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A FRAMEWORK FOR EVALUATION AND ASSESSMENT OF PROTO-MODERN BRIDGES

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ABSTRACT

Architectural edifices have been widely documented and conserved with respect to their historical significance and heritage, but the similar approach has not been emphasized for engineering edifices, especially in developing countries like Turkey. This is not only a problem of culture but also a problem of finance under high-costs of restoration. Nevertheless, the documentation and conservation of existing engineering heritage, including proto-modern road bridges, is crucial in order to adapt to the challenges of future problems, and to record the milestones in the development of construction technology and the sustainability of built and cultural heritage.

Under these circumstances, this study aims to develop a numeric-based evaluation and assessment system for proto-modern bridges in order to evaluate their urgency in restoration; in this way the limited economic sources will be canalized correctly. The proposed method evaluates the bridges not only by the physical conditions of structural elements but also by the historical and cultural values of bridges using the derived survey form. Results are interpreted according to the relative conditions of bridges to each other and the priority of maintenance is determined based on the rankings obtained. This proposed system is tested on number of case studies chosen among proto-modern Turkish road bridges with a minimum span of 15 meters and that were built between 1923 and 1955.

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A framework for the Evaluation and Assessment of Proto-Modern Bridges

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Architectural edifices have been widely documented and conserved with respect to their historical significance and heritage, but the similar approach has not been emphasized for engineering edifices, especially in developing countries like Turkey. This is not only a problem of culture but also a problem of finance under high-costs of restoration. Nevertheless, the documentation and conservation of existing engineering heritage, including proto-modern road bridges, is crucial in order to adapt to the challenges of future problems, and to record the milestones in the development of construction technology and the sustainability of built and cultural heritage.

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Introduction

Anatolia has rich heritage of historic bridges, build by various civilizations to overcome its topographic configuration. Many of these historic bridges especially from Roman, Seljuk and Ottoman periods are survived to recent decades. As being the expression and testimony of cultural and scientific evolution of these great empires, the values and uniqueness of the structures are accepted by all parts of society. Besides, they are under state protection and covered by "the Law, No. 2863, on the Protection of Cultural and Natural Properties Act of 1983", since they are older than hundred years old. Nevertheless, the official and public awareness in historic bridges does not incorporate the proto-modern bridges, which are younger than hundred years, despite the fact that they have unique technological and aesthetic value, great representative meaning, hence neither restitution nor substitution is possible in case of their loss.

Road bridges played an important role in development policies of the early Republic by their function and their physical existence. The bridge constructions not only provided the continuity of the transportation network or introduced new construction techniques and materials such as prefabrication, steel frame, reinforced concrete etc. but also the latest

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technology utilized in the construction of those bridges was also propagating the glorious illusion of development and technology under poor conditions of the young republic. Nevertheless, the proto-modern road bridges built until 1950’s started losing their importance due to the change of highway systems and they are either overloaded due to the increase of the traffic load or remained unused due to the change of highway routes [1]. This overloading or negligence has been followed by damages due to natural factors, such as earthquake and flood, which caused an extra deterioration on the structure. The deterioration and finally the collapse of bridges is less a problem in loss of a valuable cultural and technological asset but unfortunately more of losses of human lives as in the recent case of the collapse of Filyos Bridge in Çaycuma, Turkey in 2012. Therefore, cases of failure due to structural weakness cannot be disregarded.

Additionally, cultural accumulation that has been brought by different times and technologies of humankind, the historical or significant characteristics of the structures built has been also very important. Cultural property, which is the expression and evidence of human cultural evolution, and which provides information on the people of the period they belong to, can only be of genius value and meaning, and thus their importance can be preserved for humanity. These bridges are irreplaceable in case of destruction due to the changing material and methods in design and construction. Thus, these structures are valuable and unique for cultural, social and technical reasons. All those brought up the need of routine inspection, maintenance and repair for the highway bridges.

There have been different systems, accepted rules and regulations in each country for the inspection of the national bridges. Mostly, the main focus is on the structural stability of the system in order not to collapse. On the other hand, it is widely accepted that bridges are one of the important elements in the cultural heritage of a nation and they need to be conserved and protected. There are cultural heritage laws to regulate the evaluation and protection processes for cultural heritage.

Every country has determined its own rule and regulations, which are mainly similar in each nation but differentiate by some local needs and conditions. Most of the bridge inspection systems look for the criticality of the condition of the bridge leading to its failure either structurally or functionally. With a numeric-based visual inspection method, the priority of a bridge to be repaired can be determined. This quantitative evaluation provides a comparative state of bridges in order to be renovated or repaired. This is a very common method applied in many countries over the world. However, there has been no similar work that combines the structural assessment with the cultural heritage in one system.

This study combines the two aspects of bridge inspection and conservation into one unique system. In this way, the evaluation can be a wider, proposing an integrated system of many parameters joined in one larger perspective that is believed to give more valuable results. This new system has been built from the currently existing structural inspection guides and cultural heritage register criteria both in United States and Turkey [2]. Then, the significance and historical integrity parts have been formed and added to the evaluation process [3]. In this study, hypothetical cases are determined and used to apply the proposed method with the improvements covered and the results are demonstrated as a priority list of bridges that need maintenance with respect to the other bridges.

The Inspection System for Historic Bridges

Proto-modern bridges have been the critical nodes of transportation network for many years and they should be preserved in order to sustain their document value and carry their unique identities to future generations. Most of the current inspection systems around the world are based on visual examination of bridges, with a concern of structural assessment. There has been no study considering the historical value as an effective parameter in the inspection guide. The architectural and cultural heritage aspect for many highway bridges may be underestimated due to similar topologies. However, each bridge, independent from its scale and function, is a part of built environment; thus, it should also be evaluated individually with respect to its cultural and architectural value.

In order to assure this idea, a survey form is developed for field inspection to evaluate both physical condition and historical value [2]. The developed form is covering three main sub-groups explained below in detail. These are structural strength, the significance (tangible characteristics) and historic integrity (intangible characteristics). These three sub-groups combined with an inventory section, developed the “Historic Bridge Survey Form” as seen in Table 1 [4].

1. Structural Strength

Structural strength is a section that exists in most of the inspection guidelines, since structural stability and safety is very crucial and may cause loss of lives or economical damages in case of negligence. The structures need to be investigated carefully in order to observe any part that may have a tendency of possessing any problems and then to renovate them before the structure fails or causes any undesirable conditions. Therefore, routine bridge inspections need to be conducted regularly to have early diagnosis of any problem.

In this study, the parameters under the heading of structural strength have been taken mostly from the current inventory forms applied in Turkey, obtained from KGM. Simultaneously the inspection methods in United States, regulated by Federal Highway Administration, are explored and parts that have been missing in the KGM regulations are adapted to the proposal.

The final structural strength criteria is divided into three main components which are main body, earth retaining and serviceability components. Each also has sub-parameters that can be visually inspected and rated. Having components are useful for the easiness of grading and the analysis. This part of the inspection should be conducted by an engineer specialized on bridge construction [2].

Table 1. The Proposed Inspection/Survey Form

BRIDGE NAME

Inventory	Bridge name:		Bridge no:	
	Region:		Milepoint:	
	Route:		River crossed:	
	Material:		Type:	
	Current status of traffic		Builder/fabricator:	
	Date of construction:		Project Design:	
	# Spans:		Length of each span:	
	Overall Length:		Width:	
	Date of alterations:		Source:	

			Grading	normalized	Average	Total Grade
Structural	**Main Body Components**	Deck				
		Support				
		Beams				
		Piers				
	Earth Retaining Components	Abutment				
		Approach Fill				
		Stabilization				
	Serviceability Components	Coating				
		Border and Railing				
		Drainage				
		Expansion Joint				
Significance	**Distinctive (uncommon) Characteristics**	Type				
		Characteristics of period				
		Method of construction				
		Exceptional Length (span/overall)				
		Features for design				
		Use of material				
	Technological know-how	Technological Achievements				
	Work of a Master	Important engineer-architect				
		Important contractor				
	Artistic Value (Outstanding/ Distinctive Ornamentations)	On piers and abutments				
		On slab				
		On superstructure				
		On balustrades				
		On other non-structural elements				
Historic Integrity	**Historic integrity of structure individually : Authenticity**	of texture, workmanship, design				
		of Material				
		of ornaments/decorations				
		of structural design				
	Integrity within the historic district/historical context	Criterion A: Associated with events of significant contribution				
		Criterion B: Associated with the lives of person significant in our past				
Other:						
				Cummulative Grade		

2. Significance

It is quite difficult to quantitatively measure the cultural properties or historical values for a bridge. Addition to this, it is almost impossible to decide on the priority of a bridge that needs renovation with an objective decision. However, those values need to be evaluated and systemized in order to make a fair ranking in restoration of the bridges. The evaluation of the significance of bridges has been in application in United States [5,6]. However, in Turkey there has been only a resolution by the Ministry of Culture and Tourism (Resolution Number: 716) mentioned about conservation of historic bridges. However there has been no application of those regulations to evaluate within any inspection forms.

The significance of a bridge considers tangible characteristics, such as the distinctive characteristics, technological achievements, important people associated with the structure and the artistic value of the bridge. First part consist of distinctive characteristics, including type, length, features, materials, characteristics of its period, methods of construction and fabrication. The ranking has three distinct values to grade, being highly important, important or not important. Quantitative properties, such as construction year or length will be evaluated by their uniqueness for that period of time.

Second part is the technological know-how of the structure and how outstanding the technology used for the fabrication and construction of the bridge, evaluated in its own period. Third part evaluates the value of the architect or the engineer of the structure; while fourth part is the evaluation of the outstanding or distinctive ornamentation on specific regions of bridges, such as piers, abutments, slab, and superstructure. These four parts would be evaluated by experts by a historian specialized in bridge history.

3. Historical Integrity

This section is the evaluation of the structure with respect to its intangible characteristics, such as the individual integrity of the historical structure and the integrity within the historic district and historical context. When the bridge is evaluated for it own integrity, the preservation of the authenticity of the material, the ornamentations or the structural design are considered. On the other hand, for the evaluation of the bridge integrity as a whole, the location is evaluated according to its association in any important event or significant person’s lives or any specific contribution in history.

The ratings for the preservation of the individual structure is ranked as well preserved, preserved or altered. The evaluation of the location is graded between 7, being indispensible part of historic context to 1, not a part of the historic context.

The evaluation of the historical integrity section would be held by a county engineer or a local authority, who is knowledgeable about the bridge and the local context.

The Proposed Evaluation System

An integrated system has been prepared considering all the components mentioned above. For each bridge, a report is created, including all the information and inspection history. Therefore, the amount of change can also be observed and can be taken into account when it foresees a critical situation in future.

The report starts with an inventory section, i.e. identification of the bridge. This part contains data including span length, type of structure, materials used, contractor, designer, region, date of construction, date of alterations. The inventory should be filled in advance by primary sources such as archival documents or other reliable secondary sources. Having this information in the report is considered useful, since some of the evaluations can only be done by referring to these properties, such as the uniqueness of the structure in the time of its construction.

Inspections are mainly conducted by visual methods. The advantage of visual inspection is that it does not require complicated tools or machines. When visual observation cannot be enough to evaluate, related simple tools could be used.

The quantitative evaluation is done according to the grading system defined for each component. After each component has its overall average score, then they are all integrated. Although the definitions of grading systems are different for each component, the grading interval is all the same, which is between 0 and 7. Therefore, scores for all parts can be brought together and analyzed together.

After the inspection and grading, the values obtained within the range of 0 to 7 are normalized that they are evaluated with respect to 100. By this normalization, the language of grading becomes easier to read and the graphical distribution becomes more perceivable. Once the values are normalized, a structural evaluation is conducted. This step only considers the values with respect to the structural properties. This is taken primarily alone as the structural monitoring is the most significant property of the bridge, otherwise it can collapse. During this evaluation, the bridges are grouped into three zones: Zone 1, zone 2 and zone 3. They are named as the safe zone, caution zone and danger zone respectively. Taking 30% and 70% as the limits for the classification, the bridges are grouped into these three zones.

Once the bridges are assigned to a zone due to their structural conditions, the cultural and historic evaluation has been conducted among the bridges in each zone. The weighted averages of the three arms of the inspection guide, i.e. structural, significance and historical integrity, for each bridge are calculated and listed to decide on the priority of the bridges to be maintained. During this process, it is also important to observe the grade distribution throughout the elements in case there is any extreme issues that need to be specifically considered.

Hypothetical Cases: Application of the system

For this stage of the study, 8 hypothetical bridge cases are considered. They are randomly generated and graded with the notion of different distribution of conditions for different characteristics. The grades are assigned from 0 to 7 as discussed before, and then they are normalized to 100 to obtain a more meaningful values and intervals (Table 2).

Table2. Evaluation Results for the 8 hypothetical bridge cases.

	Structural	Significance	Historical Integrity	Cummulative	ZONE
H1	18.0	18.0	50.0	26.0	SAFE
H2	50.00	18.00	18.00	34.0	CAUTION
H3	82.3	43.0	69.9	69.4	DANGER
H4	71.8	76.3	44.3	66.1	DANGER
H5	40.3	55.5	78.5	53.7	CAUTION
H6	39.0	80.2	18.0	44.1	CAUTION
H7	24.9	59.6	88.3	49.4	SAFE
H8	86.2	73.0	85.8	82.8	DANGER

Step 1: The first step for the evaluation is to consider the structural characteristics and conditions of the bridges (First column in Table 2). With respect to the averages obtained for the structural evaluation, the bridges are grouped into three zones:

ZONE 1: SAFE ZONE (0-30)
ZONE 2: CAUTION ZONE (31-69)

ZONE 3: DANGER ZONE (70-100)

Although the averages are taken as the significant values for the grouping, it is always important to check the distribution of the structural elements to see whether there is any bridge that is not in the danger zone but have one or more item that needs immediate maintenance. This can easily be observed from the spider chart prepared for these bridges as in Figure 1.

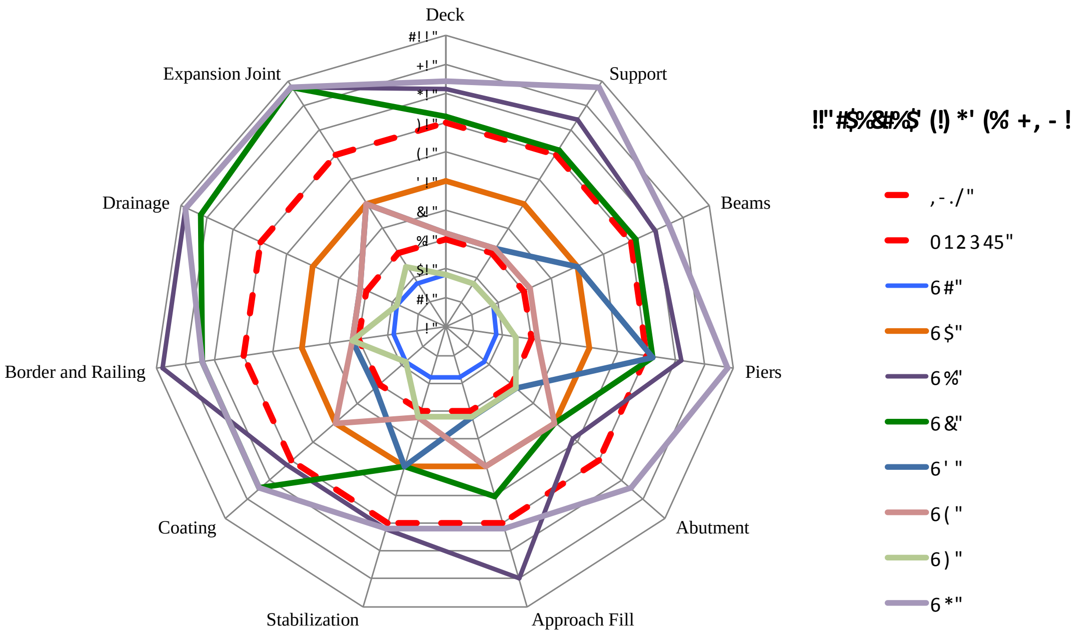

Figure 1. The distribution of structural elements and their grading for the 8 hypothetical cases

Among these 8 bridges, it is observed that none of the bridges in Zone 1 and 2 have any elements that have extreme emergency. Then the first priority list can be done by the the structural conditions, listing Z3 (H3,H4,H8) as the most prioritized and then Z2 (H2, H5, H6) and lastly Z1 (H1, H7).

Step2: Once the grouping is obtained, then the bridges can be evaluated and compared among their own group. In order to do that, the cumulative values listed in Table 2 (Fourth column) can be used.

Similar to the analysis before, it is important to check each bridge's individual elements to see whether there are any critical issues to be prioritized. Figures 2 to 4 demonstrate how the three part of the inspection is distributed and whether there is any one that needs urgent maintenance.

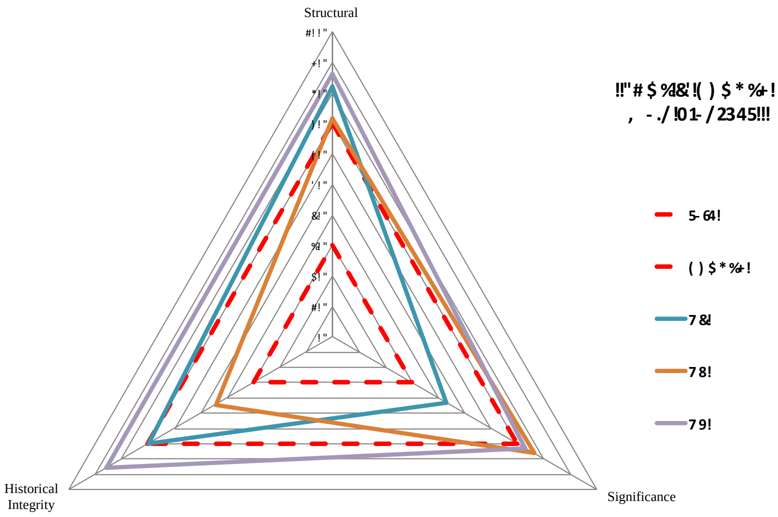

Fig 2. Evaluation results for the bridges in Zone 3 (H3, H4, H8)

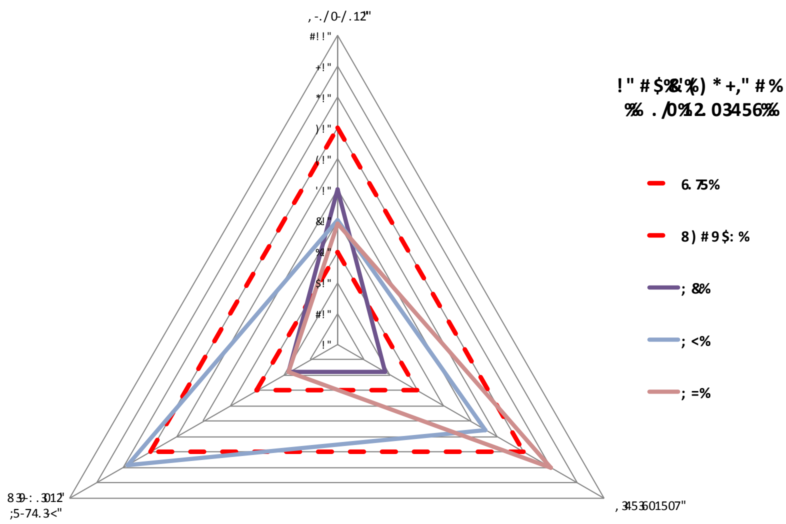

Fig 3. Evaluation results for the bridges in Zone 2 (H2, H5, H6)

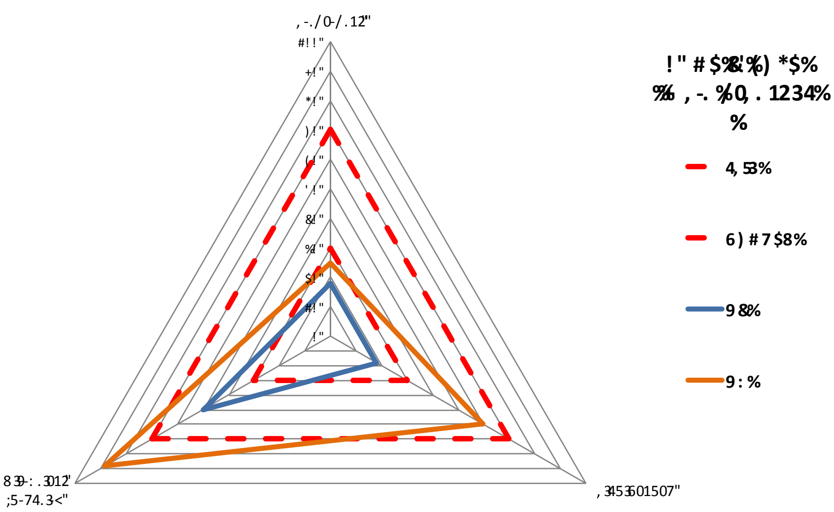

Fig4. Evaluation results for the bridges in Zone 31 (H1, H7)

By using the analytical results obtained from the evaluation (Table 2) and checking the spider charts for each bridge (Figure 2-4), the order of maintenance is determined to be: H8 H3 H4, H5 H6 H2, H7 H1.

The result obtained is more meaningful when it is compared to any result that is obtained without the consideration of the historic and cultural values. For example, if the same prioritizing is done only with the structural evaluation, which is the common method used, then the order would be H8 H3 H4 H2 H5 H6 H7 H1. That shows that by the cultural values of bridges included to the evaluation, the importance of the bridges change and the action to be taken is prioritized differently.

Conclusion and Future Studies

This study is the continuation of the previous work of the authors that were also focusing on the integration of structural and cultural values of bridges during the inspection of these bridges [2,3,4]. The motivation for this study is to emphasize the importance of the cultural values that are preserved within these publicly seen and utilized structures and to help these valuable structures to preserved and protected, not to be demolished or collapsed due to no maintenance.

It is no argument that the most important issue with the inspection of bridges is the human life. Therefore structural safety is taken as the most prioritized part of the evaluation. Then, the rest of the ordering is determined with the grading of each single element and their overall cumulative values.

It has been stated in the paper that, the proposed system always takes into consideration of the extreme cases or elements that could not be seen with the average calculation. Therefore, the spider charts are used to have an overall idea of the problems of the bridges and whether there is an urgent item to be taken care of.

This study used hypothetical cases in order to show the proposed system, its methodology and the results obtained. For the future study, the study will be conducted to the real cases. It is important for the authors that this study does not stay as a theoretical work but will be benefitted by the current highway authorities in Turkey.

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