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Research Article

Numerical Rehabilitation in Stream Crossings After the February 6, 2023 Earthquakes

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Abstract

Earthquakes can cause topographic changes and increase the risk of flooding by changing the structure and route of the river channel. The Pazarcık and Elbistan earthquakes that occurred on February 6, 2023, were also flood-triggering earthquakes. In this study, numerical solutions were performed with the HEC-RAS software as a rehabilitation study against the flood-triggering effect of earthquakes. The Sarsap Train Station region located in Yazıhan, Malatya was selected as the study area. As there was no road for vehicle connection before, after the earthquake to provide a non-stop connection with the station a bridge structure on the Eskiköprü Stream (Kuruçay) was modeled in the HEC-RAS environment. Firstly, flood recurrence flow rates were calculated using the DSI Synthetic Method. Then, the Manning roughness coefficient (n) was found according to the Modified Cowan Method. In the HEC-RAS calculation, 33 cross-sections were taken at 20 m intervals from downstream to upstream. Additionally, a bridge section with 6 gaps and 26 m width was defined to the software at Km: 0+175.00 which is the section at the most suitable distance to the station. As the result of the solutions made according to the 100-year flood flow, water surface profiles were obtained both in the bridge section and all other sections, and it was seen that the flood flow rate conveniently passed through all sections, including the bridge section. It can be said that in the rehabilitation works that will be carried out in the region, especially about the flood risk after the earthquake, this study will both reduce the risk of flood and provide a smooth connection to the station with the highway.

Key Words

“Earthquake, Eskikopru stream, Hec-ras, Flood analysis, Stream regulation”

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1. Introduction

In today's world, global climate change and some natural disasters in which human beings are directly involved cause great destruction. The most common disasters are earthquakes, floods, overflows, tsunamis, landslides, storms, tornadoes, volcanoes, and fires. Among these, earthquakes that occur in different parts of the world at any time of the day can change the topography of the region where they occur and indirectly affect many hydrological processes above and below ground. Another negative aspect of the earthquake was that it caused great social losses and economic difficulties. Two earthquakes with magnitudes of Mw 7.7 and 7.6, which occurred on February 6, 2023, in Pazarcık and Elbistan (Kahramanmaraş), affected a very large area by causing significant destruction and changes in topography. The change in topography has also changed the stream flows and routes that will present risks. Such changes trigger floods, which occur mostly in valley bottoms and lower basins and cause high water flows with the amount of solid material they carry (Ağıralioğlu, 2007). Figure 1 shows the general view of a floodplain.

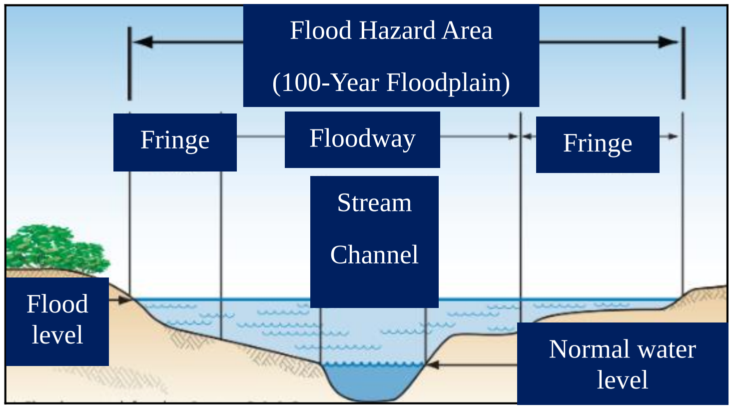

Figure 1. Floodplain profile (URL-1).

Floods cause agricultural damage, housing problems, financial losses, and damage to many underground and overground plants in the region where they occur. This situation obliges the protection from flood, and for this purpose, many studies such as flood forecasting, flood warning systems and regional river rehabilitation studies have been included in the literature.

For example, a case study on Godavari River flood modelling using HEC-RAS software was conducted by (Kute et al., 2014). For modelling, a flood caused by the Gangapur Dam, built 14 km away from the upstream of Nashik city, was considered. The maximum flow rate of the flood that occurred in 1969 was considered as the flood flow rate. The river, 14 bridges on the river and floodplains were modelled. It was stated that the established model facilitated the identification and the border of the floodplain for effective flood mitigation measures. Traore et al. (2015) tried to determine the floodplain of the Kayanga River in Senegal to increase food security and develop irrigated agriculture. Using the Hec-Ras software, they carried out some hydraulic analysis to determine the flow characteristics of the river. Here, water surface profiles, energy line, water surface height, flow rate, flow area, total surface area, volume, wet environment, Froude Number, friction loss, and head loss were calculated. Wide and narrow cross-sectional regions that allow floodplains to be predicted have been specifically defined in the system. They stated that some flow properties such as volume and total surface area decrease from upstream to downstream. It was also revealed that the flow velocity in the main channel was significantly higher than in the floodplain. Taş et al. (2016) obtained flood distribution maps with HEC RAS software, evaluated the study area in terms of flood risk and revealed the approximate flood damage cost with the help of depth-damage curves. The other (Puno et al., 2020) study was conducted on for disaster response and prevention plans for disasters of local governments. It was aimed to determine the building features and agricultural resources exposed to floods according to different flood scenarios in the floodplain of the Sawaga basin, especially by using numerical models and GIS techniques and through flood simulation and mapping. As the result of the study, it was reported that 94% of the settlement area will be damaged by floods and, according to the 5-year, 25-year and 100-year recurrence period scenarios, respectively 66%, 74% and 77% of the total flooded agricultural areas in the floodplain were under flood danger. As the Küçücek Creek passes through the industrial zone, this area was selected as the study area by (Hırca and Sönmez, 2019). In the hydraulic analyses performed with 8 return period flood flows, it was determined that the repetition years will not cause flood and the rehabilitation project will be effective. The Sungai Kayu Ara River basin located in the western part of Kuala Lumpur in Malaysia is another case study that was determined by (Alaghmand et al., 2010). HEC-HMS and HEC-RAS were used respectively as hydrological and hydraulic models to obtain river flood hazard mapping. The river flood hazard maps created were based on water depth and flow velocity maps prepared according to hydraulic model results in the GIS environment. The results showed that the amount of the rainfall and improvement condition of the river basin land use had significant effects on the river flood hazard map pattern. Baykal et al. (2022) determined the flood risk areas in Küçük Aksu Stream in Antalya province with Hec-RAS. Hec-RAS models were developed according to different recurrence flow rates, and flood distribution maps and flood depth maps were created. As the result of the model developed using 100-year flood recurrence flow rate, it was seen that 6.04 ha of residential area and 33.73 ha of agricultural area were flooded. As the result of the analysis, it was seen that the economic loss caused by the floods was between 1.152 million-1.946 million TL.

For the hydrology of the Kunhar River and the hydraulic design of the bridge on this river, HEC-Geo RAS and HEC-RAS software were used (Riaz et al., 2022). Especially since both sides of the river were used as settlement areas, analysis were carried out for three stable flow profiles to determine the bridge location. The first of these is the maximum flow rate value for the river in history, the second one is based upon the 100-year flood recurrence period, and the third profile is for the last 100-year period with a safety factor of 1.28. With evaluations based on remote sensing, the proposed bridge location was determined and confirmed by a physical field research. In that study, Yalcin, (2020) evaluated the effects of topography and land cover data analysis on the flood border, flooding depths, flow velocities, and arrival times predictions of a two-dimensional hydrodynamic HEC-RAS model under network structures of different sizes with various examples. They determined the 16 km-long flood area of the Lighvan Chai River with varying periods of return by using GIS, and HECRAS models and derived land use changes for 10 years (2000-2010) by using satellite images. The results obtained showed that approximately 67% of the total flood area was caused by floods that occurred in 25 years or shorter time (Khaleghi et al., 2015). They used the combination of geographical information systems (GIS), HEC-RAS (1D), and HEC-Geo RAS with a remote control system to obtain flood forecasting studies of the Kalpani River. The study results showed that the simulation results performed a good performance in a close and coherent way with the observed water surfaces (Ullah et al., 2016). Roshan et al., (2013) simulated the hydraulic behavior of Bashar River using HEC-RAS and GIS. The results of this study showed that the HEC-RAS model can provide suitable numerical values to investigate the hydraulic characteristics of flow in rivers, and can be used in flood hazard mapping more accurately and at a lower cost. Prafulkumar et al., (2011) predicted floods for the Lower Tapi River in India by using HEC-RAS software for 1998 and 2003. The model, calibrated in terms of channel roughness, was used to simulate the 2006 flood in the river. The performance of the calibrated HEC-RAS-based model was achieved by capturing the peaks of observed and simulated floods and calculating the root mean square error (RMSE) for interval measurement stations on the river. They estimated the Manning roughness coefficient in case of unsteady flow for the Hilla River through calibration by using the HEC-RAS model. They proved the accuracy of the study by matching observed and calculated hydrograph data (Hameed and Ali, 2013). They conducted a flood analysis of the section of Batman Stream between the New Malabadi Bridge and the Diyarbakır-Batman Highway Bridge. A total of 165 cross-sections were taken on the 1/1000 scale map of the study area with the AutoCAD Civil 3D program. With these cross-sections obtained, a one-dimensional flood hydraulic analysis of Batman Stream was carried out with the help of the HEC-RAS program. Taking into consideration the areal changes of flood damages due to different flood values, the elevations where the upper surface of the water was determined according to the Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, and Q_{500} flood recurrence flow rates in the natural bed of the existing stream (Efe and Önen, 2015). To determine the water surface profiles in the laboratory environment, an open channel system and rectangular models with different gaps and cross-sections were created on the system. This created system was also defined in the HEC-RAS program, and the results obtained in experimental studies are consistent with the HEC-RAS results (Kara, 2009). Deng and Li, (2012) made various applications to evaluate the HEC-RAS model for flood plain control of the Meg River Bridge. They also stated that the model can be applied to the analysis of still-water height changes.

This study aimed to obtain a water surface profile through HEC-RAS software for the design of a new bridge on the Eskiköprü stream (Kuruçay) to provide road access to the Sarsap Station under the responsibility of TCDD, located within the borders of Yazıhan district of Malatya province, after the earthquakes that occurred on February 6, 2023. The conditions that must be met by the gap between the bridge piers to be constructed in the determined section was discussed through HEC-RAS software. Thus, the cross-section change caused by the piers of a new bridge and the water surface profiles related to it were revealed. For this purpose, solutions were carried out with the 100-year flood recurrence flow rate in the HEC-RAS software, considering the UTM ED50 6° 37N Y: 424864 - X: 4280624 coordinates determined by TCDD 5th Regional Directorate. It was recommended that the proposed bridge width and gap of the piers, and numerical solution results can be used as a substrate for public welfare.

2. Materials and Methods

2.1. Characteristic features of the study area

Due to its geographical location, Malatya province is located within the Malatya Plain in the Upper Euphrates Section of the Eastern Anatolia Region. Malatya province is located in the Upper Euphrates Basin and the southwest of the Eastern Anatolia region. It is between 35°–54° and 39°–03° North latitudes and 38°–45° and 39°–08° East longitudes. Eskiköprü stream, located in Malatya Province, Yazıhan District, Akyazı Neighbourhood and within the borders of Yazıhan Municipality, was selected as the study area. Here, the study area is on a topography with a slope of 0-10% and no mass movement has been observed in the study area. The study area is included in the current map of Malatya province with a scale of 1/1000. Although the study area is not located in any disaster area, there is no limitation for building. There is no construction around the parcel. Figure 2 shows the building block and view of the surrounding area where the study was carried out (TCDD, 2023).

Especially considering the topographic change and current geological structure of the region after the earthquake, it has been seen that a transition route should be arranged against a possible flood risk. In the HEC-RAS calculation, a total of 33 cross-sections were considered from downstream to upstream between Km:0+000.00 and Km:0+600.00. Additionally, the bridge section at Km: 0+175.00 was also defined. Cross-section images and contour lines were obtained on the 1/1000 scale map of the study area with the AutoCAD Civil 3D program. The bridge in the software was designed to have 6 gaps and a width of 26 m. With these cross sections obtained, one-dimensional flood hydraulic analysis of Eskiköprü Stream was carried out with the help of the HEC-RAS (Hydrologic Engineering

Centres River Analysis System) program. Considering the areal changes of flood damages due to different flood values, the elevations at which the upper surface of the water reaches the Q_{100} flood recurrence flow rates in the natural bed of the existing stream were determined. According to the "Flood and Sediment Control Regulation", the calculation was made by taking into account the 100-year recurring flood flow rate (DSİ, 2019). Flood recurrence flow rates for the study region were obtained from DSI 9th Regional Directorate. These flow rates were calculated as flood flows by using the DSİ Synthetic Method. Synthetic methods are selected according to the size of the precipitation areas. In areas with a drainage area of up to 1000 km^2, the DSI Synthetic Method is widely preferred in our country. In this study, the drainage area is about 1000 km^2. Especially DSI recommends other public institutions to make calculations with this method for structures such as bridges and similar structures to be built on streams.

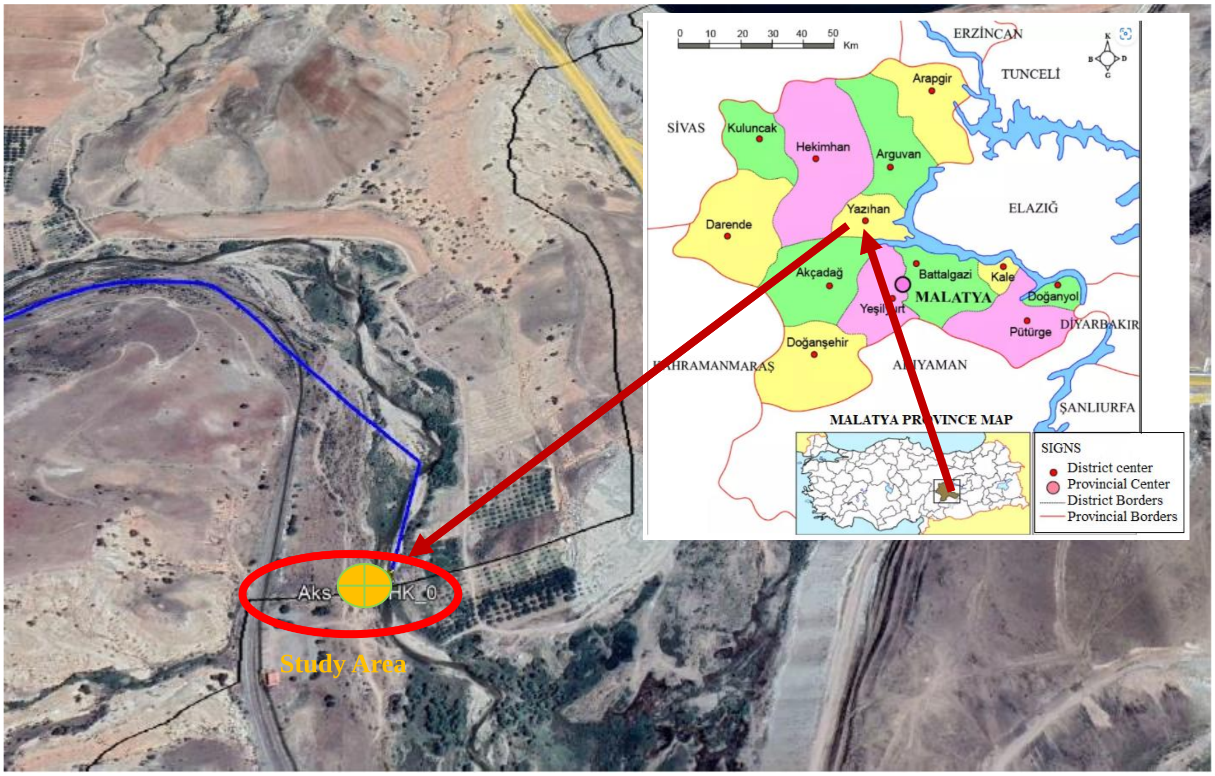

Figure 2. Building block and view of the surrounding area of the study.

2.2. DSİ synthetic method

DSİ synthetic method is generally used in scientific studies for drainage areas up to 1000 km^2. Larger basin areas are divided into smaller sub-areas and separate hydrographs are drawn for each and the delayed hydrographs are superimposed according to the section separated in the drainage area (Yüksel et al., 1999). Since the unit hydrograph used in this method is produced based on 2-hour rainfall, the unit hydrograph peak time Tp should not be less than 2 hours. This method should not be used if the Tp is less than 2 hours (DSİ, 2004; Sönmez et al., 2017). In the DSİ synthetic method, the flow efficiency (q_p, lt/sec/km^2/mm) that a 2-hour heavy rainfall will bring from the unit area can be calculated as in the equation below.

$$E = [(L.L_c)/\sqrt{S}] \quad (1)$$

$$q_p = [414/(A^{0,225}.E^{0,16})] \quad (2)$$

When Equations (1) and (2) are examined; L (km) is the stream length, L_c (km) is the distance from the basin center of gravity to the outlet section, S is the harmonic slope of the main stream branch, A (km^2) is the total drainage area and E is the length of the main stream branch. This coefficient is related to the distance of the basin center of gravity to the outlet section and the harmonic slope and is a unitless coefficient. Using the flood efficiency and total drainage area (A) obtained from equation (2), Q_p (m^3/sec/mm), which is the peak value of the unit hydrograph, and unit volume V_b (m^3) for 1 mm of rainfall (h_a) are calculated:

$$Q_p = q_p.A.10^{-3} \quad (3)$$

$$V_b = A.h_a.10^3 \quad (4)$$

With the help of Equations (3) and (4), the unit hydrograph time T is calculated. Due to the units, the T value is found in seconds, but the value is converted to hours.

$$T = \left[3{,}65.\,(V_b/Q_p)\right] \tag{5}$$

After converting the unit hydrograph time (T) obtained in seconds from Equation (5) to hours, T_p, the unit hydrograph peak time, is calculated:

$$T_p = (T/5) \tag{6}$$

After following the above steps respectively, the 24-hour rainfall-time-recurrence values obtained by the Log-Pearsen Type III method are multiplied by the corrected pluviograph values corresponding to T_p and the maximization factor (1.13). The obtained corrected precipitation values are found from the Curve number graph and the flow coefficient values are read. Flood flows with different recurrence values; It is calculated by multiplying the read flow coefficient values and the unit hydrograph peak value.

$$Q = A.K.Q_p \tag{7}$$

The data taken into account for this study area is given in Table 1.

Table 1. Data used for flood recurrence in study area.

Regional Parameters	Values and Units
Rainfall Area (*A*)	1057.40 km^2
Stream Length (*L*)	78.84 km
L_c value	40.56 km
Harmonic Slope (*S*)	0.010
Unit Peak (q_p)	16.48604 $l/s/km^2/mm$
Unit Hydrograph Peak Value (Q_p)	17.43233 $m^3/s/mm$
Unit Hydrograph Peak Time (T_p)	12.20 hour
Unit Hydrograph Time (*T*)	61 hour
Curve number (CNII)	83.0
Curve number (CNIII)	92.5

While carrying out the flood analysis of Eskiköprü (Kuruçay) Stream, firstly 1/1000 scale maps of the flood zone were obtained. A map (ED-50 system) with a width of up to 280 m was studied on the right and left banks of the existing stream bed. With the help of AutoCAD Civil 3D package program, a total of 33 cross sections were taken along the 600-meter route, every 20 m along the route. Cross sections distances were tried to be kept short, especially for the location selection of the bridge cross section. These created cross sections and longitudinal sections were transferred to the HEC-RAS program. Figure 3 shows the images obtained in AutoCAD Civil 3D environment. Based on on-site observations and investigations along the Eskiköprü Stream bed and the stream section characteristics from the field, the roughness coefficient was calculated as follows. The "*n*" Manning friction coefficient in the section was calculated according to the Modified COWAN Method (DSI Format). According to this:

$$n = (n_b + n_1 + n_2 + n_3 + n_4) * m_5 \tag{8}$$

Here, respectively, n is the Manning friction coefficient, n_b is the coefficient that varies depending on the type of material in the section, n_1 is the coefficient that varies depending on the smoothness of the section, n_2 is the coefficient depending on the change in section, n_3 is the coefficient that varies depending on the natural obstacles in the section, n_4 is the coefficient that varies depending on the vegetation in the section, and m_5 is the coefficient that varies according to the meander effect (DSİ, 2016). For this purpose, among the Modified COWAN Method (DSI Format) coefficients suitable values were selected for the study area. While selecting these values, these coefficients were determined by taking into account the observations and investigations made in the study area. Based on the observations and studies made on site along the Eskiköprü Stream bed and the stream section characteristics from the field, the roughness coefficient was calculated as stated in following values. Within the scope of this study, n_b = 0.030 (gravel); n_1 = 0.010 (treeless rock/soil slope) ; n_2= 0.005 (occasionally varying); n_3= 0.000 (negligible); n_4= 0.010 (low) ; m = 1,000 (insignificant) was chosen. When the selected coefficients were written in Equation 8, the coefficient n was found to be 0.055 and was entered into the HEC-RAS software. In addition, flood analysis of Eskiköprü Stream was carried out by entering the obtained hydrological data into the HEC-RAS program.

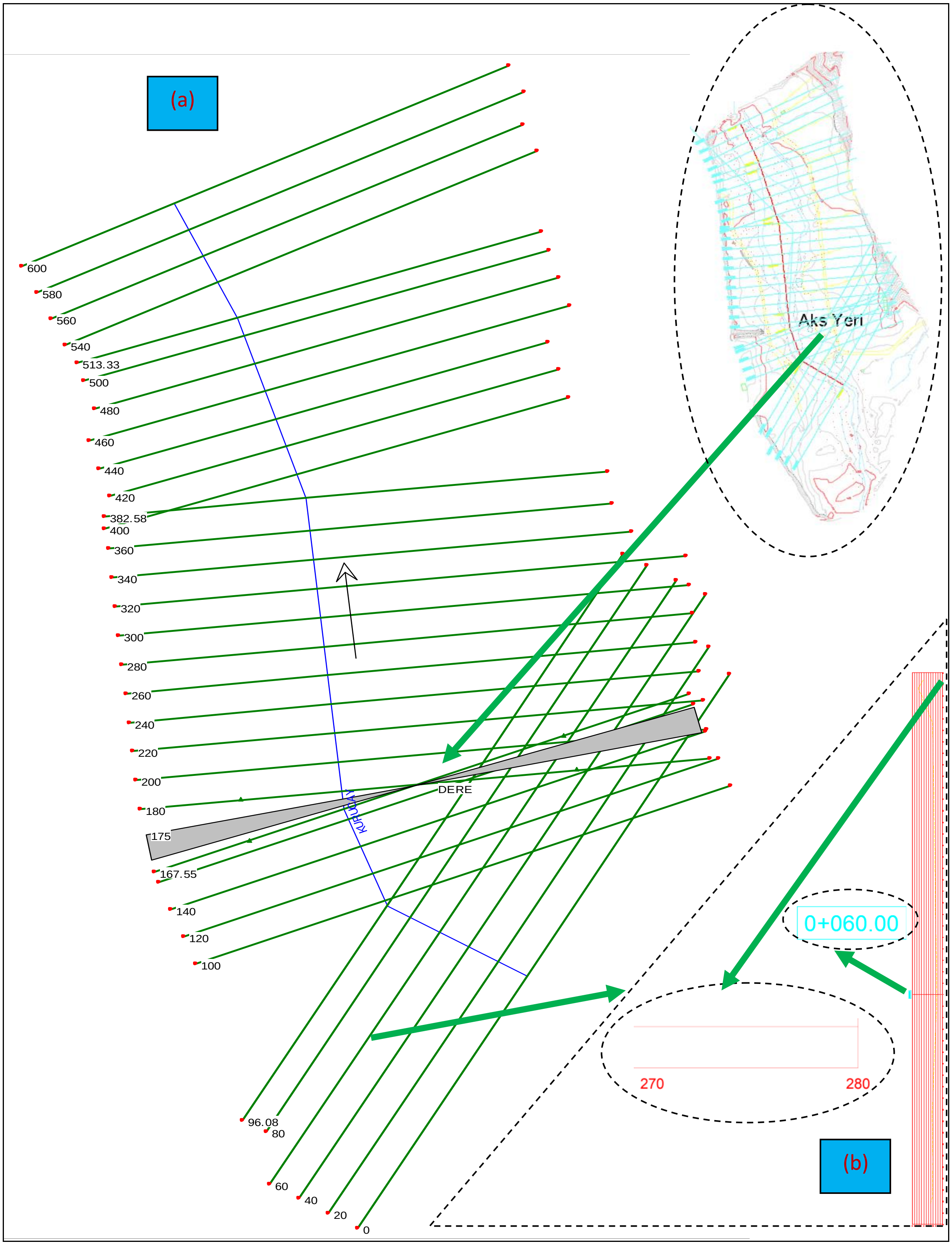

Figure 3. (a) Cross-sections from AutoCAD Civil 3D, (b) Detailed cross-section at Km 0+060.00.

3. Results and Discussion

Within the scope of this study, an attempt was made to create a transition axis for road transportation to Sarsap Station, which was under the responsibility of TCDD 5th Regional Directorate, located within the borders of Yazıhan district of Malatya province. For this purpose, considering the after-earthquake topographic change on the Eskiköprü stream (Kuruçay stream) and its current geological structure, a bridge location was determined and water surface profiles were obtained along the stream in the selected cross-sections to arrange a transition route against a possible flood risk. Water surface profiles were obtained by using HEC-RAS software, including upstream and downstream regions. In the HEC-RAS calculation, a total of 33 cross-sections were inputted into the program from downstream to upstream between Km: 0+000.00 and Km: 0+600.00. Additionally, a bridge section located at Km: 0+175.00 was defined. Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} flood recurrence flow rates were calculated using the DSİ Synthetic Method. Table 2 contains the values of these calculated flow rates.

Table 2. Flood recurrence flow rates according to project rain times.

Recurrence flow rates (m^3/s)	**Project Rain Times (hour)**						
	2	4	6	8	12	18	24
$\mathbf{Q_2}$	22.82	33.81	45.21	51.13	62.09	68.82	81.27
$\mathbf{Q_5}$	32.91	57.32	78.48	88.45	104.95	114.05	131.75
$\mathbf{Q_{10}}$	43.09	77.30	105.28	118.02	138.36	148.14	169.59
$\mathbf{Q_{25}}$	59.11	106.44	143.21	159.52	184.51	194.92	220.72
$\mathbf{Q_{50}}$	72.92	130.36	173.84	192.68	221.14	231.93	260.28
$\mathbf{Q_{100}}$	88.11	155.87	206.11	227.65	259.23	270.22	300.99

For this purpose, by adhering to the basic hydraulic design criteria and the selection of the project flow rate of the bridges to be built on the rivers, the 100-year flood flow rate (Q_{100}=300.99 m^3/s) was taken into account and the calculation was made to ensure (DSİ, 2019). US Army Corps of Engineers Hydrology Center HEC-RAS River Analysis System Model Version 6.4.1 computer program was used for water surface calculation. This mathematical modeling program was free software and it was stated that it provides precise and reliable results for the hydraulic analysis of streams by international standards (Korkmaz, 2022).

The basic calculation process of the software was based on the solution of the one-dimensional energy equation. Energy losses were calculated by friction loss in the application of the Manning formula (Tuncer, 2011). For this study, the *n* coefficient was found to be 0.055 and entered into the HEC-RAS software. Figure 4 shows the water surface profiles of three different sections: bridge downstream, bridge section and bridge upstream. When the water surface profiles of all sections were examined, the Q_{100} flood flow rate easily passed. Additionally, the bridge was defined at Km: 0+175.00 section as having 6 gaps and a width of 26 m.

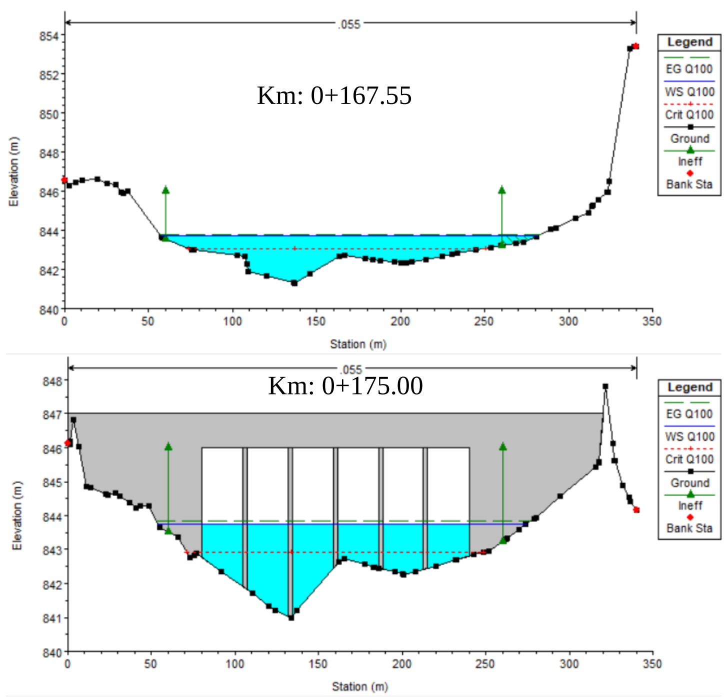

Figure 4. Km: 0+167.55 (upstream), 0+175.00 (bridge) and 0+180.00 (downstream) and water surface profiles of the entire channel.

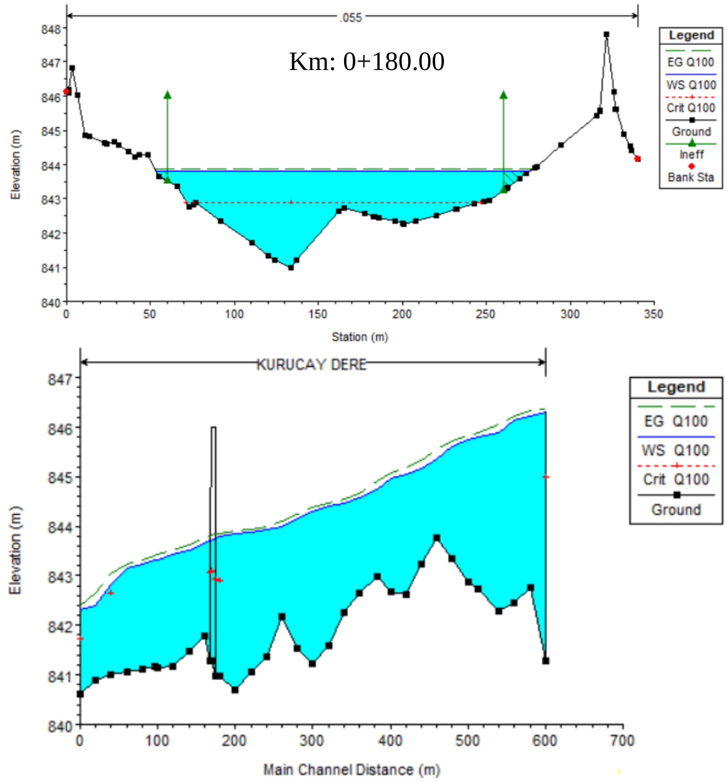

Figure 4 (continued). Km: 0+167.55 (upstream), 0+175.00 (bridge) and 0+180.00 (downstream) and water surface profiles of the entire channel.

According to the results of the waterline calculation in the defined bridge cross-section, the downstream energy level (E.G. Elev.) was found to be 843.83 m, the downstream water level (W.S. Elev.) was 843.76 m and the downstream bottom elevation (Min. Ch. Elev.) was 841.00 m. Accordingly, as a result of the calculations, the energy level under the bridge was calculated as 843.83 m, and the height calculated by adding a minimum of 1.50 m freeboard (H_p) to the water height (h) corresponding to the 100-year recurrence flood flow rate was accepted as the vertical distance that should be between the stream thalweg level and the bridge beam bottom level (DSİ, 2019).

4. Conclusion

In this study, as there was no road vehicle connection before, a bridge structure on the Eskiköprü Stream (Kuruçay) was modeled in the HEC-RAS environment to provide a non-stop connection with the Sarsap Station after the earthquake. For this purpose, 33 cross-sections from downstream to upstream, at 20 m intervals, were defined on the Kuruçay stream. Additionally, Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} flood recurrence flow rates were calculated by using the DSİ Synthetic Method. Manning roughness coefficient (n coefficient) was calculated as 0.055 using the Modified COWAN Method and entered into the HEC-RAS software. A bridge with 6 gaps and a width of 26 m was defined in the software at Km: 0+175.00. Taking all these data into consideration, water surface profiles were tried to be determined according to the Q_{100} flood recurrence flow rate. The reason behind taking into account the Q100 flood recurrence flow rate is that it is a suitable flow rate for bridge crossings to be constructed outside residential areas. When the 33 determined cross-sections and bridge sections were examined, it was seen that the flood flow rate could easily pass through the determined sections. Thus, it can be stated that this study constitutes an important basis for public administrations to select alternative routes after the earthquake. Additionally, it was seen that HEC-RAS software was an important simulation tool that can be used in possible detection of flood, and transition or regulating structures to be built on the stream route with large basin studies.

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