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Systematical Assessment of Damages Occurred in Historical Stone Bridges

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Abstract

Historical bridges constitute one of the building groups that encounter intense problems in protecting cultural assets. While many problems due to atmospheric conditions are observed in idle samples, both natural and human-made problems can be detected on bridges that are heavily used or located in urban settlements. These structures are exposed to more shock and load due to the change and transformation of the vehicles used in transportation. In addition, they experience an intense process of change and deterioration due to construction activities, disasters and unqualified additions. Within the scope of this article, the changes and deteriorations detected in historical bridges were systematically examined; solution suggestions for these deteriorations are presented.

1. INTRODUCTION

The first known rules and prohibitions regarding the protection of immovable cultural assets were imposed in the Greek civilization within the scope of protection of special / unique buildings, city beauties, or property rights [1]. Afterwards, the concept of conservation transformed into the protection of various movable cultural assets by keeping them as exhibition objects, the protection of rich and valuable parts of certain buildings, or the protection of needed structures. This transformation process only ended with the emergence of modern restoration theory at the Athens Conference on the restoration of historical buildings in 1931. At the 2nd Congress of Architects and Historical Building Experts held in 1964, the Venice Charter was revealed, and the concept of contemporary restoration was announced to the world, which is accepted today. To date, all of the documents created as a result of the work carried out by ICOMOS (International Council on Monuments and Sites), COE (Council of Europe) and various international organizations are based and diversified on this primary document. All these documents support approaches that preserve original features within the scope of conservation criteria, eliminate the problem with minimal intervention, reversibility of the intervention, and multidisciplinary scientific studies. These criteria should be followed in all steps to be taken during the restoration process.

Cultural assets deteriorate and become damaged both naturally and consciously or unconsciously by humans. For this reason, occasional intervention is necessary to address and resolve problems. Interventions should be kept to a minimum in order to preserve the original features within the scope of contemporary restoration theory. In this context, joint studies are carried out with different disciplines. Historical bridges, due to their location, constitute one of the groups where these problems are experienced most intensely.

Bridges are structures that built to provide transportation between two facet. Abutments of the bridge are positioned along the stream, for in some cases they are directly in the stream. Consequently, they are more exposed to the damage caused by water, and this creates additional problems compare to cultural assets. Furthermore, examples of alterations and deteriorations that occur on roads that are currently in use include

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the superstructure, infrastructure, and heavy vehicle traffic. In unutilized samples, problems are encountered due to intense exposure to atmospheric conditions.

Within the scope of this article, the changes and deteriorations that occur specifically in historical bridges are examined. Additionally, the interventions made for these deteriorations are summarized and systematically evaluated. Upon reviewing the studies on the subject, it has been determined that studies on historical building damages and interventions to reduce them are quite rare. Some of the studies that included in the research demonstrate the damage and interventions to the structure within the framework of the restoration of buildings [10, 21, 22, 23]. One of the buildings was prepared as an application guide [20], and some of them was specialized in the context of earthquake or static problems. [7, 11, 24]. There are very few publications directly related to the subject, including one article [8] and two conference papers [9, 12].

2. FACTORS CAUSING DETERIORATION IN MATERIALS AND STRUCTURE

The factors causing deterioration in materials and structures will be examined under four main headings: atmospheric conditions and natural factors, biological causes, natural disasters, and human-induced causes, as illustrated schematically in the table.

Table 1. *Factors Causing Deterioration in Materials and Structure*

Atmospheric Conditions and Natural Factors	Biological Causes
Natural Disasters	Human Causes

2.1. Atmospheric Conditions and Natural Factors

The building material are directly affected by the atmospheric conditions and natural factors, and these factors, depending on the climate zone and location of the building, cause deterioration. Sunlight, air, water, temperature, humidity, and wind can be counted in this context.

Air, whose main components are hydrogen (78%) and oxygen (21%), causes deterioration in building materials with dust and acidic gases [26]. These gases are generally concentrated in industrial and urban centers where air pollution is intense. Acidic gases such as carbon dioxide and sulfur dioxide react with stones and cause accumulation on stone surfaces [2]. This formation, called black accumulation on the surface, can be named "Soiling", "Compact Black Deposit", "Dendrict Black Crust" and "Calcereous Concretion" depending on its density [13]. Black accumulation on the surface is especially common in building stones consisting of carbonate rocks. This crust consists of gypsum formed by carbonate minerals and sulfur dioxide (SO2) reactions. It also causes a negative appearance in terms of aesthetics. Concentration leads to a reduce in the perception of details by covering fine lines and gaps [3, 13]. As a result of the expansion of urbanization and the development of industry over time, many bridges that constructed outside the city have remained in the city limits. Therefore, the supports of ancient stone bridges have deteriorated due to exposure to acids, especially gases. This shell breaks off from time to time under the influence of water, causing loss of sections in the stones (Fig.1a).

Water influence spoilage in many ways: In addition to the damage caused by rain, snow, ice, and groundwater, the moisture in the building stones increases gradually since the piers of historical bridges are constantly in the water.

Furthermore, water can enter the building through the details at the material junction, inadequate insulation, or damaged parts resulting from neglect [2]. It is known that rain and snow penetrate deeply into the porous material, causing various chemical reactions within the structure. Croci states that as a result of this chemical reaction, acidic water will affect sedimentary stones and sandstone, leading to the formation of clayey material. [4]. Salinization, efflorescence, frost-induced deterioration, and micro karstic formations can be seen as water progresses through the stone.

Salinization is the dissolution of sulfate, nitrate, and chlorine-containing salts. It occurs through the condensation on the surface of certain stones as water evaporates. These salts, which recrystallize on the surface, appear as white stains on the stone surface [2, 5]. Similarly, efflorescence occurs when the salt dissolved in the water. The pores of the stone accumulate efflorescence as the water evaporates. As the salt molecules accumulate in the pores, pressure is created. The pores of the stone crack, and its structure deteriorates, eventually they can be detected as blisters on the stone's surface [26, 6]. In bridges that are constantly exposed to water, this type of deterioration can be seen in many examples. They are generally detected locally and regionally, with a higher concentration under the arches of bridges and inside the vaults (Fig.1b). Deeply penetrating water that freezes in the stone causes to an increase of the frozen water’s volume; the pressure created for this reason causes deformation and dissolution. Especially in the case of existing cracks, water freezes in these cracks, and this leads to increase in volume. Moreover, increase in volume causes cracks to widen and profile losses [2] (Fig.1c). Microkarst formations, on the other hand, are a situation where the calcium carbonate (CaCO3) mineral melts when it encounters with water in the structure of the stone and leaves a perforated surface in its parts [5]. In addition, another problem caused by the water that contained in the stone is that it creates a suitable environment for mold, fungi, and algae [2].

One of the biggest problems caused by water on bridges is the changes in the ground level due to natural causes that occur over a long period. Depending on the stream's natural regime and the river basin's hydrometeorological status, changes in the base level are observed in continuous or periodic periods. These changes cause balance problems and lateral erosions on the slopes. Another problem caused by rivers is the scour around the piers due to the increase in foreign materials rubbing on the piers. This problem may cause the bridge to collapse and the foundation to settle over time [7] (Fig.1d).

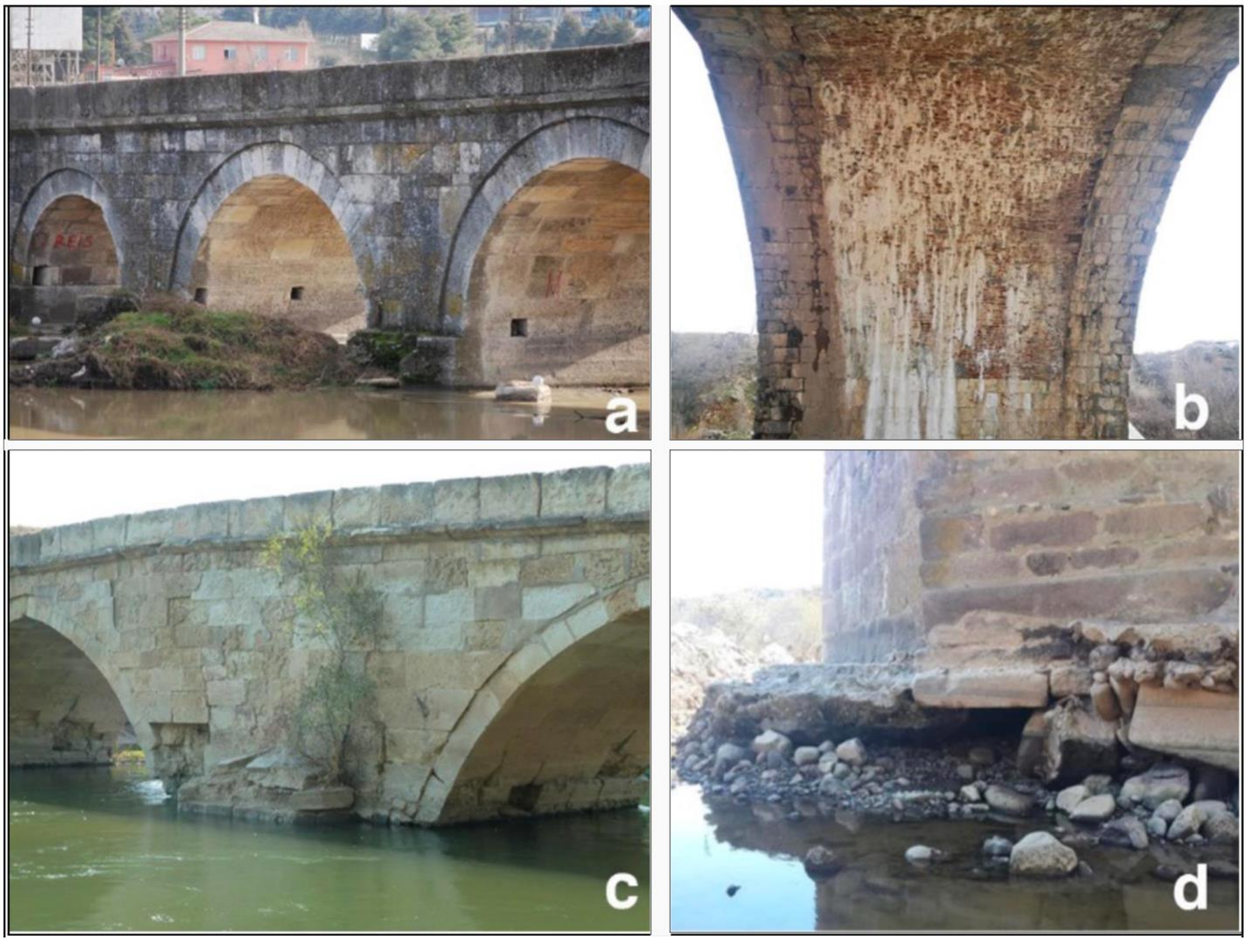


Figure 1. a) *Büyükkarıştıran Bridge (Kırklareli)[23],* ***b)*** *Kalender Bridge (Diyarbakır)[25],* ***c)*** *Karabıyık Bridge (Yozgat)[25],* ***d)*** *Behramkale Bridge (Çanakkale)[19].*

2.2. Biological Causes

Animals, plants, fungi, insects, and bacteria are the primary agents of biological degradation. Animals cause damage to bridges by removing or gnawing building materials. In addition, acids and salts found in animal feces can cause chemical deterioration on stone materials. Similarly, various fungi feed on minerals such as calcium, aluminum, iron, and potassium causing chemical degradation in both the stones and the binder between the stones. [2, 9].

Similarly, when the seeds enter the tiny holes on the bridge germinate, the growing roots affect the structure mechanically and chemically. Roots growing, especially in the joints between building stones, cause the mortar to break and erode over time, leading to cracks and breakage in the stones; Therefore, it causes structural losses (Fig.2a). However, the acids secreted by plants through their roots as they grow can react chemically with the materials and damage their structure [26].

2.3. Natural Disasters

Natural disasters are factors that are unknown; and they can unexpectedly result in severe destruction to historical buildings. Within the scope of natural disasters, the two most important disasters that have a negative impact on historical bridges can be considered as floods and earthquakes. Since bridges are built over streams, they receive the most damage during floods. The damage appears primarily in the flood wounds on the flood splitter (selyaran) part of the abutment or directly on the abutment themselves. Depending on the flow rate and the amount of material it contains, flood disasters cause damage such as cavities and movements in the abutment, superficial or holistic damage to stone surfaces, or loosening of joints. In addition, another effect that has a negative impact on bridges during the flood process is the dynamic effect that occurs as a result of the materials carried by the flood hitting the bridge piers. Rock fragments, which usually occur as a result of landslides, hit the piers and deck at high speed. They have a significant destructive effect. Another negative effect of the flood is the buoyancy force exerted by the suddenly rising water level on the deck. [7]. If the pushing force of the water overcomes the shear stress and occurs at the base of the abutment, effects such as slipping, sitting or turning are also observed on the abutment [8] (Fig.2b). The red line shown in figure refers to the historical bridge that was destroyed in the flood. The piers of the reinforced concrete bridge, which was built right next to the historical stone bridge, narrowed the flow section of the water. Also, during the flood disaster that happened in the region, the historical bridge was completely destroyed in consequence of the precipitation, which was carried into the stream bed, colliding against the abutments.

Another disaster that negatively affects historical bridges is earthquakes. Bridges built with stone material with high resistance to compressive stresses under vertical loads, but they can be damaged under horizontal forces caused by effects such as earthquakes (Fig.2c). For centuries, metal elements that can absorb tensile forces, such as tensioners, clamps, and tenons, have been used in many masonry structures to resist horizontal forces [10]. In bridges, the formation of outward rotations in the spandrel walls (tempan) and emptying the fill, along with the lost facade wall, are common occurrences in earthquakes. It is thought that the collapse of the facade walls is caused by the infill wall interaction [11]. However, one of the points where earthquake damage is most intense is the arches. Cracking and openings, especially in the main arch stones with large spans or along the middle axis of the bridge, are among the causes of earthquake damage [8].

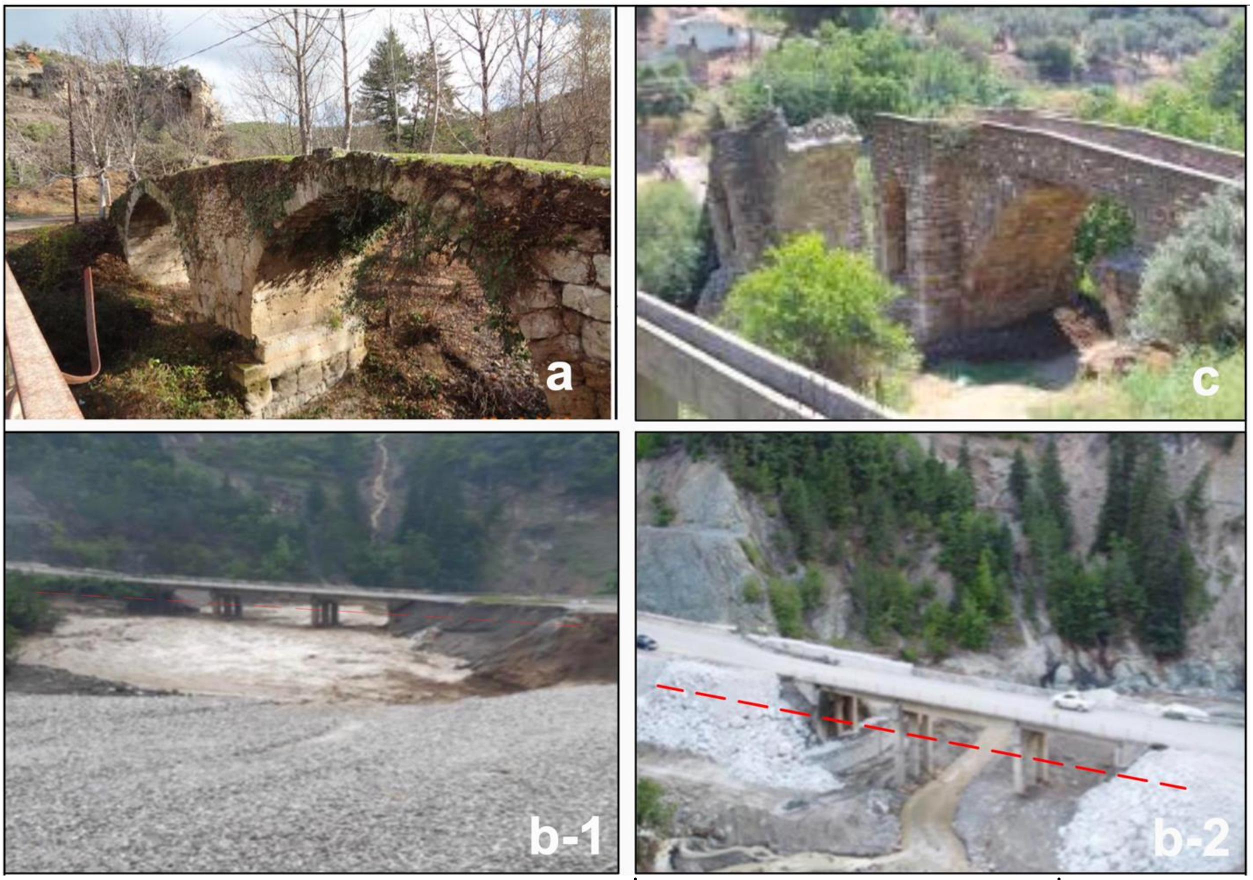


Figure 2. a) *Konarı Bridge (Karabük) [25],* ***b-1,2)*** *İkiçay Bridge (Kastamonu) [25],* ***c)*** *İkizdere Bridge (Aydın) [25]*

2.4. Human Causes

Reasons such as faulty design, faulty use and repair, contemporary life activities that transform the natural and artificial environment into harmful conditions, fire, vandalism, installation additions, and tourism can be listed as causes of human-induced changes and deterioration affecting buildings.

Mistakes made within the scope of the design and location selection principles of historical bridges have increased in recent years due to various factors. These mistakes inevitably cause problems on bridges. Wrong location selection in bridges, differences in the ground, stream characteristics, or flow rate are important criteria that affect the bridge's durability. Yanmaz states that problems are encountered if there is an error in the positioning of the bridge piers [7]. For example, the fact that the middle piers are positioned in the large speed zones in the opening is an important factor that causes undermining around the abutment. Similarly, the large number of piers is a factor that causes the gap between the piers to be filled with material, thus results in an increased flow rate in the narrowing gap, which in turn causes scouring at the bottom and increasing the headwater water level [7].

Choosing the wrong material for bridges also causes serious consequences. In this context, problems caused by facing stones constitute a significant percentage. Stones referred to as facing stones in the literature are cut stone blocks that are present on the outer and inner surfaces of the double-walled stone masonry and form the facade. The water absorption value and void ratio of these blocks, which form the façade of the bridge and have a direct relationship with water, is an issue that requires conscious selection. Drainage is critical as removing water without damaging the structure affects its stability. Weakness of the coating and drainage system may cause surface water to leak into the filling part of the bridge and cause the filling material to crumble over time, undergo chemical and physical deterioration, crumble and fall out, and cause voids to form within the filling. Water leaking into the fill may cause expansion during temperature changes and directly affect the material strength under freezing and thawing. The clayey mixed with the filling material can expand with the water leaking into the filling and put pressure on the facade walls [10] (Fig.3a, k).

Among the causes of degradation caused by humans, activities aimed at or indirectly affecting the riverbed have an important place. These problems, which arise within the scope of various zoning and settlement activities as well as rehabilitation activities on lands opened for development, lead to important consequences such as the bridge remaining idle or collapsing. In this context, changing or restricting the stream bed is important. Changing the stream bed increases the flow rate by causing the amount of water to pass through a narrower section [9]. In addition, comprehensive interventions that change the water flow regime in the stream bed also damage the bridge. The constructions built around the bridge also narrowed the section and changed the water regime. Changing the water regime causes sediment accumulation or unbalanced load on the abutments. Removal of bridge base material within the scope of various other constructions, similarly the increase - decrease or drying of the flow rate of the stream due to Hydroelectric Power Plant (HEPP), dam construction and similar reasons, and increase in basin sediment yield due to negativities in land use are also among the negative effects. The decrease in base level is on the downstream side; the decrease in water causes increased bottom erosion from the source side. Sediments increasing in the water cause scouring around the bridge piers and support settlement at the base. Changes in the river bottom and thalweg elevation (river bottom level) can lead to hollowing out of bridge piers, loss of foundation materials, and the emergence of wooden piles. Narrowing the stream passage by filling the riverbank increases the flow rate, and the amount of material dragged due to turbulent currents. This results in scouring in the piers. Soil withdrawal from the river bottom also creates turbulent currents and damages the abutment (Fig.3b-1,2) [12].

Additions and interventions made to historical bridges as a result of improper practices over time are also among the factors that accelerate the deterioration process of the structures. In this context, the use of bridges for installation purposes, additions made on the bridge to facilitate vehicle-pedestrian passage, and asphalt applications poured come to the fore. Plumbing pipes placed across the stream, meant to be fixed on historical bridges, create a situation that accelerates physical and chemical deterioration, regardless of their content. Especially since they are on one side of the bridge, they create a statically unstable situation and bring additional load to the bridge (Fig.3c). Similarly, within the scope of contemporary living conditions, another overload situation faced by historical bridges on highways is pouring asphalt on the bridge and adding railings. This situation not only creates an additional load on the bridge but also causes irreversible damage to the bridge since it is added with the help of converted elements. However, reinforced concrete extensions, which were built to expand the historical bridge, are incompatible with the bridge's texture, material and static condition, even though these are the most commonly used extension elements (Fig.3d).

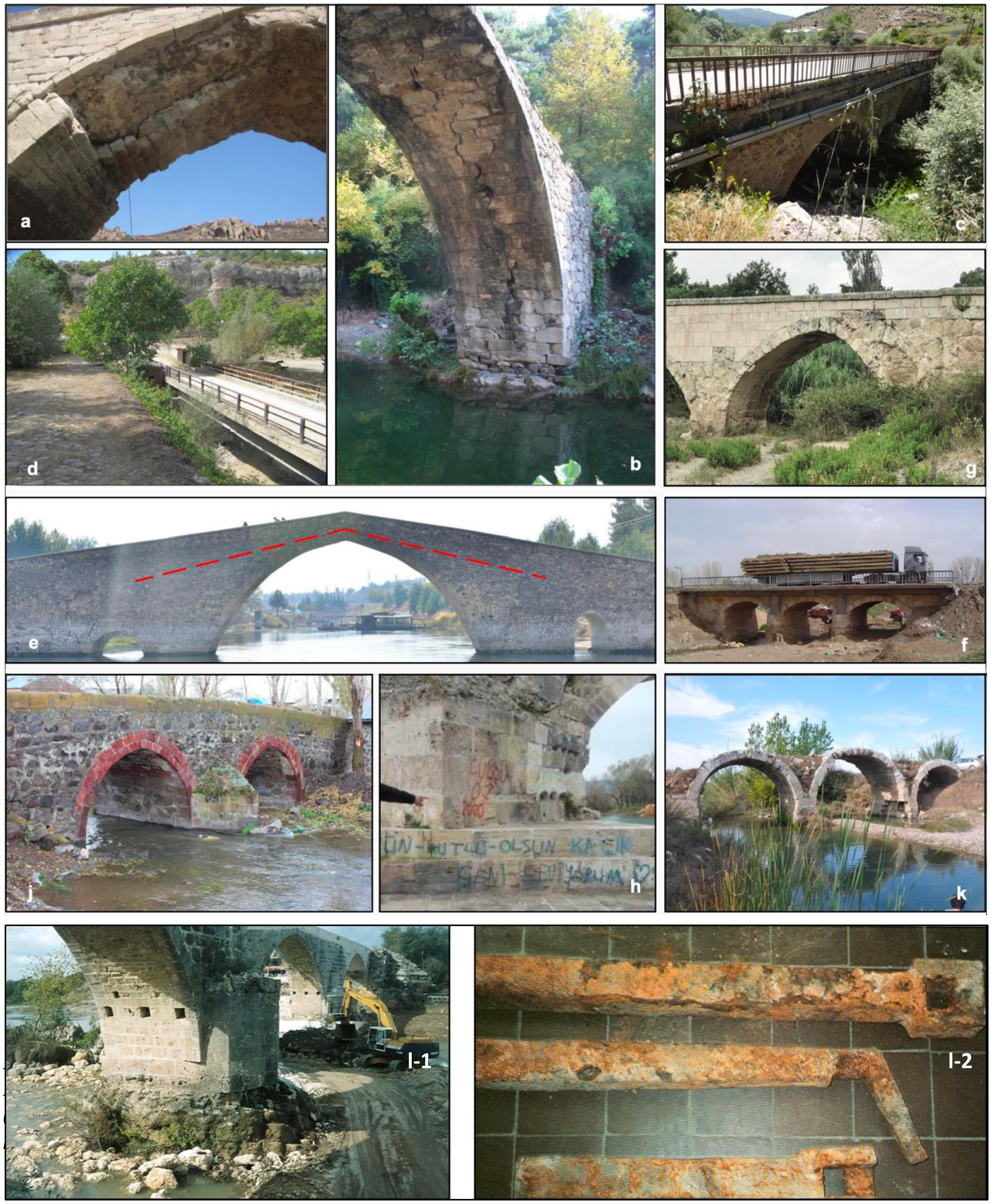
Bridge arches, which still operate smoothly today, continue to carry more than the loads foreseen at the time they were built, thanks to their compressive force carrying capacity, stone material and arch form. However, the load increase on the fill may cause swelling and collapse of the facade walls. In addition, as a result of the horizontal forces occurring in the arch stones due to overloading, separations are also observed in the arch vaults, and these are within the scope of the problems that occur as a result of overloading. Changing the slope of the original bridge is a common practice to ensure easier access to contemporary living conditions and integration into modern transportation systems. Changes are made to ensure more accessible connections between ring roads and bridges and to enable more comfortable passage for vehicles may cause deterioration on the structure. Changing the bridge slope imposes new backfill loads on the arches (Fig.3e). However, the dynamic effects of vehicle traffic passing over it may cause damage to the arches and/or abutment. In this context, in addition to the vibrations and loads created by heavy traffic and heavy tonnage vehicles passing over the bridge, situations such as wear and tear on the original structure may also occur (Fig.3f).

Another problem is that the practices implemented, even if well-intentioned, towards the changes and deteriorations that have occurred over time need to be fixed. In this context, there are many examples of changing arch openings or disrupting their geometry. This situation not only disrupts the original structure but also creates static instability. Changing the arch form causes the thrust line to become more unfavorable than the ideal arch curve [9] (Fig.3g).

The use of inappropriate materials is also considered within the scope of faulty practices. Not using suitable materials for building and binding mortars is among the most common repair mistakes. When choosing a building material, stone should be selected by bearing in mind that the physical characteristics of the original material, the strength and self-weight of the material, the void ratio, capillary water absorption value and chemical content, environmental conditions, and its relationship with other building materials. If these criteria are not met, an imbalance in the stiffness distribution will occur due to the difference in strength, resulting in regional damage [9].

As in many traditional structures, improper application of the details used to connect structural elements in bridges can lead to various damages. Vertical and horizontal clamps are used to connect stones in bridges. The clamps are made of iron, and lead is poured between them and the stone as a subsidy. This method prevents the stone from being damaged due to the shrinkage and expansion in the metal in hot and cold weather. Due to errors made in this context during application, cracking, and explosions are observed in the stones; section losses occur over time.

Vandalism is another human-caused problem on historical bridges. Vandalism, which means intentional damage, is one of the problems faced by all cultural assets, including bridges. In this context, writing names and various inscriptions anywhere on the bridge, especially by scratching with a hard object or with spray paint, is one of the most common examples of vandalism. Apart from this, various situations, such as shooting at the bridge or tearing off various materials, may also occur. Similarly, treasure hunting and wars are among the methods of destruction that damage cultural assets and historical bridges. For example, the Mostar Bridge, built in 1566, was destroyed in an attack in 1993 and was restored and opened in 2004. Treasure hunting generally causes damage as a result of the legends circulating about the bridges, as well as the excavations carried out in the foot sections or around the decorated spandrel wall stones. In addition to causing static damage to the bridge, such interventions also cause the bridge to collapse, because timely intervention is not possible (Fig.3h,j).



3. INTERVENTION METHODS, EVALUATION AND RECOMMENDATIONS

There are many types of deterioration encountered in historical bridges. Some of these problems may result in the collapse of the structure if left untreated. There is a need for intervention in many different contexts, starting from the material and moving to a diversified scale within the scope of binding, structure, and environmental effects.

3.1. Interventions on Stone Material

From simple to complex, there are a wide variety of methods within the scope of material interventions. Problems caused by spray paint applications, color change, crust formation, or biological pollution can be considered as problems caused by natural or human-made deterioration on the upper surface of the stone. The stone must be cleaned as part of the solution to these problems.

3.1.1. Cleaning the Stones

The decision must be made for stone cleaning through extensive research on the stones. Hence, testing and binding are both necessary processes carried out in a laboratory environment, and an expert must accomplish the application. When deciding on cleaning with two different methods, Mechanical and Chemical, it is crucial to choose the method that causes the most minor damage and provides the best efficiency.

In addition to the method in which the upper surface is abraded within the scope of mechanical cleaning, cleaning by spraying atomized water and laser cleaning can be considered. In the abrasion method, mechanical tools such as scalpels, brushes, steel scrapers, hammers, and chisels (in rare cases), small electrical tools, or spraying tools are used to abrade the surface. In this method, the upper surface of the stone is abraded until the dirt layer on the stone's surface is removed. Sand, aluminum, micro glass, or various nutshell powders sprayed onto the stone's surface using compressed air or nitrogen to ensure surface abrasion to the desired extent with low and controlled pressure.

In cleaning using atomized water spraying, tiny water drops sprayed with low pressure create a smoke and effective cleaning. This method is preferred because it is very effective, but also less harmful.
In laser cleaning, adjustments are made to ensure that the dirt layer absorbs the laser radiation more strongly than the lower layer, and by removing the dirt layer, the underlying surface is prevented from reflecting the laser beams. It has not found widespread use in Turkey because it is expensive and requires special preservatives. This method is generally used for cleaning metal surfaces.

In chemical cleaning, it is necessary to understand the type of dirt, the petrographic structure of the foot, to which it is attached, and the characteristics of the pollution formations in the area washed by rainwater or in the wells. Chemical cleaners are divided into two groups: alkaline or acids, and they provide cleaning by applying them to a suitable surface. However, they need to be cleaned from the surface afterward. This method can be carried out by washing or applying the poultice by leaving the cleanser on the surface [13].

3.1.2. Interventions for Melting, Splitting and Breaking of Stones

The filling method addresses melting, non-structural cracks, and small-scale discharges in stones. In this context, various mixtures of epoxy resins can be used with pressure tools or simple mechanical syringes.
When pieces break off in the stone, interventions are made in various ways. In this context, if there is a broken piece of the stone, it is possible to adapt it to its place; if not, it is possible to complete this part by using a similar foreign stone, different natural material, or artificial stone. The size of the broken piece is important for the bonding method to be used in completion. While polyvinyl acetate or acrylic resin can be used for small parts, typically strong adhesives like polyester, and epoxy resin are preferred. In selecting the adhesive material, it is essential to have good adhesion and durability, ensuring that it does not lose its adhesive properties over time. It should also not undergo volumetric changes, should be elastic or rigid, and should be mechanically similar to the surfaces to be bonded [27]. However, the imitation method in question is not preferred as it does not last long due to the historical bridges being in water. Instead, a refutation process is carried out at the relevant place.

In cases where the original piece broken off from the stone cannot be found, it is completed with a foreign stone. In this method, the color, texture, hardness, brightness, and composition of the foreign stone to be used for completion must be compatible with the original stone. In order to distinguish the integrated parts of the building from the original part, integration with different materials is sometimes preferred. In such applications, the renewed part is placed behind or in front of the original surface and is presented in a different color, character, or texture to make it noticeable. Artificial stone (cast stone) has an important place among the different materials that can be preferred. In this method, if the completion is to be made with a decorated-profiled piece, this previously prepared piece is reinforced and glued with steel bars and armatures. However, for large and numerous pieces, stones prepared as precast elements outside the construction site are assembled instead. In the production of artificial stones, they must resemble the original stone when wet and dry, as well as being affected by environmental conditions similar to the original stone. In historical bridges, melting and corrosion are not intervened unless there is a static problem. Sert et al. state that when stones need to be completed, the decision is made with expert opinion, and the appropriate one, among the reinforced or unreinforced completion options, is decided [16].

3.2. Interventions for Ground Reinforcement

One of the most important reasons for the settlement of the abutments of historical bridges is ground deterioration. Geological structure of the ground on which the bridge is located and settlements in the riverbed caused by the loads carried by the bridge, with the influence of the stream, give rise to deep discharges, material losses and serious deformations in the foundation and piers of the bridge over time. In this context, it is necessary to increase the soil strength by strengthening the ground. The methods used for this purpose include raft foundation stone fortification, foundation expansion, pile driving and injection systems. Experts make the decision on which methods to use after conducting the required measurements and modeling [28].

3.3. Interventions for Biological Formations

Joint discharges, cracks, fractures and partial collapses can be considered as problems caused by plants growing into the joints and gaps on bridges. These problems are decided by experts within the scope of intervention for stone material. However, in order to intervene in the problems, the building must first be cleared of plants. In this context, annual or small plants that have grown on the surface are washed with a special medicine, withered, and then cleaned from the surface. After the trees are cut at the point closest to the root, a special chemical is placed in their core areas. Root rot occurs within a certain period of time, and then the rotten roots are removed [2].

3.4. Interventions Regarding Structure

The scope of structural interventions includes interventions to cracks that create structural problems and interventions to ensure structural integrity.

3.4.1. Interventions for Cracks

Three different methods are used in the repair of cracks that occur under impact or structural impact in stone masonry walls and similar bridges: stitching, seaming and injection. These methods can also be applied together according to need.

In the stitching method, the section where the structural crack is located is removed by decaying to a size determined by the expert, and the remaining wall is cleaned and moistened with water. In order to prevent the two sides from opening further, if necessary, the edges of the crack are tied with metal clamps and the gap is filled with suitable material. However, since the historical bridges are in direct contact with water, using metal clamps is rarely a preferred method due to the possibility of metal elements deteriorating in a short time due to moisture and water and the possibility of causing damage to the surrounding area. In the clamping method, both sides of the crack are connected to each other with clamps by placing them in the open gaps and securing them with lead or special adhesives. These seams should be protected from atmospheric conditions by covering them as necessary. In applications on historical bridges, it is generally seen that it is used to connect railings and foundation stones to each other. In the injection method, plastic pipes are placed into the holes opened from both sides towards the crack; the appropriate material is squeezed into these pipes using an injection pump. After ensuring that the crack is completely filled, necessary covering interventions are carried out. This method can also be used as a strengthening method in sections that cannot be dismantled and are structurally problematic [29].

3.4.2. Empowerment Interventions

Within the scope of strengthening bridges, tensioning, injection, Fiber Reinforced Polymer (FRP) rods, Carbon Fiber Reinforced Polymer (CFRP) tapes or new elements can be used.

The strengthening method with tensioners is used to increase the low tensile strength of stone walls and to connect bent and deteriorated wall connections to the building system. Walls that deviate from the vertical and bend due to factors such as excessive settlement on the ground, excessive or disproportionate loading, are brought into alignment with the help of tensioners and reconnected to the building body. Although wood or metal can be used as tension material, metal is preferred in masonry structures, especially in the context of opening spans [2]. It is not a method used on historical bridges.

FRP rods provide good results in stone masonry walls that have low structural tensile strength. This material, which has low density and compatible mechanical properties, is also resistant to corrosion and chemicals [14, 15]. FRP bar applications are generally made by emptying the mortar between the building blocks and where these gaps exist. Alternative methods are preferred in areas such as historical stone bridges, which are considered to prevent damage to building stones and preserve their originality [2, 4].
CFRP is a fabric-shaped material that, similar to FRP rods, increases the ductility of masonry structures and makes them resistant to tensile. In practice, epoxy is applied to the cleaned surfaces and adhered; it is then fixed by applying epoxy again. Since CFRP fabrics are not fire resistant, it is recommended to protect them with plaster afterwards. This method is widely used in historical buildings, especially in the context of sheathing the problematic wall and increasing the cross-section. However, in this method, the original wall elements that need to be protected are covered in a non-recyclable manner, and concrete material is used. This method is not preferred due to reasons such as the upper surfaces of historical stone bridges being largely unplastered and the epoxy applied to the surface cannot be removed without damaging the original stone material. However, in historical concrete or reinforced concrete bridge reinforcement applications, CFRP windings can be used in cases where reinforcement is insufficient (Fig.) [28].

3.4.3. Reconstruction

Reconstruction is a restoration method that means the reconstruction of buildings or parts of buildings that have serious structural problems and cannot be protected and strengthened economically and effectively by different methods, with original or compatible materials and techniques. This method, which is generally preferred for problems related to arches or piers in historical bridges, appears as a method that requires interdisciplinary work along with serious calculations and analysis [9].

4. EVALUATION AND CONCLUSION

Historical bridges constitute important examples of transportation of cultural assets that have survived from past civilizations. The most basic component of protecting historical buildings and the environment is ensuring that the buildings find a place in contemporary life and that the necessary maintenance is carried out accordingly. In particular, the interventions made on historical bridges both in their direct exposure to atmospheric conditions and in their adaptation to today's living conditions are factors that accelerate deterioration. Atmospheric conditions and natural factors, biological causes, natural disasters and human causes stand out as the most common causes of deterioration in historical bridges.
For these reasons, historical bridges often need intervention within the scope of conservation and restoration. The scope of the intervention varies depending on the degree of damage to the materials in the bridge, and the original material and texture should be adhered to as much as possible during the repair, and the compatibility of the materials planned to be used with the original material in terms of both mechanical and chemical durability and color and texture properties should be investigated.
The main purpose of conservation and conservation studies is to make reversible interventions, if possible, without compromising the originality while solving the problem. For this reason, it is important that

planning studies be carried out seriously in a multidisciplinary manner. In this context, the materials and equipment to be used must be decided under the supervision of experts, starting from a detailed documentation study and determination of the current situation. When making these decisions, it is important to conduct the necessary analysis, calculations and tests, and if necessary, to make decisions after partial tests. It is necessary to determine and diagnose the physical, chemical and mechanical properties of the original materials found in historical bridges, the causes of deterioration, the factors that cause deterioration, and the selection and development of conservation methods to be applied in the light of these. These materials have the quality of documentation because they can transfer the construction technique of bridges, which are cultural and symbolic structures of that city, to the next generations. After the appropriate conservation method is selected among the 'interventions for stone materials, interventions for soil strengthening, interventions for biological formations, and interventions for structure'; the restoration application phase begins. It is also important to constantly monitor the method decided to be applied and to consider and plan alternative methods when necessary.

Historical buildings and bridges are highly affected by intentional or unintentional damage caused by people, apart from natural factors. In the context of short-term methods to prevent intentional harm, increasing supervision and applying punitive action come to the fore. However, providing training in this context in schools at all levels and raising public awareness will ensure much more sustainable results in the long run. Within the scope of unintentional damages, construction activities come to the fore. Bridges on rivers that have been subjected to interventions on their flow direction, flow rate and bed through various construction activities may face serious problems in the long term, if not in the short term. However, irreversible problems occur on bridges over which highways pass, both due to improvement works and unforeseen loads.

For this reason, all institutions and organizations that have a share in planning and development works must be audited; it is important to make conscious, scientific and multidisciplinary decisions and to ensure their implementation by monitoring in the long term. In addition, it is important to make disaster planning for all kinds of structures, including historical bridges, and to create alternative solutions and measures in a multidisciplinary manner.

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