforcement of column, head, seat and pile of the foundation, the use of concrete casing, FRP fiber for shear reinforcement of the head, preparation and installation of reinforced elastomer seat and installation of pile on the columns were selected.

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