Bathymetric Survey for Estimating the Local Scour at Suramadu Bridge

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Abstract: The Suramadu Bridge is the longest bridge in Indonesia, located at Madura Strait causes an increase in the speed of ocean currents as well as obstacles to seawater flow acceleration of ocean currents due to the reduce of the wet cross-sectional area of seawater flow. This influence cause changes in the seabed bathymetry along the Suramadu Bridge and the potential for local scouring on the bridge foundation. In dangerous stage of scouring, can affect the stability and carrying capacity of the foundation structure under the bridge. The Suramadu Bridge has operated since 2009, has been almost 10 years, and bathymetric surveys is needed to ensure the actual conditions on the seabed under the Bridge. The purpose of the bathymetric survey activity is to obtain the latest bathymetric data and the scouring patterns arround the main pillar (P46 and P47) of the Suramadu Bridge. The Bathymetric Survey method used are SBES and MBES. The first Bathymetric survey was obtained at the year of 2016 since the bridge had operated, shows that the scouring was indicated at the main pillar the increase is about 7 – 8 m. Based on the bathimetric survey data of the 2017, shows the scouring is increased is about 1 meter below the result of bathymetric survey of 2016 at the seabed in the main bridge.

1 BACKGROUND

Many bridges around the world failed or damaged because of extreme scour around piers and abutments. Any constructed bridges must be continuously monitored for any changes in the structure of the bridges that usually focus on the changes of the soil in the area of the bridges constructed. The typical changes can be seen is from the bridge scouring or in this case (Akib, 2011).

Suramadu Bridge is located in the northern part of East Java Province, Indonesia. With an overall length of 5.4 km, it spans Madura Straits and connects Surabaya and Madura Island (Jatnika et al, 2006).

Suramadu Bridge in Madura Strait reduces the wet cross sectional area of sea water, increase the ocean current speed and acceleration. The seabed along Suramadu Bridge can be change after more than 10 years after the last study of bathymetri in 2005.

Scour is a natural phenomenon caused by the erosive action of flowing water on the bed and banks of alluvial channels. The local flow around a hydraulic structure such as a bridge pier or abutment is associated with an enhanced sediment-carrying capacity, such that scour may occur near a structure even when there is no transport of sediment away from the structure. At a bridge site, scour around bridge piers or abutments may lead to reduced support and hence constitute a potential catastrophic hazard (Masjedi, 2010).

Scour is local lowering of streambed elevation that takes place around structures that are constructed in flowing water (Akib et al, 2014). Local scour is the removal of sediment from around bridge piers due to flowing of water. A large amount of local scour is dangerous to the bridge piers and causes the structure tend to collapse and loss of life without any warning (Ahmad et al, 2016).

Local scour around a bridge pier is largely depending on the shape of the bridge pier and how the design is fashionable from the view of construction. Local scour is a complex phenomenon which depends on the discharge, depth of flow, geometry of the pier and type of sediment particle (Roy, 2017).

Scouring depth assessment for Approach Bridge and Main Bridge of Suramadu Bridge for a 20-year return period carried out in 2005 for pier foundation P37 - P56 by Yu (2005) from the Department of Hydraulic Engineering of Tsinghua University Figure 1 and Table 1. In 2016 was the first study of Bathymetri on Suramadu Bridge by Bathymetry Consultans was hired by Ministry Of Public Work

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and Housing, and the result was the local scouring 7 – 8 meters at the main pilars (P.46 and P.47). So, that to ensure that the scheme of local scouring not damaged the bridge, in 2017 the survey of Bathymetry was continued by Bathymetry Consultans was hired by Ministry of Public Work and Housing.

The location of activities was along the Suramadu Bridge corridor and around the main pillar (P46 - P47) with a corridor width of 500 m to the left and right of the bridge. Conduct a detailed bathymetry survey along the Suramadu Bridge corridor and around the main pillar (P46 - P47) with corridor width of 1 km.

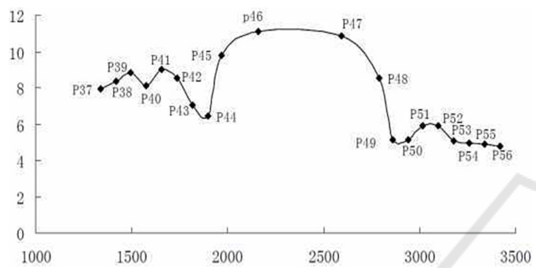

Figure 1: Maximum Scouring Depth on Pier 37 - Pier 56 of Suramadu Bridge for a 20-Year Period Based on 2005 Study Results.

Table 1: Scour depth at major piers under tide with 100-year return period.

Pier Number	Scour depth (m)	Pier Number	Scour depth (m)	Pier Number	Scour depth (m)	Pier Number	Scour depth (m)
P37	8,35	P42	8,94	P47	11,36	P52	6,16
P38	8,79	P43	7,41	P48	8,9	P53	5,28
P39	9,27	P44	6,7	P49	5,34	P54	5,19
P40	8,88	P45	10,2	P50	5,35	P55	5,09
P41	9,42	P46	11,5	P51	6,17	P56	4,99

The purpose of the bathymetry survey activity is to obtain data on the latest bathymetry conditions and scouring patterns in the main pillar of the Suramadu Bridge. In addition, this paper gives recommendation and mitigation if needed. Protecting the bridge piers against scour is a crucial step to preventing bridge failure because there is a close relationship between bridge failure and scour at bridge foundations (Tang et al, 2009).

2 METHOD

2.1 Data Collection

Bathymetry is a method or technique in determining sea-depth or seabed profile from the result of sea-depth analysis (Anugroho et al, 2017). From late 2017 the survey using Single Beam Echo Sounder (SBES) and Multi Beam Echo Sounder (MBES). Survey location along Suramadu Bridge with corridor width of 1 km (500 meters to the right and left side of the bridge). Tide measurements carried out at these locations used for correction when carrying out bathymetry measurements.

Data processing of multibeam depth survey results was carried out using Qinsy software and single beam echo sounder was processed using Hydro pro navEdit and Terramodel software. The License of the software was licensed to Bathymetry Consultant that hired by Ministry of Public Works and Housing. And the Author was a part of Bathymetry Consultant Members.

2.2 Determination of Bench Mark (BM)

This survey started with data collection. The first data in this study is determine of Bench-Mark (BM) points as measurement reference points that represent the bridge spans and survey corridors. Mapping changes in seabed elevation along the Suramadu Bridge, especially in the area around the bridge foundation.

The navigation system used to determine the position of moving objects such as ships when conducting bathymetry surveys known as DGPS (Differential GPS). This differential correction can either be a pseudo range correction (such as RTCM SC-104) or coordinate correction. With differential correction, the coordinates obtained have relatively higher horizontal position accuracy compared to the absolute method (Abidin, 2000).

2.3 Bathymetry Survey

According to IHO (International Hidrographic Organization), the bathymetry survey is "measured or charted depth of water or the measurement of such depth". Tides also affect the survey due to sea level variations, so tidal observations needed to reduce the results of the survey on the dynamics of the seawater (Rinaldy et al, 2014).

Sounding is one of the methods of determining depth using the principle of the reflection of an aquatic wave (Qhomariyah and Yuwono, 2016). The device used for this activity is echo sounder. The using of this device is an indirect measurement of depth by measuring the travel time of acoustic wave pulses emitted by Transducer (Figure 2).

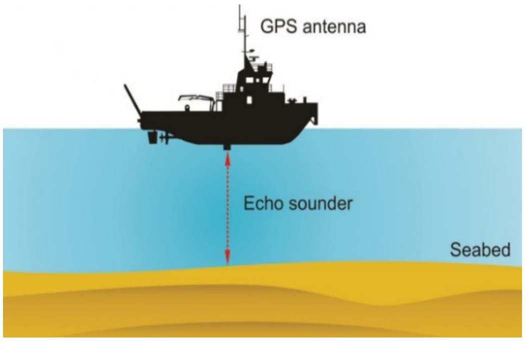

Figure 2: Bathymetri Measurement.

Bathymetry surveys use a combination of Multi-Beam Echo sounder (MBES), is a survey equipment for areas > 3 m deep and Single-Beam Echo sounders (SBES) for areas < 3 m deep with 100% coverage for locations near bridge foundations. Using Real Time Kinematic (RTK) Global Positioning System (GPS) equipment.

Bathymetry surveys carried out using a combination of Single beam Echo sounder (SBES) and Multi beam Echo sounder (MBES) equipment. Furthermore, SBES and MBES work methods and work principles explained in the following sub-chapters:

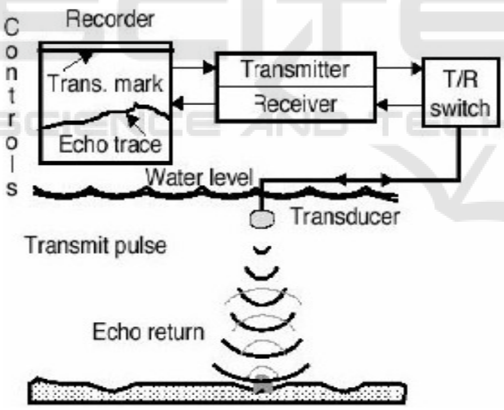

Figure 3: Echo Sounder Working Principle.

Acoustic waves with a frequency of 5 kHz or 100 Hz will maintain their intensity loss to less than 10% at a depth of 10 km, while acoustic waves with a frequency of 500 kHz will lose their intensity at depths of less than 100 m. The principle of this method is distance measurement by utilizing acoustic waves emitted from the transducer (transmitter). A transducer is a part of an echo technology device that converts electrical energy into mechanics (to generate sound waves) and vice versa. Acoustic waves travel through the water to the seabed and reflected back to the transducer (received by the receiver).

Bathymetry measurements influenced by the dynamics of seawater media in the form of tides, making it very difficult to determine the same object at different times. Thus on the measurement of the depth of the seabed it is necessary to do three measurements at the same time, namely the measurement of the depth, the measurement of the position of the depth measuring instrument and the measurement of tides.

2.4 Determine of Point Control

The control points used in the bathymetry survey activities along the Suramadu Bridge were determined using BM VKS2. The use of this control point is intended as a verification point for Differential GPS that is used as a horizontal positioning system or navigation during the survey. Here are the results obtained.

Point Name : BM VKS2
Stipulated by : BPPT
Location Point : Tambak Wedi Surabaya
Geodetic coordinates
WGS 84
Latitude : 7 ° 12 '29,201 "S
Longitude : 112 ° 46 '40,130 "E
UTM Zone (Zone 49S)
East : 696303,803
North : 9202862,814
Point Condition: Good

Verification of the coordinates obtained from the VSPS Hemisphere VS330 positioning system is carried out against the BM VKS2 Benchmark coordinates located on the west side of the Suramadu Bridge in Tambak Wedi. Verification was carried out on September 13, 2017 before the start of water depth measurements.

This verification is intended to ensure that the position system used, including the geodetic parameter system entered in the navigation software is in accordance with the coordinate system and the position value of the coordinates of the control points. If the difference between the coordinates is more than the tolerance required, then the equipment used must be replaced or calibration must be repeated while ensuring that there are no wrong parameters in the software used.

The DGPS antenna is placed above the existing control point, then the coordinates obtained from the position of this antenna are recorded in the navigation software that is used for approximately one hour with an observation interval every 5 seconds (Figure 3 and 4). The coordinate data obtained are then averaged and the results are compared with the coordinates of the existing control points.

Figure 4: Determine Point Control.

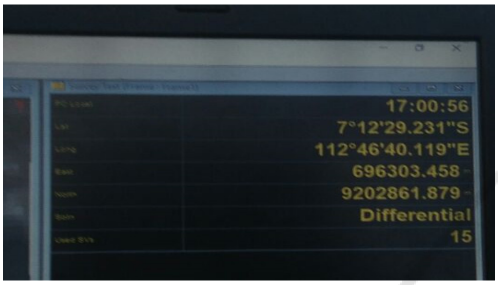

Figure 5: Output of Determine Point Control.

2.5 Singlebeam Echosounder

Single beam echo sounder is a measurement device that uses a single beam as the sender and receiver of sound wave signals. The working principle of SBES is to use the principle of measuring the phase difference in pulses, which is calculating the time difference from the time of the emission and reception of the acoustic pulses. SBES is also quite accurate, where SBES is able to provide accuracy to 0.1 meters at depths of less than 100 meters (Lekkerkerk et al, 2006).

Bathymetry systems using a single beam generally have an arrangement: a transducer (transmitter/ receiver) mounted on the hull or the bearing side of the ship. This system measures the depth of water directly from the inquiry vessel. Transmitter mounted on the hull sends acoustic pulses with high frequency contained in the beam (sound waves) directly down the water column. The receiver will capture acoustic energy emitted from the transmitter.

The data obtained from the process is the time interval the waves begin to emit and the waves received again, so that the depth data obtained by the recording device is a function of the time interval. The process described in the equation (Poerbandono et al, 2005):

$$d = ½ (v\Delta t) \quad (1)$$

Where :
d : see water level (m)
v(t) : sound wave velocity (m/s)
Δt : interval (s)

Transceiver consists of a transmitter that has a function as a control of the wavelength of the emitted pulse and provides electrical power for a given frequency and the receiver receives repeatedly reflected waves at high speeds, up to the order of the speed of the millisecond. Continuous water depth recording from under the ship results in a high-resolution depth measurement along the surveyed lane.

The single beam echo sounder used to make 3D combined with the physical surface of the base location, the physical surface of the seabed location, which used to conduct preliminary surveys before using multiband sonar. Single beam echo sounder consists of two types, namely:

a. Single frequency is a single echo sounder that uses only one frequency, namely high frequency.
b. Dual frequency is a single echo sounder that uses two frequencies, namely high frequency and low frequency. High frequency provides more accurate depth in relation to shipping safety, while low frequency is able to penetrate into the seabed mud deep) so it is not safe for shipping.

The frequency range used in this system according to the WHSC (Woods Hole Science Centre) Sea-floor Mapping Group operates the frequency range from 3.5 Hz to 200 kHz. Single beam echo sounder is relatively easy to use, but this device only provides depth information along the track line traversed by the ship. This activity the use of Single beam Echo sounder (SBES) for areas that covered by Multiband Echo sounder (MBES) because, the ship is less than the minimum MBES operation.

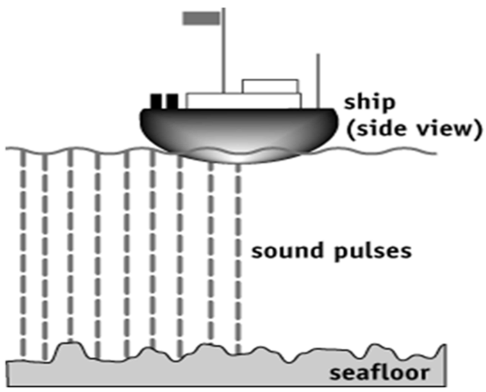

Figure 6: Bathymetry SBES Method.

Correction for bathymetry measurements by the SBES method with the following equation:

$$D = Du + s - h + BC \quad (2)$$

Where :
D : *definitive of hight*
Du : *echosounder water level measuring*
s : *transducer*
h : water level hight
BC : *barcheck correction*

Figure 7: Echo sounder SBES Filed Survey.

2.6 Multibeam Echosounder

Multi beam Echo Sounder (MBES) is a used in seafloor mapping alng with a Single Beam Echo Sounder (SBES). MBES can measure a wider range of water depths and can acquire high resolution images simultaneousley through the beamforming process. (Jung et al, 2017).

Multi beam sonar (MBS) technology developed to examine in detail large stretches of the seafloor surface, providing accurately positioned and excellent 2-D and 3-D images of features as small as a few centimetres or covering areas as large as hundreds of square meters (Stanley et al, 2011).

The principle of operation of this device based on the sound beam (beam) that emitted and reflected directly toward the seabed, and captured again through sensors that are on the MBES device. The detection algorithm on the seabed, to determine the depth and distance of the transversal, calculates the two-way propagation time between sending and receiving. Multi beam Echo sounder can produce bathymetry data with high resolution.

Unlike the side, scan sonar beam pattern that owned by MBES it widens and crosses the hull. Each beam emits one sound pulse and has its own reception. When the ship moves, the MBES sweep results in an area of the seabed surface area (Moustier, 2005).

The transducer contained in the multi beam sonar consists of a series of elements that emit sound pulses at different angles. Usually only one beam is transmitted but it produces a lot of reflected energy from each of the transmitted sound pulses. The ability of each transducer element to reclaim the reflected sound pulse depends on the calibration method of the ship's motion applied.

This MBES has excellent accuracy in measuring depth. In addition to having excellent accuracy, the advantage of using this MBES is a wide range of measurement areas (Moustier, 2005). Coverage of the seabed area that surveyed by ships using multi beam in one sweep is called swath. The swath width for each type of multi beam echo sounder can vary.

The principle of MBES is roughly the same as measurement devices that use acoustic waves, such as SBES and sonar side scans, which is simply by emitting acoustic waves through its reflected wave transmitter.

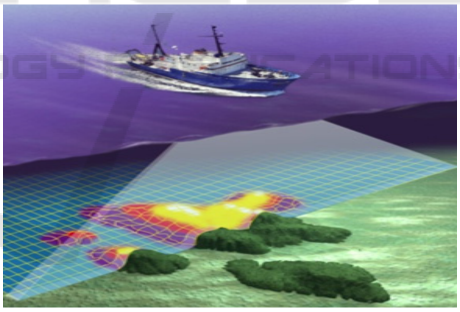

Figure 8: Bathymetry MBES Method.

Then measure the time difference between the waves when the initial emitted until the reflection of the wave is captured again by the sensor. With the previously determined speed of sound propagation in the study area, so that it can be calculated the depth of the seabed.

Transducer configuration is a combination of several projectors arranged like an array (matrix). The projector is part of the MBES transducer which functions as a channel to emit acoustic pulses towards the seabed. All acoustic signals from all directions reflecting objects on the seabed will be received again by the hydrophone array. All acoustic signals will be received by each hydrophone simultaneously with a difference in time of reception of 4/3 to 8/3 mill seconds depending on the length and duration of the acoustic signal.

In general, MBES uses interferometric techniques to detect the direction of reflected waves as a function of time. By using the accumulation of acoustic signals received on two separate arrays, an interference pattern will be formed.

Based on the existing relationship a direction will be determined. When this information is combined with distance, depth data will be generated (Sasmita, 2008). The geometrical image of the acoustic waves emitted by MBES can be seen in Figure 7.

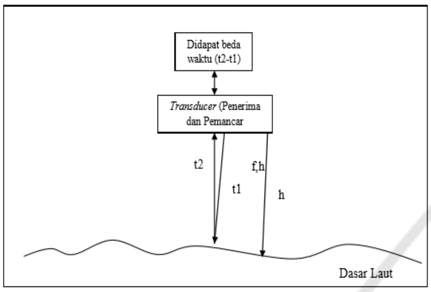

Figure 9: Transducer Mechnisme.

The phase difference of pulses in MBES means that it is a function of the difference between the transmitting and receiving time phases. Then the calculation of the travel time and direction of the beam angle of each stave is determined from the measurement of the MBES pulse phase difference.

Figure 10: Echo sounder MBES Field Survey.

3 RESULT

The results of the bathymetry survey obtained around the seashore can be concluded as follows:

a. The area around Surabaya was surveyed as far as 1.7 km in front of the beach. The area surveyed is in accordance with the planned area in the 500 m corridor to the left and right of the Suramadu Bridge.

b. According 2016 bathymetery data Table 2, that the water sea level was 7 – 8 m.

c. In the results of the cross section overlay data for 2016 with 2017 across the position of Pillar 46 also obtained changes in the form of sedimentation and scouring at certain spots. The part that forms the ridge or embankment tends to occur sedimentation while the lower part occurs scouring. Sedimentation values that occur along cross sections 500 west and 500 east are 0-0.7m per year and the highest sedimentation rates are seen in the cross section of STA 575 and 600. While the scouring value is 0 - 0.9 m per year especially in the STA 700 area up to 825.

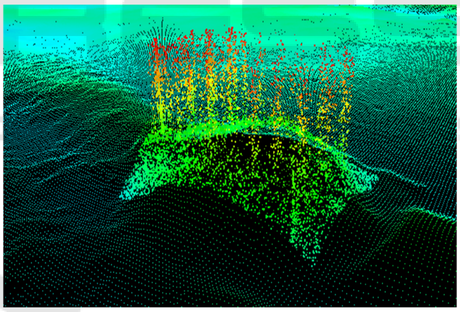

Figure 11: Seabed in P46 Pillar.

d. When looking at changes in the results of the cross section on Pillar 47, the back of the west and east pillars is very visible in the 3D image as shown below, where changes occur in sedimentation at the top of the embankment and scouring at the bottom of the embankment such as dark appearance on the underside of the embankment. The value of this change varies with the sedimentation value of 0 -1 m per year as seen in the cross-section and sedimentation 0 - 1.1 m per year.

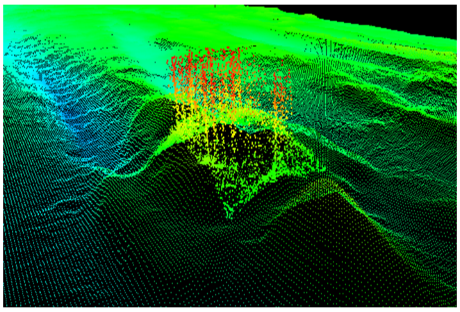

Figure 12: Seabed in P47 Pillar.

Besides the seawater depth map, from measurements with Multi beam echo sounder, you can also see the profile of the seabed surface around Pillars P-46 and P47. The condition of the profile seen in the 3D image below.

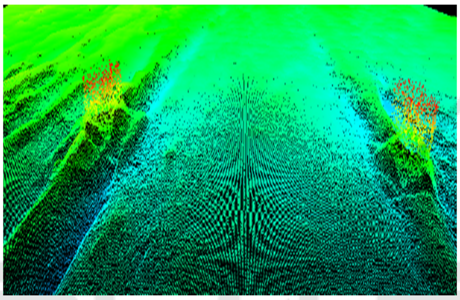

Figure 13: 3D Image Sea bed in Main Bridge.

Table 2: Bathymetry Data.

No. Of Pillars	Preliminary data	Design	2016	2017
46	-19,995	-31,495	-27,495	-28,395
47	-15,600	-26,960	-23,100	-24,200

From the table above presented in the graph, in Figure 13. From the data obtained from preliminary data, bathymetry survey data in 2016 and 2017, which can explain that scouring, occurred in the main span until 2016 occurred at 7-8 meters, but in 2017, the scouring has stabilized result 0 – 1 meters.

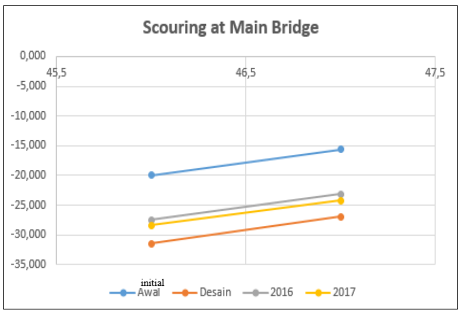

Figure 14: Scouring Graphic in Main Bridge.

4 CONCLUSION

The survey results are also presented in the form Point Cloud with a grid size of 1.0 m. All depth data use the MSL reference so that it will be commensurate when compared to 2016 measurement data that use the same reference. The maximum water depth that measured in the corridor of the survey area is 22.8 m and this depth find to the west of the Main Pillar of P-47.

The water depth of 22.8 m is in the elongated scouring area that occurs along the southern part of the P-47 pillar where this scour is parallel to the sedimentation, which is located side by side in the northern part of the P-47 pillar. Underneath there is a scoring direction to the west of Pillar 47.

The depth of water between the main pillars to a distance of 300 m from the bridge ranges from 15 to 22 m with a composition that is almost evenly distributed and regularly in the West and East. Sedimentation occurs forming embankments longwise to the west and followed on the main pillars that range between 0 - 1 meter form the embankment which can be seen clearly on the appearance of 3D images.

5 RECOMMENDATION

To ensure that the local scouring is not gives damege to the bridge in the further, bathymetry survey has to periodically, that level of local scouring can be estimated as reference to maintenace the bridge.

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