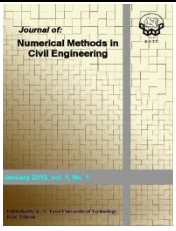

Numerical Methods in Civil Engineering

Investigation of Impact of Bridges Built on the Main Surface Water Collection Canals by Hydraulic Simulation (Case Study: Mianroud Canal - Tehran)

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ARTICLE INFO

Article history:
Received:
January 2020.
Revised:
February 2020.
Accepted:
March 2020.

Keywords:
Critical points,
District 5 of Tehran,
Mianroud Canal,
Bridges,
HEC-RAS.

Abstract:

Familiarity with storm water management and how to assess damage and deal with it to minimize and control it is very important in urban management systems. There are several methods for flood control that are considered depending on the hydraulic conditions. The use of main canals for surface water collection, flow diversion, catchment management, etc. are among the methods considered by urban designers. Meanwhile, the use of various softwares such as SSA, HEC-RAS and the use of engineering tools such as GIS in its environment has attracted the attention of many researchers. In this paper, the hydraulic studies of Mianroud canal in the area of District 5 of Tehran Municipality, which is one of the important surface drainage arteries of Tehran, have been considered with the help of mathematical model for flood risk zoning. Vulnerable areas have been identified and finally management strategies to control and reduce flood risks have been discussed according to the river regime and the conditions of the region. The results of the Mianroud canal crossing capacity at the intersection with the existing bridges show that the canal built at the site of the sixth bridge is unquestionably incapable of passing floods with a return period of ten years. The canal will be able to pass the 25-year-old flood only at the location of the second and seventh bridges and will overflow at the location of the other bridges. In the 50 and 100 year return periods, the canal will almost lose its function and will flood the surrounding areas with 100% fullness.

1. Introduction

The importance of urban floods is considered because of the harmful effects they can have on urban structure, human health, and the environment. Statistics show that flood damage in the last five decades has accounted for more than half of all-natural disasters in the world. Iran's climatic and geographical conditions are such that every year we see the occurrence of floods accompanied by considerable damage. The escalation of the flood damage in the last two decades has led to an understanding of the fact that efforts must be made to reduce its harmful and destructive consequences.

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Meanwhile, we are witnessing a decrease in water infiltration in urban areas mainly due to the destruction of upstream watersheds (such as destruction of vegetation and road construction, as well as the uncontrolled expansion of urban and industrial lands). Urban runways and residential areas adjacent to rivers have the greatest potential for flood risk. Therefore, the implementation of new policies regarding land use management and rational urban development in order to reduce the effects of its destruction is essential.

The city of Tehran is in the southern foothills of the Central Alborz Mountains and downstream of several catchment areas. The area of Tehran up to an altitude of 1133 meters has caused a structural difference in the physical texture of this city and as a result, it has become prone to natural hazards such as floods. On the other hand, the predominant precipitation regime in Tehran is in the form of thunderstorms, which reduce the chance of rain penetrating into the soil, and as a result, a significant part of the precipitation becomes surface runoff. Therefore, rivers and lakes of urban watersheds have a high degree of risk for flooding and damages. Achieving sustainable urban development requires the design of appropriate models for the management and protection of rivers and lakes in urban watersheds.

Accordingly, in these areas, determining the level of flood progression and its height relative to the land surface figure and determining the characteristics of flood in different return periods (flood zoning) is crucial and is a prerequisite for designing structures in canals. One of the most common methods is to use the geographic information system and combine it with hydrological and hydraulic models. After determining the flood zoning maps, it is necessary to prepare flood risk maps, in which the safe areas are identified. Proper flood estimation and the resulting risk, in addition to determining the points with the highest risk, make it possible to identify the organizing points and reduce the growth rate of flood damage. Experts believe that if structural methods are combined with non-structural methods, they will be the optimal solution to minimize flood damage. This case highlights the need for a comprehensive study of floods in the upper basins of Tehran.

Flooding of the floodplain and its use in spatial planning is one of the non-structural measures to reduce flood damage.

Today, flood zoning maps are prepared by developing many techniques and methods, including GIS, Digital Elevation Model (DEM). Some of these methods are based on hydrological data and information layers such as land use, soil type, basin slope, rainfall, and so on. The success of these methods depends on the accuracy of the information layers and their assumptions. But there are other methods based on the use of hydraulic models (such as Autodesk® Storm and Sanitary Analysis (ASSA), Hydrologic Engineering Center - River Analysis System (HEC-RAS), and MIKE Flood) and combining their results with geographic information systems. In these methods, with the help of numerical models, the flood flow is simulated and after calculating the flow profile by the model, the flood zone is transferred to the study area with different return periods.

In order to widen the floodplain, one-dimensional models have been used repeatedly due to low data requirements, ease of execution, and fast computations. The HEC-RAS one-dimensional model has been used for this purpose for many years.

This model includes river hydraulic calculations in the steady-state and non-steady state for water surface profile calculations and sediment transfer calculations at the moving boundary.

Alaghmand et al. (2012), in a study, compared the capabilities of HEC-RAS and MIKE 11 hydraulic models in the risk of river flooding in the Sungai Kayu Ara basin [1]. Cook et al. (2008) compared the capabilities of the one-dimensional HEC-RAS model with the FESWMS model in flood mapping [2]. Heydari et al. (2013) used the HEC-RAS model to simulate the flood zonation of the Johor River-Kota Tinggi Region [3]. Pistocchi and Mazzoli (2002) employed the HEC-RAS, HEC-HMS and ArcView models for hydrological risk management [4]. In another study, a combination of the above models (HEC-RAS and HEC-HMS) was applied to model rainfall runoff and evaluate the flood zone map [5]. Similarly, a combination of HEC-RAS and GIS models has been used to analyse the impact of urbanization on floods in Swan Creek watershed [6] and in river network floodplain delineation [7], respectively. Also from HEC-RAS model for flood forecasting [8], flood risk analysis [9], application of canal design [10], flood control in rockfill dams [11], calibration of roughness coefficients [12, 13], assessment of flood inundation mapping of Surat city [14], and simulations of past floods [15] have been utilized.

The SWMM model has been applied by several researchers for their research. For example, Babaei et al.[16], Chen et al. [17, 18], Jiang et al.[18], Liao et al.[19], and Wanniarachchi, S. and N. Wijesekera [20], utilized this model to simulate urban floods. The capabilities of the SWMM model have also been applied for modern LID-BMP methods [21, 22]. Furthermore, the mentioned model has been adopted to estimate sub-catchment area parameters for Storm Water Management Model [23], storm water flood analysis in small and medium cities for climate change [24], for calibration and validation of the model [25], to simulate the response of the catchment to flood events [26] and to calculate of manhole water depth and sub catchment peak flood [27]. Experience of urban floods in recent years and the importance of recognizing bottlenecks are among the most important reasons for this research. This study tries to investigate the risk of flooding in the area of Mianroud canal in Tehran using the hydrodynamic model of HEC-RAS and Geographic Information Systems (GIS).

2. Research Methodology

Hydrology Simulation: For modeling the basin, in order to calculate the design floods, the runoff precipitation model of the desired basin was prepared using HEC-HMS software. The Mianroud channel and Kan River Model consists of 43 sub-basins (Fig 1). Determination of rainfall losses as well as conversion of rainfall to runoff was implemented using the methods of Soil Conservation Service (SCS).

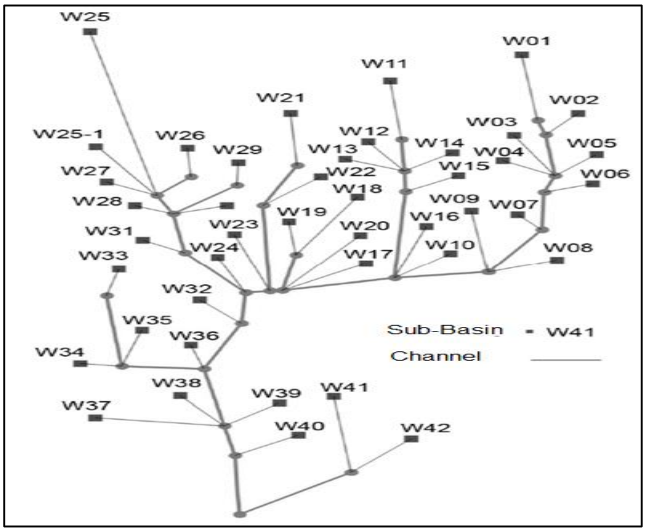

Fig. 1: The main drainage network of the Mianroud channel and the Kan River

Hydraulic Simulation: To simulate the hydraulic behavior of the urban runoff transmission system and flood zoning, first, the information needed to implement the model such as the geometric characteristics of the canal, the flow rate of the discharge channel, the roughness coefficients of the main waterway, and the floodplain of the study area are prepared. Subsequently, the flood zoning using Hydraulic models such as HEC RAS is performed in ArcGIS environment for 10, 25, 50 and 100-year scenarios.

The research process including problem definition, data collection, methodology (hydrological simulation and hydraulic simulation), evaluation criteria and output (problem objective) are summarized in Table 1.

Table 1: Problem methodology

Project definition:	*Objective 1: Investigation of hydraulic effects of bridge construction on canal*	Recognize sensitive and critical points
	Objective 2: flood risk map preparation	Prepare a flood zoning map in case of overflow from the canal
Input data	*Topographic map*	GIS environment
	Land use map	Tables and GIS
Methodology	*Hydrological Simulation*	Rainfall runoff modelling (HEC-HMS & WMS)
	Hydraulic Simulation	1D for canal (HEC-RAS & SSA)
		2D for Flood zoning map (HEC-RAS)
Evaluation criteria	*Classification*	Return periods of 5, 10, 25, 50 and 100 years
	Assessment	Compare with available results
Output	*For Objective 1:*	Checking the adequacy of flood passage in the canal
	For Objective 2:	Production of flood risk map in case of overflow from the canal

Problem theories:

The HEC-RAS model is used to display the water surface profile, stimulate the flow of steady and unsteady states, calculate the sediments transferred to the shores, and qualitative analysis of water. In flow analysis, this model could provide water surface profile in super-critical and sub-critical conditions, and through it, hydraulic structures such as bridges and ports can be modeled. Due to the high capabilities of this model, it has been widely used to manage rivers and floodplains. To define the topography of the region in the two-dimensional HEC-RAS model, we can directly use the Digital Elevation Model (DEM), and unlike the other one-dimensional model, there is no need for HEC-GeoRAS and cross-sectional definition. All steps in the software itself are done with the help of the RAS-Mapper module. In many two-dimensional models such as CCHE2D, FLOW2D, IRIC etc. A computational cell can be either dry or wet, but in the new HEC-RAS model, a computational cell can be both dry and wet. This model uses the concept of sub grid variability to calculate the flow parameters within each cell, while most two-dimensional models do not have such a valuable capability. The model can be run in two modes: Diffusion Wave and Full Momentum. The momentum equation is assumed to be an incompressible flow according to equation 1:

$$\frac{\partial \upsilon}{\partial t}+u\frac{\partial \upsilon}{\partial t}+\upsilon\frac{\partial \upsilon}{\partial t}= - g\frac{\partial H}{\partial y}+\upsilon_t\left(\frac{\partial^2 \upsilon}{\partial x^2}+\frac{\partial^2 \upsilon}{\partial y^2}\right) - C_f\upsilon + f_u \quad (1)$$

In this regard, u and v are the velocity components in the Cartesian coordinates, H is the height of the water surface from the base level, g is the gravitational acceleration, v_t is the eddy viscosity coefficient, C_f is the bed friction coefficient and f is the Coriolis parameter.

To be sure, the manning coefficients obtained in the measurement model were added to the obtained coefficients by 15 to 30% and then deducted, and then the model was re-executed for the new values obtained and the difference in level, depth, and speed. The difference measured in all the results obtained was small/insignificant.

3. Study area

The metropolis of Tehran, with an area of about 700 square kilometers, is one of the largest cities in the world with special features and specifications. Tehran's drainage system has many complexities that are mostly due to the heterogeneous development of the city, regardless of the comprehensive criteria of urban planning and urban planning in recent decades. Due to the fact that the whole metropolitan area of Tehran is surrounded by high mountains, in addition to surface water in the urban area, rainwater runoff in the northern and eastern mountains of Tehran enters the urban area of Tehran by rivers. The Mianroud Canal route in Tehran, which was designed in the 1960s, is one of the most important water collection routes in western Tehran, directing the floodplains of the Darkeh, Farahzad, Neyzar and Hesarak rivers and flowing into the Kan River. As one of the main surface water management facilities in the west catchment area of Tehran, this canal is located in the vicinity of important infrastructures such as Tehran-Karaj freeway and lines 4 and 5 of Tehran metro. Therefore, its critical points are among the floodplains of priority for a city in Tehran. The canals leading to the Mianroud canal all have a north-south direction and extend in the direction of the dominant slope of the city. This has caused the slope of the canals leading to the middle river to be steep and high, and as a result, the flow velocity in them is high, which results in the occurrence of erosion phenomenon in some intervals in the mentioned canals. Mianroud canal has a relatively low slope due to its extension in the east-west direction, and this has caused hydraulic problems in some parts of this canal. (Fig 2)

Fig. 2: The study area

4. Results

As expected, due to the increase in impenetrable levels in the cities, the volume of runoff will increase significantly and will cause an overflow of runoff transmission channels resulting in innumerable problems in the city. Analysis of the allocated capacity in relation to the critical points located in the network includes reviewing the flow capacity of discharge through sensitive sections on the network channels as well as the amount of their capacity shortage and the percentage of filling of the upstream channel for discharge flood with return periods of 10, 25, 50 and 100 years. In figure 3, as an example, the inlet hydrograph of the Mianroud canal from different branches with a return period of 100 years is shown.

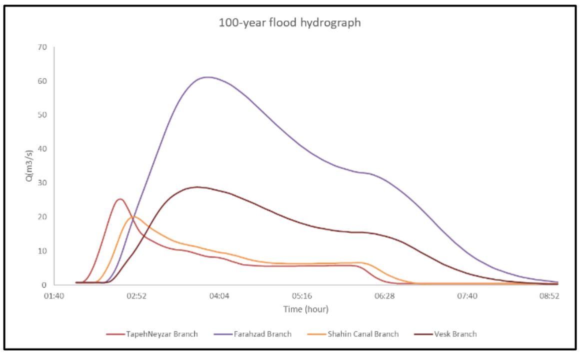

Fig. 3: Input hydrographs to the Mianroud canal with a 100-year return period from various branches

The following are the results of hydraulic modeling of flood points and modeled bridges, separated by the intervals in the channel.

The results of vulnerability studies in these areas show that a combination of upstream and urban factors exacerbates the vulnerability of these areas. Factors such as providing bridge deck space in the canal and ignoring the volume of water collection and transfer canals, vertical slope levels and curvature coefficients are involved in determining the vulnerability of urban areas.

The first bridge

The improper deck of the bridge has blocked most of the canal by 40.47 %. Figure 4 shows a view of the bridge and its hydraulic modeling specifications. The capacity of this bridge is sufficient for floods with a 10-year return period, and the flow passes through the bridge in a free surface, observing the free height. For floods with a return period of 25, 50 and 100 years, the type of flow in crossing the bridge is under pressure and overflows the canal and the deck of the bridge. (Fig 11 and Fig 12)

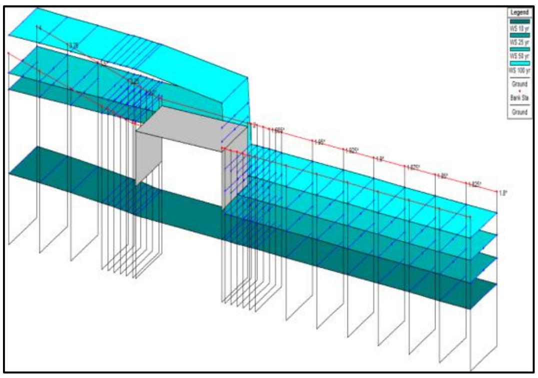

Fig. 4: Perspective view with bridge capacity analysis for the 1st bridge

The second bridge

The deck of the bridge has reduced the cross-sectional area of the canal by 27%. Figure 4 shows the results of the hydraulic modeling of the bridge. The capacity of this bridge is sufficient for floods with a return period of 10 years, and the flow passes through the bridge in a free surface, observing the free height. For floods with a 25-year return period, the flow is converted under pressure by observing the free height, and in 50-year floods, the flow overflows from the upstream canal, and in 100-year floods, in addition to the upstream canal, it overflows. (Fig 11 and Fig 12)

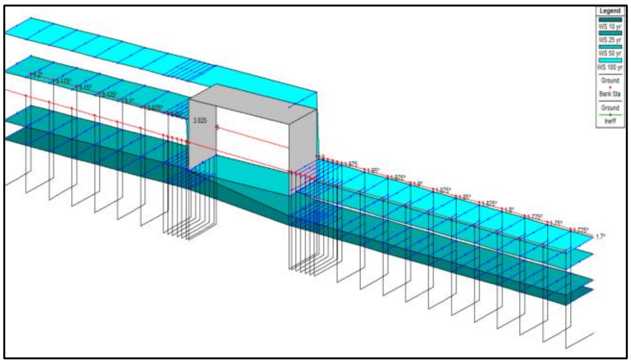

Fig. 5: Perspective view with bridge capacity analysis for the 2nd Bridge

The third bridge

The deck with a height of 1.8 meters has reduced 47.37% of the canal cross section (Fig 6). The flow at the crossing of this bridge is free for flooding with a 10-year return period under pressure with respect to free board. For floods with a return period of 25, 50 and 100 years, the stream overflows the deck and upstream canal. (Fig 11 and Fig 12)

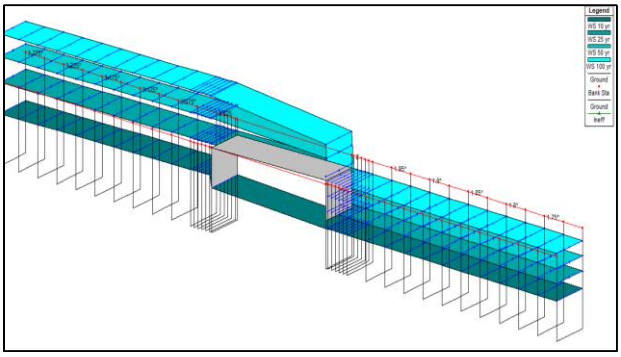

Fig. 6: Perspective view with bridge capacity analysis for the 3rd Bridge

The fourth bridge

The deck of this bridge is part of the ramp, which has been built on the Mianroud canal. The width of the upstream canal, 25 meters from the bridge, is gradually reduced from 9 meters and reaches 6.2 meters at the entrance of the bridge. In addition, the reduction of the cross-sectional area of the canal due to the bridge deck is 28.95% (Fig 7). For floods with a return period of 10 years, the flow passes through the bridge under pressure by observing the free height. For floods with a 25-year return period, the flow will be under pressure. In this case, although the flow does not overflow from the bridge deck, it exits through the upper channel and the left wall; it then enters the Tehran-Karaj metro area and the center's catchment area. For floods with a return period of 50 and 100 years, the flow overflows the canal and the deck of the bridge, and as a result, the capacity of the flow passage through the channel under the bridge is not sufficient (Fig 11 and Fig 12).

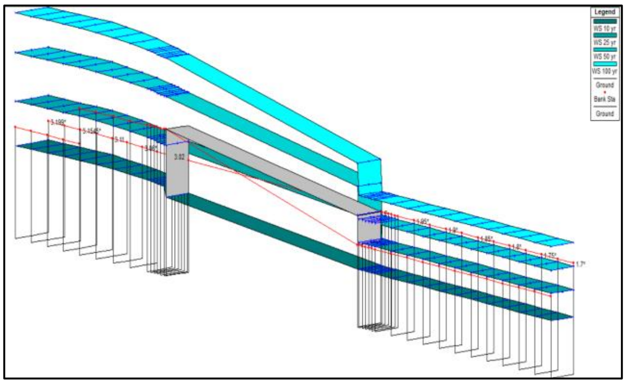

Fig. 7: Perspective view with bridge capacity analysis for the 4th Bridge

The fifth bridge

The reduction of the cross section of the canal at the entrance of the bridge compared to the upper canal is 22.86% (Fig 8). For floods with a return period of 10 years, the flow passes under the bridge under pressure without observing the free height. For flooding with a 25-year return period, the flow is under pressure, and although the bridge deck is not submerged, the flow overflows from the upper channel. For floods with a return period of 50 and 100 years, the stream overflows the canal and the bridge deck. (Fig 11 and Fig 12)

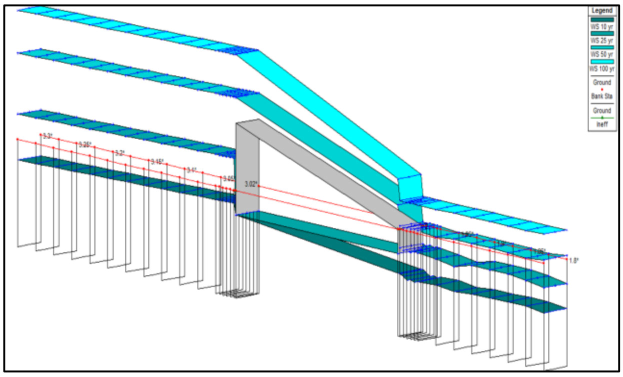

Fig. 8: Perspective view with bridge capacity analysis for the 5th Bridge

The sixth bridge

At a distance of 27 meters from the entrance of the bridge, a ramp with a length of 15 meters has reduced the width of the canal cross section from 14.8 meters to 7.8 meters. The cross-sectional area of the canal covered by the bridge has been reduced by 57.18% compared to the upstream canal with a width of 14.8 meters (Fig 9). The narrowing of the cross-section of the existing ramp, the arrival of discharge from the evacuation of the Vesk canal, and the reduction of the cross-sectional area of the canal at the bridge site have led to a leak from the canal for flooding with 10, 25, 50, and 100 years; In 25, 50 and 100 years discharge, in addition to the flow out of the upstream canal, the flow will also cross the bridge deck and flood the access route to Eram Park. (Fig 11 and Fig 12)

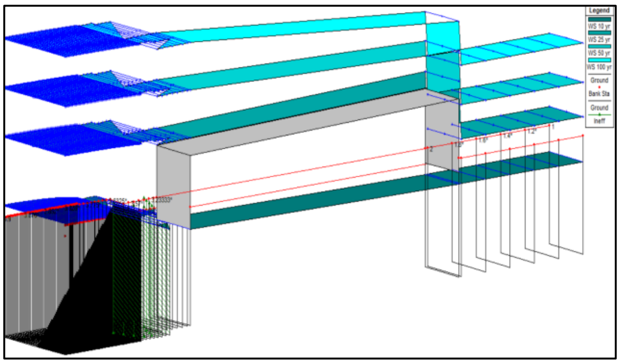

Fig. 9: Perspective view with bridge capacity analysis for the 6th Bridge

The seventh bridge

The bridge was built at the end of the Flood Diversion Channel of West Tehran and 27.28% of the cross section of the canal at the bridge site has been reduced by its deck (Fig 10). For floods with a return period of 10 and 25 years, the flow passes through the bridge as a free surface with respect to free height, and for floods with a return period of 50 years, the flow passes through the bridge under pressure without observing free height. In this case, the current is placed on the border of the overflow from the bridge deck. To flood with a 100-year return period, the stream overflows the bridge deck and its upper canal. (Fig 11 and Fig 12)

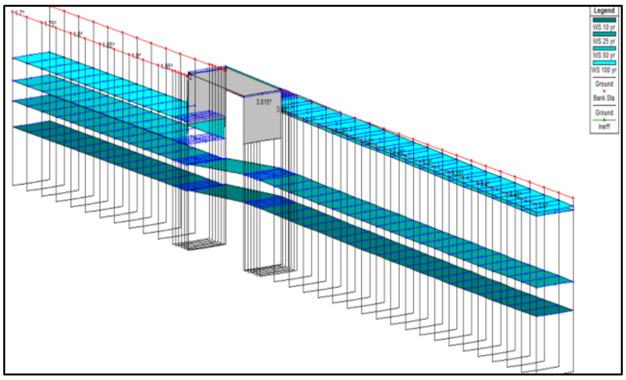

Fig. 10: Perspective view with bridge capacity analysis for the 7th Bridge

5. Discussion

Current status performance

One of the most important bottlenecks in the floodplain canal are the bridges and culverts built on it. Bridges and Culverts are structures for the passage of cars and citizens, and while they are part of the network of streets and inner-city roads, they are also part of Tehran's main surface water network. Proper design and implementation of bridge and caliber structures will minimize the flow of energy at the intersection with these structures. Improper implementation of them not only increases the rate of energy loss, but also causes problems such as water receding or turning the structure into floodplains. The impact of these facilities, especially in times of flooding, cannot be ignored. So, a closer look at the impact of these structures on the hydraulics of the canal flow has been considered.

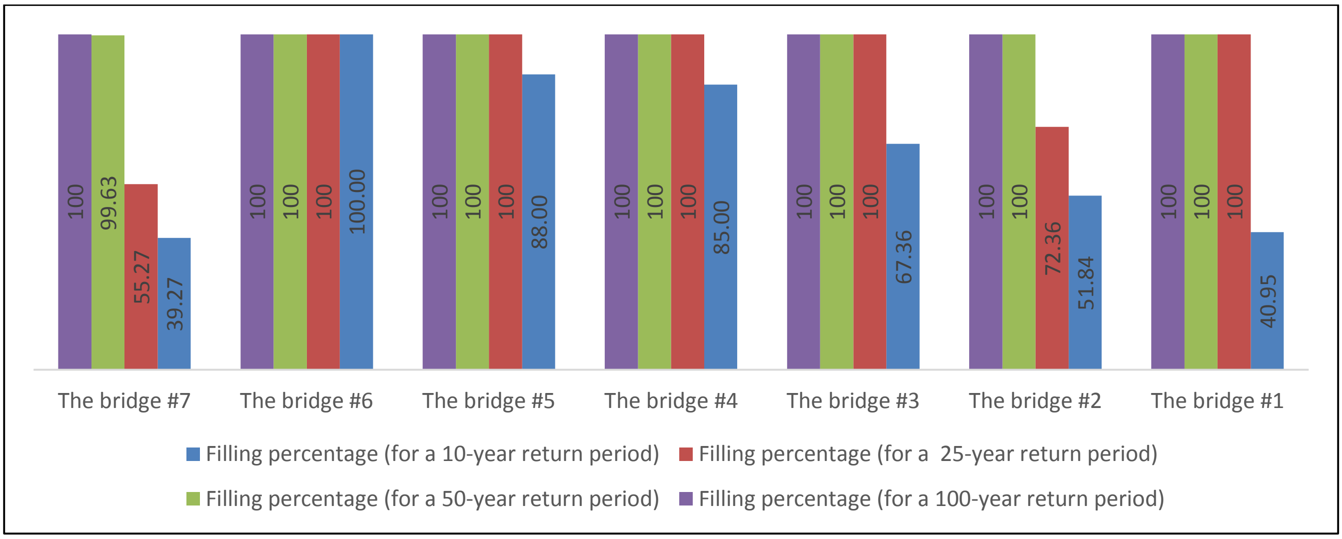

Fig. 11: Percentage of channel duct filling rate in return periods of 10, 25, 50 and 100 years

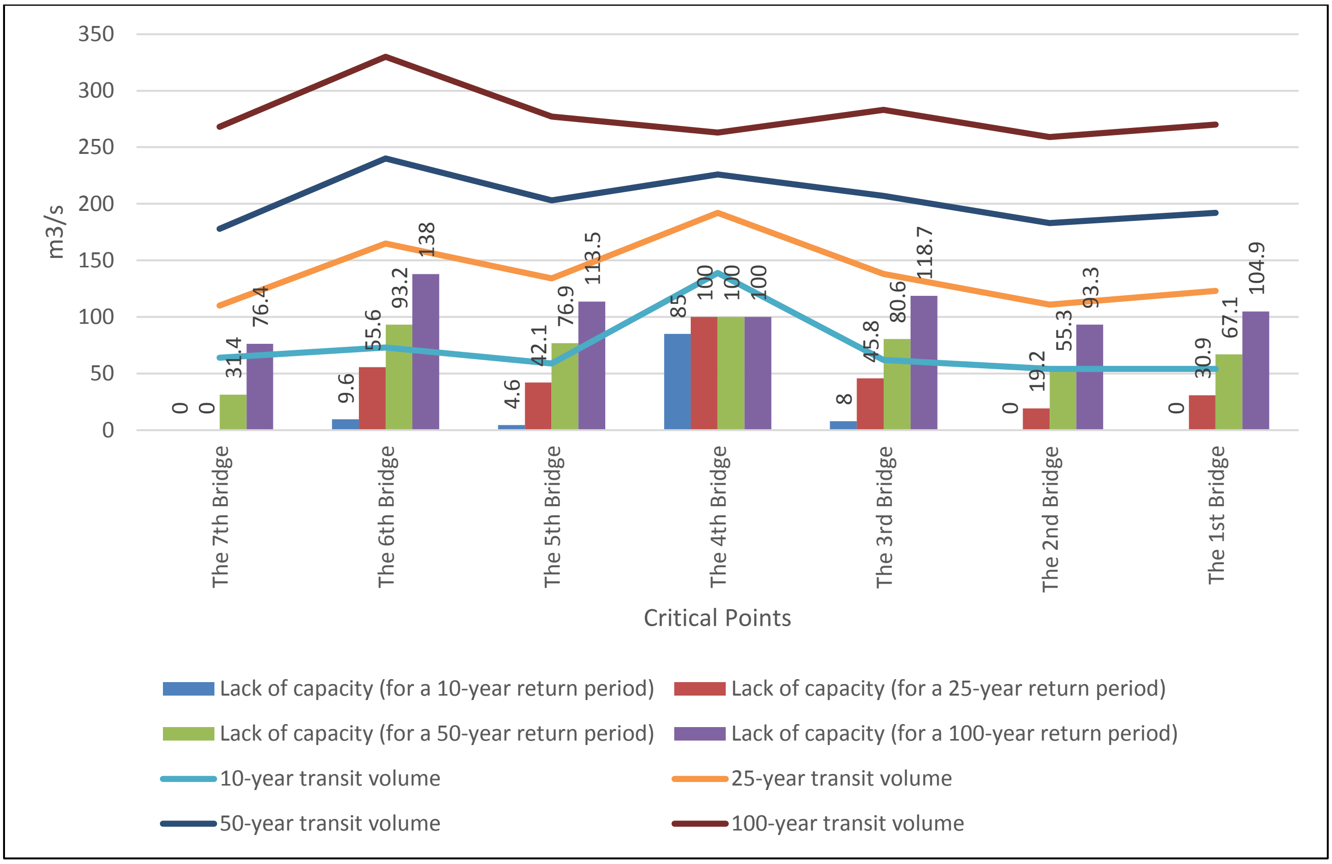

Fig. 12: Comparison of passing volume and capacity shortage for return periods of 10, 25, 50 and 100 years of studied bridges

The flood zone and vulnerability map are shown in Figure 13. In this case, in addition to the water escape points, water escapes from the seventh bridge constructed on the Mianroud canal. Naturally, the range of the flood zone has become larger than floods with shorter periods and the flood wave has progressed more.

It should not be forgotten that in the two-dimensional model, the results of critical points do not correspond to the one-dimensional channel results. The reason is that the volume of the output flood in the two-dimensional model does not return to the channel. So, the results of the one-dimensional model will be more cautious for design.

Fig. 13: Flood zone and vulnerability map (by HEC-RAS 2D model)

Proposed structural solutions:

In order to strengthen and improve the hydraulic capacity of the main channels in this area, several methods are proposed, namely;

1. Demolition of bridges built on surface water conduction canals (bottlenecks)
2. Increasing the height of the canal wall in a reasonable and appropriate way considering the characteristics of the place (limited increase and proportional to the urban landscape)
3. Use of auxiliary duct
4. Construction of storage tanks to adjust the flood flow peak
5. Diversion of current from one channel to the adjacent channel
6. Improving the floor and wall covering of the canal

6. Conclusion

In this study, the impact of bridge construction on surface water collection canals in the area of Mianroud canal was investigated. Obviously, if the cross section of the canal is used to build structures such as bridges on it, it will reduce the volume of passage in times of floods. But it is important to know the bottlenecks preceding the flood. The risk, vulnerability as well as operational plans should be considered in the following items:

1. The flood phenomenon, despite all its complexities, can be studied, and appropriate methods can be introduced to control and reduce its damage. Accordingly, emergency management (in the form of flood guidelines and action plans) is extremely important to prevent and reduce flood damage.
2. Managing and accessing the vulnerability of urban areas to surface water in metropolitan areas is of particular importance, because planning upstream of these areas will lead to better management in downstream human centers.
3. Correction and reorganization of the route of the canals can reduce flood damage and help the proper use of its water resources. Therefore, it is suggested to consider the climatic, biological, topographic, and hydrological conditions of a basin and its waterways, and to construct the required structure in it.
4. In this study, the amount of suspended sediment in the canal has been omitted due to limited information and lack of access to it. It is suggested that future studies address the importance of sedimentation in canals, as sediment can have negative effects on reducing the volume passing through the canal and can also cause flooding to overflow out of the canal over time.
5. In flood risk analysis, especially in urban areas, the depth of flooding attracts attention, however, the potential role of the flow rate is undeniable. This is observed by considering factors such as multiple uses along canals and main tunnels for collecting and transporting surface water, particularly in sudden floods. Research on flood-prone areas shows that, regardless of the management operations applied in those areas, flood risk-based zoning is largely based on the depth or return period of the flood.

Acknowledgments:

We would like to thank the Deputy of Technical & Development Affairs - Tehran Municipality for their support and cooperation in visiting and accessing the data. We also thank the reviewers for their careful reading of our manuscript and their many insightful comments and suggestions.

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