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Flooding and Its Effects on River Bridges in Western Black Sea Region

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Abstract: Investigation of the events occurred in Turkey in which river bridges are severely damaged or collapsed showed that these events are usually experienced during flooding and most of the bridges collapsed due to the excessive scouring around bridge piers. Hence, besides loss of life and property directly caused by flooding, damages and failures of river bridges and similar losses caused by such destructions must be taken into account. Floods cause sudden and substantial increase in the water level and in the amount of flow of the rivers. As a result of these significant changes dynamic conditions in bridge opening might change, pressurized and weir flows might take place and scouring around piers and abutments might deepen. For all these reasons, floods have significant importance for river bridges and their effects should be taken into account and assessed. In recent years due to possible climate changes in Turkey as all over the World and changes in rainfall-runoff relationship variations in the intensity and frequency of floods are detected. As a result, river bridges might be under greater risk. To examine the aforementioned hydraulic effects and to develop a safety-inspection methodology for river bridges a research study is being carried out in Western Black Sea Region where floods and partial or complete failures of river bridges are frequently observed. In the scope of the current study the hydraulic effects on the river bridges are examined and their impacts on bridges are aimed to be taken into account and incorporated into a safety-inspection system. This paper informs the observations made during field trips of the current research.

***Index Terms*—Bridge piers, floods, river bridges, scouring.**

I. INTRODUCTION

When collapsed or heavily damaged river bridges are investigated in Turkey, it is found that the most important cause of the problem is the lack of assessment of the hydraulic factors either during design stage of the bridge or while it is in operation. Some of the hydraulic factors affecting river bridges are the degradation of the river bed, excessive scouring around bridge piers and abutments, pronounced backwatering effect, and possibility of hydraulic jump formation due to excessive constriction at bridge opening [1].

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River bridges are quite complex structures located in a very dynamic system and affected by many parameters that are continuously interacting with each other. For example, flooding caused by a short but very severe precipitation or sudden snow melt due to changes in climatic conditions, changes in the rainfall-runoff relationship and in the amount of runoff due to changes in land cover (LC) and land use (LU) in the basin, occurrence of hydroelectric power plants or dams, sand and gravel withdrawal from streams affect stream discharges. So bridges in river environment are influenced by these factors either directly or indirectly. Therefore, river bridges should be inspected on a regular basis. Problems with their probable causes and consequences should be determined and explored in order to take necessary preventive measures to protect bridges. Hence, it is important to take into account the hydraulic factors, especially scouring which is the most hazardous factor of all. Inspection of the river bridge and channel stability should be conducted periodically. The inspection should also be performed after natural disasters, such as earthquakes and especially after flooding in order to observe the consequences of these additional impacts on the bridge. Therefore, a safety-inspection system is required for these inspections to be performed consistently, adopted together with a comprehensive inventory to reflect the changes and status of the bridge in a database. One of the shortcomings of river bridges in Turkey is the lack of a safety-inspection system that enables up-to date, practical and accurate assessment of the bridges, especially taking into account the hydraulic factors. Observations, evaluations and where possible simple measurements should be stored in a database and the statues of the bridge should be updated after each inspection. So, development of a safety-inspection algorithm that is in accordance with primarily the needs, economics and socio-economic conditions and policies of governmental agencies' of Turkey besides scientific and technological requirements is vital. The algorithm should also be accurate and be independent as much as possible of the personal opinion of the engineer that will carry out inspection of the bridge. Thus, the current system specified in the Bridge Inspection Handbook adopted by General Directorate of Highways (KGM) should be updated to provide a more specific assessment and establish a system in which present and changeable hydraulic conditions in particular could be observed, evaluated, and recorded

II. Floods And River Bridges

In Turkey, there has been many flood events that had caused severe damage or failure of river bridges so far. For example, among severely damaged or collapsed river bridges are Gökçeler in Muğla in January 2010, Curidere in Ordu in 2011, Yarpuz I in Osmaniye, Güzelceçay 2 and Abdest in Sinop, Gökdere in Adana and Kadıköy in Mersin in 2012 and Dolbazlar in Antalya in January 2014 and two river bridges, one new and the other one old in Malatya Doğanşehir in 2014. However, Çaycuma river bridge in Zonguldak collapsed in April 2012 causing 15 people dead besides loss of property. Hence, flooding and the hydraulic events observed during flooding when there is sudden and significant changes in discharge and water level of streams, their effects on river bridges and consequences should be investigated in detail.

During flooding, the water level increases due to the increase in flow discharge. Thus, the water level in case of a severe flooding can reach up to the lower girder of the bridge deck. In such cases, the flow is no longer a free flow but known as a pressurized flow. Further increase in the amount of stream discharge will also increase the water level well above the lower girder level and can even exceed the bridge deck. In this case, the bridge will act as a broad crested weir and the flow is known as weir type of flow. Under these conditions, the transport of sediment on river bed under bridge deck can significantly be affected. Since failure of most of the river bridges is observed to be due to excessive scouring around bridge piers [2], the sediment transport in these types of flow and their effects on scouring in bridge openings should inevitably be investigated.

It is extremely crucial to know flow conditions in the vicinity of river bridges during flooding in order to identify scouring and other hydraulic effects caused by these flow conditions to take necessary precautions on time. Since inspection of river bridges during flooding is mostly not possible due to safety reasons, inspection of bridges right after flooding should be carried out to examine degree of scouring around piers and abutments. Besides, apparent aggradation and degradation of river bed, failure of banks, approach embankments and other similar changes in the vicinity of bridges should also be observed. So, assessment of these changes will enable necessary precautions to be taken before these effects sum up and reach to a critical stage where the river bridge is under risk. At this point, use of a simply applicable, practical, sustainable, and affordable safety-inspection system gains importance. It should be unbiased as much as possible since the self-assessment and evaluation of the control engineer plays a vital role for the bridge. That is why a reliable inspection should be conducted by a an experienced team to decrease the bias.

III. Studies Of Safety-Inspection

Safety-inspection studies of river bridges regarding hydraulic evaluation have not been extensively explored in the literature as done for structural evaluation. Hydraulic evaluation is generally taken into consideration as part of structural inspection or very limited. Johnson et al. [3] carried out a study on equilibrium of gravel river bed and proposed a check list for evaluation of channel stability. Several researchers adopted present methods in the literature to assess channel stability in the vicinity of bridges ([4],[5],[6]). In these studies, they proposed a checklist consisting of 13 different indicators that affect channel bed stability. These indicators are determined from observations without requiring any complex tool or experimental analysis. Researchers then classified these indicators and computed their weighted averages. Finally, they sum up these weighted averages to obtain a stability rating for the gravel bed streams. They concluded that the method proposed enlightens the control engineer about the probable problems but not likely the magnitude of these problems. Since the method is quite clear and determination of parameters is easy and practical, Yanmaz et al. [7] also adopted this method in their study in Turkey.

Johnson [8], proposed a new preliminary assessment method by rearranging the method proposed by Johnson et al. [3] and including new observations and indicators that can characterize the channel stability. Johnson [8] adopted Knox's [9] definition for stream stability in her method. Johnson [8] modified this definition as "for use at bridges as a stable channel in the vicinity of a bridge is one in which the relationship between geomorphic process and form is stationary and the morphology of the system remains relatively constant over a defined distance upstream and downstream from bridge, and with minimal lateral movement". The channel stability assessment procedure for bridge applications should have the following characteristics given by Johnson [8] as (1) It should be brief so that it can be completed rapidly, (2) It should be simple in that extensive training is not required although some training will likely be required, (3) It should be based on sound indicators as discussed in the literature, (4) It should be based on the needs of the bridge engineering community. This method developed by Johnson [8] is based on observation at bridges in 13 physiographic regions of the continental United States. Thus, the researcher noted that the method should be used cautiously due to the limited number of observations and also not taking into account every stream type and stream order within each region that observations were carried out.

In Turkey, tenths of new bridges are included to the existing bridge inventory each year. Furthermore, a large number of bridges in operation are under desired adequate level of maintenance due to the insufficient maintenance budget allocated from the state budget. Large number of bridges in need of maintenance and limited budget necessitated the development of a Bridge Management System (BMS) in Turkey. Thus, a study funded by a research project entitled 'The Development of the BMS' for the General Directorates of Highways (KGM) in Turkey was carried out. The BMS contains a newly developed element condition rating model based on element condition state distribution. The project was completed in 2012 and the necessary inventory studies of all bridges in Turkey were completed at end of 2015. Thus, with the BMS being in operation, KGM would be able to monitor the costs needed for maintenance and reconstruction of bridges in Turkey and to prepare the following year's budget accordingly based on technical and administrative reports prepared by BMS.

Yanmaz et al. [7] proposed a safety-inspection system for river bridges in Turkey and applied the method to a series of bridges. The method was tested with a limited number of bridges in a narrow region. A research project is currently carried out by a research group under the leadership of Prof. Yanmaz from Middle East Technical University (ODTÜ) in cooperation with a researcher from Gazi University and an engineer from KGM in order to develop a comprehensive safety-inspection system applicable to river bridges in Turkey. The system is aimed to be applicable, simple and sustainable taking into consideration the structure-water-soil interactions where in Turkey bridges are mostly monitored on as needed basis according to current Bridge Inspection Manuel [10] which is gathered under only four main groups without any sub-classification. In this monitoring system performed the hydraulic factors are not taken into account sufficiently, but rather focus on the structural inspection. Thus, the aim of the current study is to develop a safety-inspection method in which present and changing hydraulic effects can be specified, assessed, monitored and shared in a database.

IV. Safety-Inspection Studies of Several River Bridges In Western Black Sea Region

As a result of preliminary analysis and investigation of the past failures and collapses of river bridges in Turkey, Western Black Sea Region is chosen as a pilot area in the project. In this region, bridge failures and collapses are frequently seen as a result of excessive scouring around bridge piers and abutments due to both hydraulic and geomorphologic reasons especially after sudden snowmelt and heavy rains. In the scope of the project, five river bridges are selected with different watershed features, such as basin shape, land use/land cover and basin size, with different structural properties of the bridges, channel bed, flow conditions, banks and bed material (Table 1). The common feature of all these bridges is to have high risk of flooding or scouring.

For analysis of scouring and channel bed stability, bathymetric measurements at different stream sections, five in the upstream and four in the downstream of the bridge, are taken twice a year to investigate the changes along the river bed. Both the channel stability and scouring around piers and abutments can thus be examined.

Furthermore, observations made at the bridge and along the river in the vicinity of bridge can give indications about effective future hydraulic factors and their consequences on the bridge, such as development of scour holes around bridge piers and aggradation/degradation of channel bed.

TABLE I
River Bridges and Their Features Examined in Pilot Region

Name of Bridge	Province	Name of River	Type of Bridge
Bartın I	Bartın	Bartın Creek	[a]RC – Simply Supported Beam
Bartın III	Bartın	Bartın Creek	[a]RC – Simply Supported Beam
Gökçebey (Tefen)	Zonguldak	Filyos Creek	[a]RC – Gerber Beam
Filyos-V	Karabük	Filyos Creek	[a]RC – Simply Supported Beam
Çatalzeytin	Kastamonu	Akçay Creek	[a]RC – Gerber Beam

[a]RC : Reinforced concrete

One of the provinces in Western Black Sea Region that frequently experiences flooding is Bartın. Thus, two river bridges from Bartın are included in the study. For instance, a major flooding occurred in Bartın in 21 May 1998 leading to inundation of many locations with loss of property and damages to other river bridges. Photo 1 shows a photograph taken at Orduyeri Bridge in Bartın in October 2015 in which the increased water level during flooding is marked on a nearby building. From conversations made face to face with local people of Bartın, it was confirmed that Bartın I bridge was also overtopped during this flood event. In this paper, observations and preliminary assessments of three river bridges namely Bartın I, Bartın III and Filyos V are presented. Bartın I river bridge is located in Bartın and was subjected to severe flooding resulting in pressurized and weir type of flow during 1998 flood. Bartın III Bridge is also located close to Bartın city centre while Filyos V is located close to Karabük province in Western Black Sea Region.

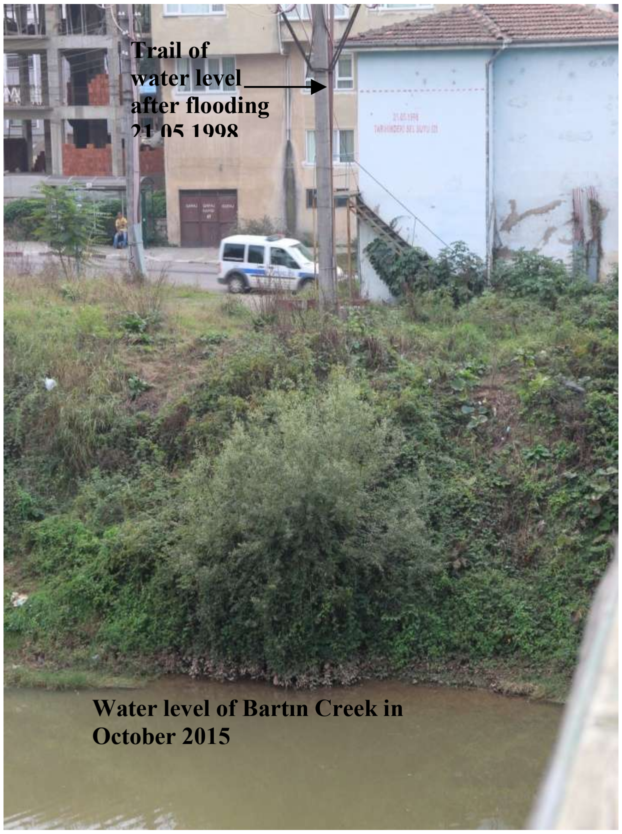

Photo1. Bartın Creek and trail of increased water level on a nearby building at Orduyeri River Bridge, October, 2015

Bartın I Bridge comprises of two river bridges, each one a two lane, one-way bridge located in the 15th Region of KGM, on the Safranbolu-Çaycuma (Karabük-Devrek) road. Bartın I Bridge constructed as two separate RC bridges on Bartın Creek in 1979 as simply supported beam of L=3x20.0 m length with three-spans and has got two piers and two abutments. In this area, Bartın Creek is rather meandering with very steep river banks on both sides of the river. The banks in the vicinity of the bridge are covered with trees of small trunks and dense bushes. Examination of old photos of the area and observations made during field trips show that new residentials are built in recent years and thus the LC of the area has shown to decline rapidly. This condition is an important factor that directly affects the rainfall-runoff relationship in the area since vegetation cover delays the amount of precipitation that immediately turns into flow, thus reducing the severing and likelihood of probable flooding. The first thing that stands out in Bartın I Bridge during the inspection is the amount of scouring observed around piers of both bridges (Photo 2).

Photo 2. Piers of Bartın I Bridge

During inspections it is seen that piers that are exposed with sheathing sheet on are protected from the effect of abrasion of water while the pier without this protective shell has serious concrete abrasion and weakened sections (Photo 3).

Photo 3. Abrasion on pier of Bartın I Bridge

Bartın III Bridge was constructed as a two-lane, two-way river bridge situated on Bartın-Amasra road in 1984. However, with the increase in traffic growth of Bartın city and the evolvement of nearby town Amasra as a holiday resort, the bridge became inadequate in meeting this traffic load. So, in 2010 a new bridge with two-lane was constructed at the immediate downstream of the old bridge. Thus, both bridges began to serve as a two-lane one-way river bridge. Bartın III Bridge is situated on Gökırmak which is the large tributary of Bartın Creek. Both banks along the creek in the vicinity of the bridge have smooth slopes, having only some steep slopes at some locations.

Stream is meandering and surrounded by residential areas and businesses which have been increasing rapidly. Both banks of the stream are covered by slim trees trunks and shrubs. During field visits the flow of the stream in the vicinity of bridge was found to be very calm, even in autumn and spring time. However, during an inspection it was witnessed that the discharge of the stream dramatically and quickly increased just after a day’s rainfall. The flow under the bridge became quite severe and elated carrying increased amount of fine sediment (Photo 4). This means that the drainage area of the basin is large and the precipitation quickly turns into runoff. Hence, it can be concluded that the risk of an intense rainfall causing flooding that would affect bridges in the area is quite high. Past flooding events experienced in the area is also evidence of this observation.

Photo 4.Downstream of Bartın III Bridge (December 2014)

The first striking feature about Bartın III Bridge observed during the inspection as in Bartın I bridge, is also the excessive scouring around piers of the bridge (Photo 5). As seen in Photo 5, even the bond beams which should have been embedded in the river bed are exposed due to scouring and serious corrosion in the concrete of the beams and columns; cracks in places and formation of cavities, even reinforcements are seen.

Photo 5.Piers of Bartın III Bridge (October 2015)

Filyos V Bridge, located at the border of Karabük on Karabük-Yenice road is a two-lane, two-way river bridge. The bridge was built in 1990 on Filyos Creek, as a concrete, four-span bridge with a length of L=(4x20) m. The bridge has a simply supported beam and has two frame shaped triple column pile pier and two abutments.

In May 1998, a settlement of magnitude 65 cm was observed at one of the piers. So in July 1998, the bridge deck has been reinstalled back to its original position (Photo 6).

Photo 6.Low water level under Filyos V Bridge (October 2015)

Although the exact date of the settlement of that pier is not recorded thus not known, the period, May 1998, it happened is remarkable. When the meteorological records of the area are investigated, it is found that the basin had severe rainfall during that period. This also coincides with flood event which struck and devastated Bartın. Available data and information about that flood event in May 1998 show that the region had heavy rain in a reasonable time span and this flooding may be likely the reason for that settlement at the pier of Filyos V Bridge. This also shows the important implications of flooding on river bridges. However, it should be noted here that, it is not possible to reach a definite conclusion due to the lack of any record or report about this problem or repair of the bridge pier. Once again, the importance of having an up-to-date inventory about bridges is clear. During the inspection of Filyos V Bridge, it was observed that there also was settlement at one of the bridge approach fill. The problem was aimed to be solved by rock fortification. However, even today it still seems there might be settlement in the approach fill in small amounts (Photo 7).

Photo 7.Abutment of Filyos V and settlement at bridge approach filling

During field visits to the bridges Filyos V, Bartın I and Bartın III and also the other two bridges involved Gökçebey and Çatalzeytin, observed hydraulic factors that can be effective on bridges can be summarized as follows:

1) Bridge location and skewness: Location of bridges in a basin is crucial. For example, flow caused by either severe precipitation or sudden snowmelt especially on steep slopes or basins with high gradients runts into the river in a short time at high speed. In this case, bridges situated at such locations can be exposed to more frequent and severe floods, thus increasing the risk of being inundated and having excessive scour around piers and abutments. Furthermore, if the bridge is skewed, this would also affect the velocity field of flow, resulting in more complex three-dimensional flow structure increasing scouring potential around the piers.

2) LU and LC of the basin: LU and LC of the watershed also affect the rainfall-runoff relationship. Descending vegetation and forest cover and developing residential areas can affect rainfall-runoff relationship on negative sense resulting in greater amount of precipitation to continue as runoff and thereby increasing the risk of flooding in the area.

3) Hydroelectric Power Plants (HPP) located on the river: There has been a dramatic increase in the number of HPPs in Black Sea Region, especially in the last decade or so. Suspended sediment carried in the flow would settle down in the reservoir of a HPP so the discharged water to the downstream from the plant would be clear from sediment. Thus, the balance of the natural channel river bed morphology wouldn't be attained; there likely to be degradation at the channel bed due to clear water condition in the flow. This means that scouring around piers would increase.

4) Presence of sand and gravel pits: One of the serious changes that can take place after the bridge is opened to traffic is the withdrawal of sand and gravel from river bed. Particularly in Western Black Sea Region, the need for sand and gravel for construction sector is supplied from streams. According to the regulations in Turkey, the location of such pits should be at least a kilometer downstream of the bridge. In fact, this distance should be determined for every bridge separately because of site specific variations of flow, bed material, geometric features of rivers, and bridge characteristics. Since neither location nor the operation of withdrawal of sand and gravel is not according to the regulations, there happens to be serious amount of degradation on the river bed resulting in excessive scouring around bridge piers. Although the Prime Ministry Circular No 2006/27 [11] is published to solve this problem, gaps in the legislation and failures in applications still do not enable a proper operation.

5) Steep river bed slope: Where the river bed slope is steep, necessary measures, such as check dams and weirs should be taken to prevent further degradation of the river bed.

6) Confluence of river branches: When the river tributary on which the bridge is situated confluences with another tributary upstream or downstream of the bridge, sediment transport capacity the river bed can be affected.

7) Meandering of river: If the river meanders in the vicinity of bridges, the flow structure becomes fully three-dimensional so increases scouring around piers and abutments.

8) River restoration works: The General Directorate of State Hydraulic Works (DSI) is the state agency of Turkey which is responsible for flood protection and restoration of rivers. In the perspective of these works, the purpose is to enable the river bed sections to carry discharges of determined recurrences like (Q_{100}, Q_{500}). However, during field studies, it was observed that, these type of works could be carried out without sufficiently taking into account their direct effect on the nearby bridges or their indirect effect which arose by changing the hydraulic conditions of the river flow in the vicinity of bridges. Therefore, collaboration between DSI and KGM is crucial when such work is carried out in the vicinity of river bridges.

9) The presence of wastes in the flow, such as tree trunks and branches: During field studies, tree trunks, branches and similar wastes in all sizes are observed to be stuck and deposited around bridge piers of each and every bridge inspected. In case of accumulation of such materials around bridge piers, flow structure in these areas are affected, becoming three-dimensional and complex; increasing the risk of scouring around piers and abutments. Furthermore, materials which accumulate over time or during flooding around piers might block the bridge spans and so reduce the flow area. These in return increases the flow velocity in this region and thus increases or trigger scouring.

10) Fortifications against scouring: During field studies at bridges where observations and bathymetric measurements are performed or other bridges in the area are considered, it was seen that large boulders are placed around the bridge piers as precautions against scouring. However, three-dimensional turbulent flow will occur in the gaps and around these large boulders and rocks thereby increasing the possibility of scouring on the river bed under these rocks. Furthermore, random displacement of these boulders and rocks as a result of severe flow or flooding would also increase scouring problem.

V. Conclusion

Studies show that the principal reasons of failure or damage of river bridges are hydraulic factors. Among these factors, flooding is the most important and destructive factor. Scouring around bridge piers and degradation at river bed could arise and the bridge could seriously be damaged or collapse as a result. Therefore, these hydraulic factors that affect river bridges so severely should be examined carefully during bridge inspection and recorded in the database of BMS of KGM. Thus, these hydraulic effects on the bridge could be tracked and thereby necessary precautions could be taken. In order to develop a safety-inspection method that takes into account the hydraulic factors effective on river bridges, a project is currently undertaken and Western Black Sea Region is chosen as pilot area where failures or damages of river bridges due to scouring and other similar hydraulic factors frequently happen. Study about development of a simple and applicable safety-inspection method is still ongoing. It is believed that inclusion of river bridges from other regions of Turkey that might be under various hydraulic effects would improve the inspection methodology. However, the present study is assumed to be an initial step taken in this area, a pioneering study arising awareness to the causes of failures of river bridges and launching the development of an appropriate system for inspection of river bridge in Turkey.

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