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Evaluation of The Safety of the Way Sekampung Bridge Against Extreme Flooding for the 50 Year Return Period

Burhan Najib Al Rasyid, Ofik Taufik Purwadi, Subuh Tugiono, and Ahmad Zakaria*

Department of Civil Engineering, Engineering Faculty, Lampung University, Bandar Lampung 35141 Indonesia
***Corresponding author: ahmad.zakaria@eng.unila.ac.id

Abstract: This study aims to evaluate the Sekampung Way Bridge, located on the Sumatra Cross Road on the border between Bumi Agung Village in Tegineneng District, Pesawaran, and Mandah Village in Natar District, South Lampung, with coordinates 105 °10’ 33.75 “T 5 °11’ 49.65” S, which is in the process of being rebuilt to improve services to road users. In conducting a bridge planning study, river hydrological factors must be analyzed to consider the flood level and vertical clearance so that the bridge remains safe despite extreme flooding. According to highway regulations, permanent bridges are generally planned with a service life of 50 years. For rivers that do not carry drift, the minimum clearance value was 1.0 m. Therefore, the hydrological analysis was carried out using the Nakayasu HSS method with a Q50 discharge of 426.96 m³/second in 2.7 hours. The results of 1D and 2D hydraulic analysis using HEC-RAS version 6.4.1 show that the elevation of the flood water level with a 50-year re-period is at an elevation of +75.23 m to +75.38 m, while the base elevation of the Way Sekampung Bridge is at an elevation of +79.44 m. Therefore, the clearance of the Way Sekampung Bridge is 4.21 m to 4.06 m, and it can be concluded that this bridge is safe from flood risk with a 50-year re-enactment period, although the potential for flooding around the Way Sekampung River Bridge area is large. This is due to the slope of the river at the location of approximately 2.5%.

Keywords: Hydrology, Hydraulics, HSS Nakayasu, HEC-RAS.

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1. Introduction

Bridges function as links between regions and are very important because they can help ensure the equitable distribution of development and the economy in each region. The Way Sekampung Bridge, located on the Sumatra Cross Road section on the border between Bumi Agung Village in Tegineneng District, Pesawaran, and Mandah Village in Natar District, South Lampung, was rebuilt to improve services for road users. When planning the construction of a bridge over a river, many factors must be considered.

In addition to the structure and bearing capacity of the soil, the hydrological and hydraulic factors of the river must also be considered for bridge planning. It is important to consider the flood face level and vertical clearance to ensure that the bridge remains safe from the potential for extreme flooding [1]. Hydrology is a discipline that studies the existence of water on Earth in liquid, solid, or gaseous forms. It also includes the study of the properties of water, its distribution, and its cycles on Earth [2]. Water that evaporates into the atmosphere will move and undergo a condensation process, form clouds, and then fall back to earth in the form of rain.

Some of the rain is held back by the vegetation, while the rest seeps into the soil. Hydrological cycles describe the movement of water from the ground surface to basins, lakes, and rivers, and then back to the sea [3]. Hydraulic analysis calculates the current capacity of a river by utilizing the planned flood discharge and flood water level profile along the river course being analyzed [4].

HEC-RAS is the most frequently used application in hydraulic analysis. HEC-RAS is an application specifically designed for modeling river flow. The application was developed by the *Hydrologic Engineering Center* (HEC), which is part of the *Institute for Water Resources* (IWR) under the auspices *of the U.S.. Army Corps of Engineers* [5]. According to the Circular Letter of Highways No. 05/SE/Db/2017 concerning Practical Guidelines for Bridge Technical Planning, the minimum vertical free space for bridges is 1.0 m above the lowest girder, considering river flows that do not lead to erosion at the flood water level with a 50-year reinforcement. Therefore, the purpose of this study was to analyze the safety and vertical clearance *of* the bridge. HEC-RAS was used to assess the elevation of the flood water level in accordance with the planned flood discharge and to calculate the *clearance value* on the Way Sekampung Bridge.

2. Methodology

2.1. Time and Place

The study was conducted from April to June 2024. This research focuses on the Way Sekampung Bridge, which is located on the Sumatra Cross Road, right on the border between Bumi Agung Village, Tegineneng District, and Mandah Village, Natar District, with coordinates 105°10'33.75"T 5°11'49.65"S. This study aims to analyze the condition and design of bridges in depth. The location of the study is shown in **Figure 1**, which shows the position of the bridge.

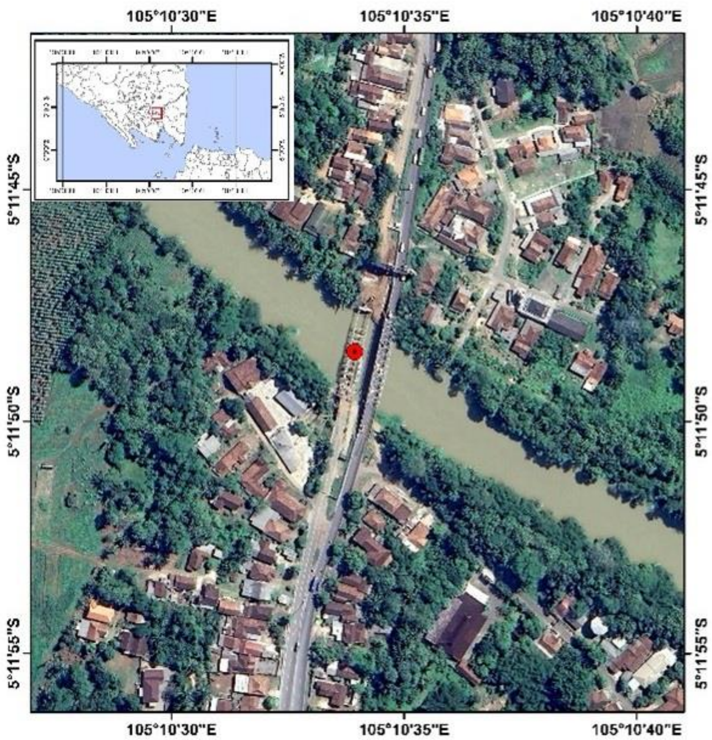

Figure 1. Research Location.

2.2. Tools and Materials

The devices used in this study included a laptop unit equipped with several important software programs, namely Microsoft Excel, Microsoft Office, Geographic Information System (GIS) software, Google Earth Pro software, and HEC-RAS version 6.4.1. The data used in this study included several types, namely digital elevation model (DEM) data obtained from DEMNAS, rainfall data from 2013 to 2023, and river profile data. These data are used for in-depth analysis related to topography, rainfall patterns, and river flow characteristics relevant to bridge studies.

2.3. Data Analysis Procedure

2.3.1 Stages of data collection

Primary and secondary data play a very important role in this study. Primary data were obtained directly from the cross-section of the Sekampung Way River, providing detailed information on the river profile characteristics. Secondary data included a map of the Way Sekampung sub-watershed, rainfall data from 2013 to 2023, and digital elevation model (DEM) data. The DEM data used must be adjusted to the coordinates of the study area, namely UTM 48 S, to ensure the accuracy and relevance of the analysis. It is also known that the slope of the Way River in the village at the location around the bridge is approximately 0.025 or 2.5%.

2.3.2 Hydrological and Hydraulic Analysis

The two main stages of data analysis in this study were hydrological and hydraulic analyses. This process begins with the evaporation of water on the Earth's surface due to sunlight, which then descends into the sea and land in the form of rain, snow, hail, and fog. Plants hold some of the rainwater for a while before it seeps into the soil. Some water seeps into the ground through cracks in the rocks, whereas some water flows on the ground surface as a runoff stream. Examples of visible surface runoff include lakes, reservoirs, and swamps. The hydrological cycle occurs when some of the water on the surface collects and moves to form a river, which then moves towards the sea. This repetitive cycle is known as the hydrological cycle [6].

Hydrological analysis began with the creation of the Way Sekampung sub-watershed. A watershed is an area where all water flows into a river. This area is bounded by the topography of a place, so surface flows form on it rather than below the ground surface as groundwater [8]. The creation of river areas includes mapping and characterizing river areas, including determining area boundaries, calculating area, and identifying rainwater collection points.

The data obtained from this step are crucial for understanding the pattern of water flow along the Way Sekampung River. Once the basic hydrological data are available, the next step is hydraulic analysis. At this stage, the focus was on the behavior of water flow over a given period, including the calculation of maximum runoff used to determine the height of the Way Sekampung Bridge and the Flood Water Surface (MAB) at various replay periods. The average rainfall in a watershed can be calculated using three methods: the arithmetic average rainfall method, Thiesen Polygon average rainfall method, and *isohyet average rainfall* method [7].

The Way Sekampung sub-watershed rainfall catchment area includes six stations with different coverage. Data from these stations were used to calculate the average rainfall using the Thiessen Polygon average rainfall method. This calculation was based on rainfall data from 2013 to 2023. The Thiessen Polygon method allows for a more accurate determination of rainfall distribution by considering the distance between the observation station and the connected area. The data obtained from this calculation are important for further analysis of rainfall patterns and their impact on water flow in the Way Sekampung sub-watershed.

Based on the data obtained, an analysis was carried out on several statistical indicators (parameters) used in analyzing hydrological data, such as the mean, standard deviation, *curtosis* coefficient*, and* skewness coefficient [8]. The data from the calculation of the statistical parameters were then analyzed using frequency analysis. Frequency analysis is often applied in hydrology to predict the magnitude of future extreme flood discharges using a probabilistic approach [9]. Several methods are often used to analyze the distribution of data, including the Gumbel, normal, log-normal, and the last one the Pearson

Type III log distributions. [10]. The results of the calculation of the frequency indicator (parameter) were then compared with the statistical parameter requirements table to determine the match of the data distribution. The requirements for statistical indicators (parameters) for some types of distributions are listed in Table 1 [11].

Table 1. Statistical Parameter Requirements.

Distribution	Requirements
Normal	Cs = 0
	Ck = 3
Log Normal	Cs = $Cv^3 + 3Cv$
	$Ck = Cv^8 + 6Cv^6 + 15Cv^4 + a16Cv^2 +$ 3Ck
Gumbel	Cs = 1.14
	Ck = 5.4
Log Pearson Type III	Any others

Furthermore, the Log-Pearson Type III distribution method was used to calculate the design rainfall. The Log frequency distribution – Pearson Type III is the result of a transformation of the Pearson Type III distribution type, which allows for better calculation of rainfall on data showing significant skewness and kurtosis characteristics. This transformation helps in handling data that do not follow normal distributions and provides more accurate estimates for extreme rainfall [12], and is commonly used to analyze data related to minimum discharge and maximum flood discharge. After applying the Log-Pearson Type III method to calculate the data, the next step was to test the match of the data to ensure the accuracy of the model. Two types of testing data match that are often applied in this analysis are the Kolmogorov-Smirnov test and the Chi-square test. The Kolmogorov-Smirnov test evaluates how well the empirical distribution of the data corresponds to the expected theoretical distribution, whereas the Chi-squared test evaluates the difference between the observed and expected frequencies according to the model's distribution. Both tests are important to ensure that the data obtained accurately reflect the characteristics of the selected distribution and provide valid estimates of rainfall or flood discharge [13].

Rainfall calculations were effectively performed on an hourly basis, starting from the first hour to the sixth hour. Subsequently, a design flood discharge analysis can be performed. Draft flood discharge refers to the maximum amount of flood discharge that is expected to occur over a certain period of timeTop of Form [4]. The flood discharge for each was calculated using the Nakayasu Synthetic Unit Hydrograph (HSS) method, the Nakayasu HSS method was chosen because of its ability to generate flood discharge estimates that are in accordance with the specific hydrological characteristics of the study area. Nakayasu's HSS method utilizes basic hydrological data, such as the maximum amount of rainfall in a given period and the rate of surface flow into the river, to generate a graph depicting the water flow conditions from the beginning of the rainfall, during the flood period, to the end of the flood [14]. Using this method, hydrographic curves close to the real conditions during the flood period can be generated.

$$Q_p = \frac{1}{3.6} \cdot \frac{AR_e}{0.3T_p + T_{0,3}} \tag{1}$$

With, Q_p= peak flood discharge (m^3/det), A = watershed area (km^2), R_e= effective rainfall (mm),
T_p = Flood start time to hydrographic peak (hours), $T_{0,3}$= concentration time (hours)

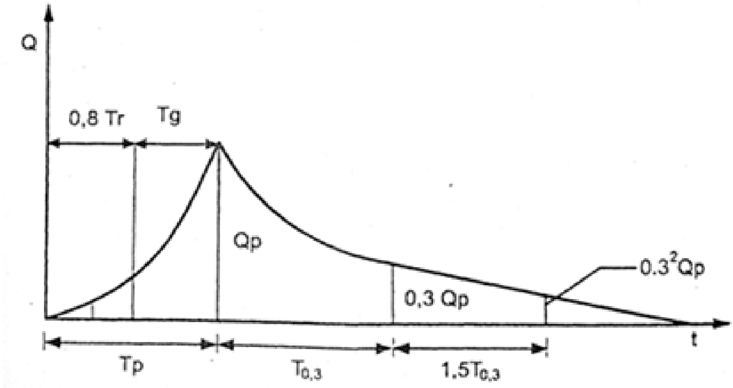

Figure 2. Hydrograph of the Nakayasu Synthetic Unit.

The design flood discharge obtained from the Nakayasu method, with a 50-year re-period, was used as an input in the HEC-RAS application version 6.4.1 for *1D and 2D analyses of unsteady flow*. The vertical clearance is measured from the elevation of the flood water level to the lowest boundary of the bridge girder. The clearance value is determined by considering the type of river and the objects under the bridge [15]. The type of river and the objects under the bridge are important factors in determining the *clearance value*.

3. Results and Discussion

In the creation of the Sekampung Way sub-watershed, GIS-based software was used as the main tool to process and analyze the required geospatial data. The Sekampung Way sub-watershed analysis included six nearby rainfall monitoring stations that were still within the range of the sub-watershed. The six stations included the PH 005 Kemiling Rainfall Station, PH 007 Way Semaj Rainfall Station, PH 015 Podorejo Rainfall Station, PH 033 Natar Rainfall Station, R 002 Wonodadi Rainfall Station, and R106 Argoguroh Dam Rainfall Station. The total area of this sub-watershed was 249.2748 km². A map depicting the area of the Way Sekampung sub-watershed is presented in **Figure 3**.

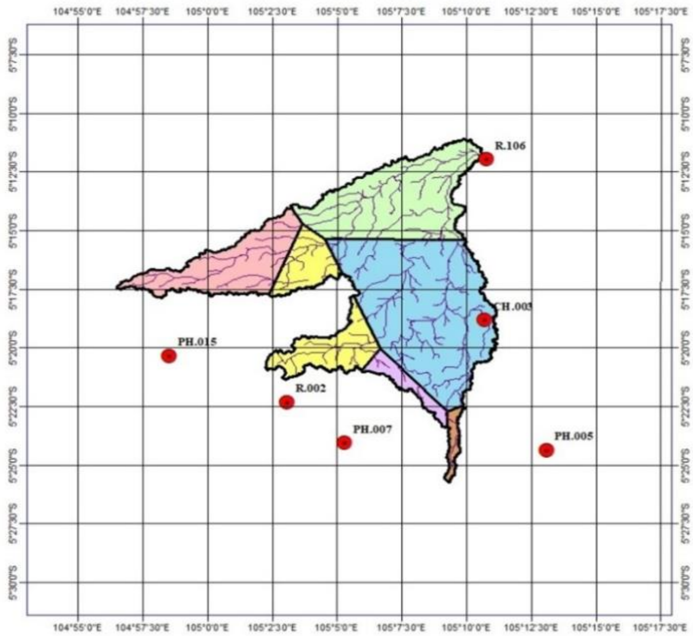

Figure 3. Map of the Sekampung sub-watershed.

In the sub-watershed map shown in **Figure 3**, each rainfall station has its own rainfall area coverage. The catchment areas for each station were as follows: PH 015 Station had an area of 37.5 km², PH

Station 005 covered an area of 3.9040 km², CH Station 003 covered an area of 101.3 km², Station R 106 covered 61.8 km², Station PH 007 had an area of 8.1 km², and Station R 002 covered an area of 36.7 km². Each of these rain catchment areas represents the distribution of the station's rainfall. The percentage data of each station were used to calculate the average rainfall using the Thiessen Polygon average rainfall method. The results of the calculation of average rainfall using the Thiessen Polygon average rainfall method are presented in **Table 2**

Table 2. Average Rainfall.

			Maximum Rainfall (mm)						
No	Year	Date	PH 005	PH 007	PH 015	PH 003	R 002	R 106	$\bar{R}$
1	2014	12-Feb	71	17	100	0	111	113	61.1
2	2015	28-Feb	0	4	60	75	42	1	46.1
3	2016	7-Feb	39	28	19	49	85	78	56.1
4	2017	21-Feb	140	130	118	0	122	107	68.7
5	2018	4-Apr	76	52	105	0	24	85	43.3
6	2019	28-Dec	0	6	1	192	0	10	80.8
7	2020	13-Feb	125	51	94	82	31	58	70.0
8	2021	22-Mar	49	0	0	100	0	2	41.9
9	2022	16-Mar	112	3	90	6	18	84	41.3
10	2023	8-Mar	56	20	14	47	0	34.5	31.3

The results of the calculation of the average rainfall using the Thiessen Polygon average rainfall method were then applied to calculate the statistical parameters required in the test. The statistical parameters were as follows: mean value of 54.1, standard deviation of 15.08, slope coefficient of 0.33, taper coefficient of 3.06, and coefficient of variation of 0.29. The values of these statistical parameters were used to test the distribution of the statistical data. This process allows for the assessment of the accuracy of the distribution model and the deviation of the data from the expected distribution. The results of the distribution test of these statistical parameters are presented in **Table 3**

Table 3. Statistical Test Parameters for the Selection of Distribution Types.

No	Method	Requirement	Value	Information
1	Gumbel	Cs = 1.14	0.33	Not Compliant
		Ck = 5.4	3.06	Not Compliant
2	Normal	Cs = 0	0.33	Not Compliant
		Ck = 3	3.06	Not Compliant
3	Log Normal	Cs = CV^3+3CV	0.90	Not Compliant
		Ck = $CV^8 + 6CV^6 + 15\,CV^4 + 16\,CV^2 + 3$	4.48	Not Compliant
4	Log Person Type III	Any others		Meet

Calculation and frequency analysis and data suitability tests showed that the rainfall data in this study tended to follow the log-Pearson Type III distribution. This distribution was used to estimate the planned rainfall for different repetition periods, with a primary focus on the 50-year repetition period. The Log-Pearson Type III method is effective in capturing extreme rainfall patterns that may occur over time, providing more reliable estimates for planning and risk management. The results of the planned rainfall calculation for the various re-periods are presented in Table 4, in detail.

Table 4. Rainfall Plan Log person Type III

P	Tr	K_{Tr}	R_{Tr}
	Years		mm
0.01	100	2.19	99.7
0.02	50	1.95	93.0
0.04	25	1.69	85.9
0.1	10	1.26	75.6
0.2	5	0.85	66.9
0.5	2	0.03	52.4

Based on the data in **Table 4**, the planned rainfall for the 50-year re-enactment period was 93.0 mm. The planned rainfall was then determined, and the data were distributed gradually from the first hour to the sixth hour. The rainfall distribution shows that in the first hour, the rainfall reached 55.02%, whereas in the sixth hour, the distribution value decreased to 5.90%. Furthermore, the flood discharge of the Nakayasu HSS design for the 50-year re-enactment period was calculated. The results of the calculation of the design flood discharge for various periods are shown in **Figure 4**.

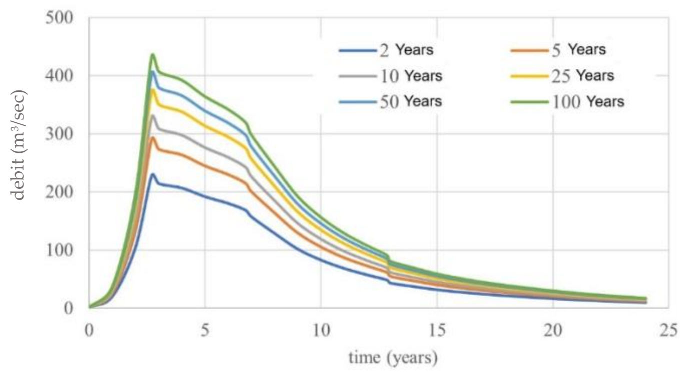

Figure 4. Flood Discharge designed by HSS Nakayasu.

Based on the graph, the planned flood discharge obtained through the Nakayasu HSS method in the 50-year re-enactment period was recorded at 403.74 m³/s. This discharge was expected to occur at the peak of the flood, which occurred at the 2.7th hour. Furthermore, the planned flood discharge data generated from the Nakayasu HSS method were used as input in the HEC-RAS application version 6.4.1. This application is used to simulate flood flows in detail, both in one-dimensional (1D) and two-dimensional (2D) hydraulic analyses. In addition, the height of the water level for the 2 to 100 years of the Way Sekampung River can be seen in Figure 6.

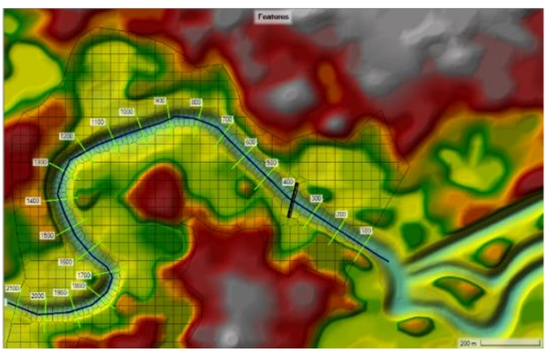

Figure 5. Way Sekampung river from above.

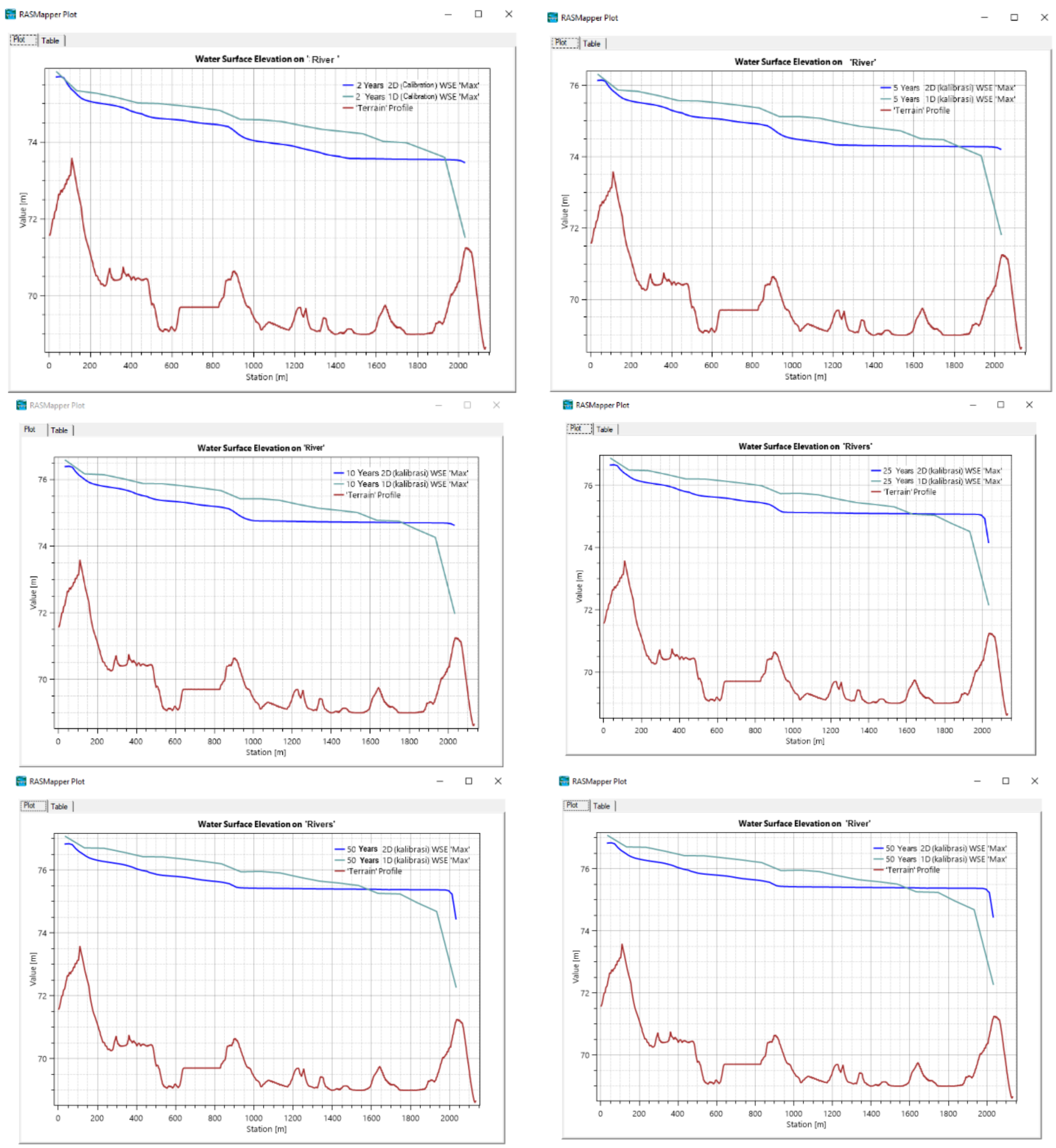

Figure 6. Elevation of the water level on the longitudinal section of the Way Sekampung River.

The HEC-RAS model was applied using two methods: one-dimensional (1D) and two-dimensional (2D) modeling. In 1D modeling, the geometric data consist of a combination of several transverse cross-sections that make up the river channel. In contrast, in 2D modeling, the model is constructed by dividing the area into interconnected cells through its boundaries to depict the flow of the river in detail. The purpose of applying these two methods was to compare the simulation results of the HEC-RAS software in 1D and 2D formats and to analyze the *clearance* of the Sekampung Way Bridge more comprehensively. The results of the 1D and 2D HEC-RAS analyses for flood discharge for the 2 to 100-year redesign period are presented in the figure below:

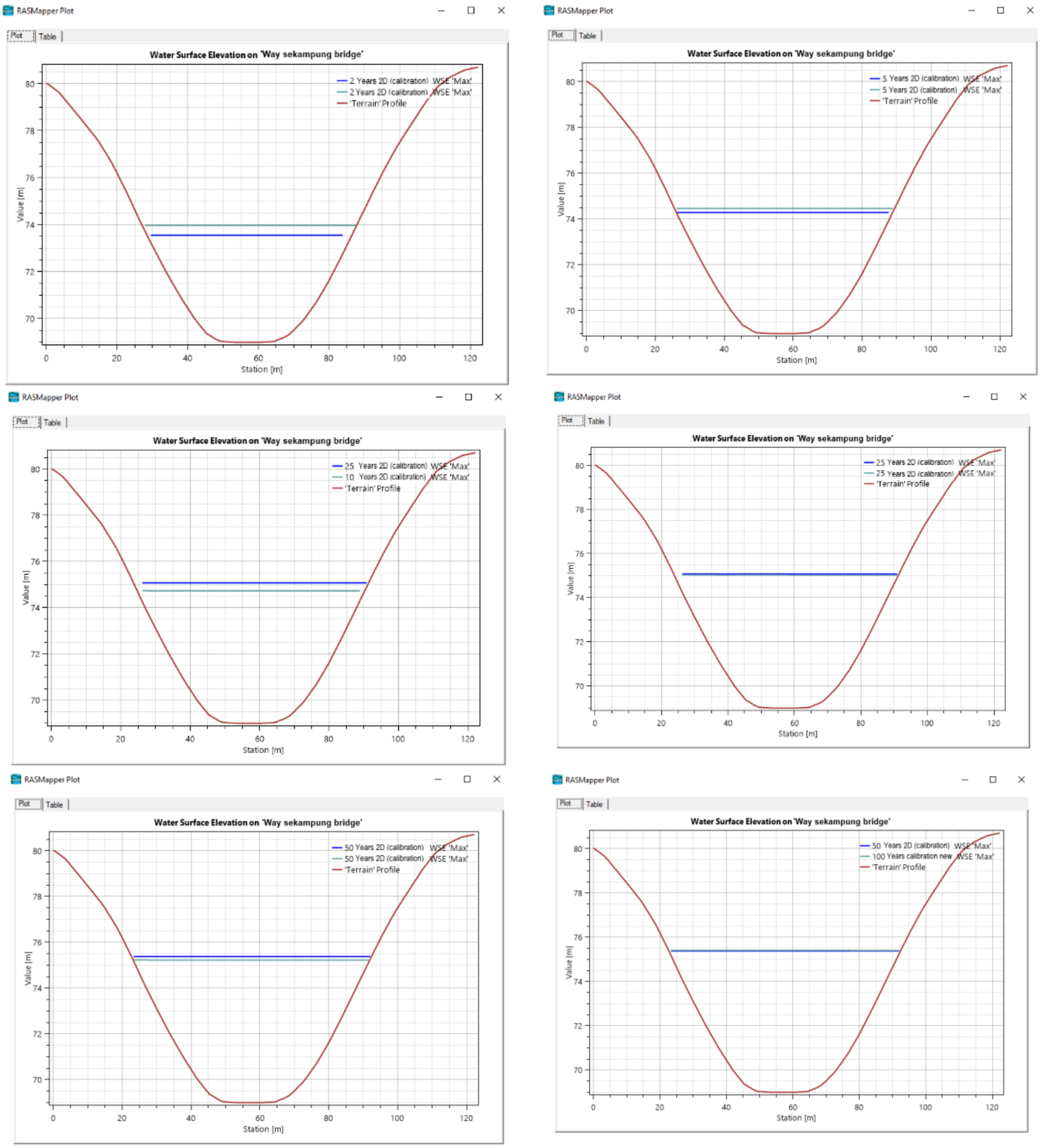

Figure 7. The flood-water level is repeated for a period of 2 to 100 years.

Hydraulic analysis using HEC-RAS v 6.4.1 for 1D and 2D repetition periods of 2 to 100 years can be seen above. The results of the HEC-RAS v 6.4.1 analysis with 1D analysis resulted in a flood water level of +75.23 m, whereas the flood water level in the 2D analysis reached a height of +75.38 m. The lowest girder of the Sekampung Way Bridge is at an elevation of +79.44 m. A 50-year clearance analysis using HEC-RAS 1D yielded a *clearance* value of 4.21 m, whereas *a clearance* analysis using HEC-RAS 2D yielded a *clearance* value of 4.06 m. The results of the HEC-RAS 1D and 2D analyses show that the vertical clearance (*clearance*) of The Way Sekampung Bridge is in the safe category and can withstand the flood discharge of the 50-year redesign period, even though the slope of the Way Sekampung River around the bridge location is 2.5% or less than 5% [16]. This slope condition has sufficient potential for flooding around the Way Sekampung River Bridge area.

4. Conclusion

Based on the results of the hydraulic and hydrological analysis study of *the clearance* of the Way Sekampung Bridge on the Way Sekampung River, Pesawaran Regency, the following conclusions were drawn: The results of the flood discharge analysis designed for the 50-year re-period using the Nakayasu Synthetic Unit Hydrograph method showed a peak discharge value of 426.96 m^3/s, which occurred at a peak time of 2.7 h. In the analysis using HEC-RAS 1D, the flood water level was recorded at +75.23m, whereas the HEC-RAS 2D analysis resulted in a flood water level elevation of +75.38 m. The results of the analysis using these two methods show that the clearance of the bridge is in the safe category. The base elevation of the bridge girder is +79.44m; therefore, the *minimum measured bridge clearance* is 4.06m. Considering the minimum distance of vertical clearance set at 1 m, this *clearance* value is still safe or meets the necessary safety standards.

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