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# THE INFLUENCE OF THE NEW LRT PIER TO THE SEDIMENTATION PATTERN AROUND AMPERA BRIDGE IN MUSI RIVER, SOUTH SUMATERA, INDONESIA

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**ABSTRACT:** Sedimentation rate, which is the most important parameters of the inland water way performance like Musi River becoming one of a major research topic in Indonesia. The influence of additional pier for the new LRT Bridge constructed parallel to Ampera Bridge to the sedimentation pattern of Musi River was discussed in this paper. Currently, as most of the rivers in Indonesia, a complete field data observation of discharge, sediment characteristic is a luxury one to have. That's why mathematical model, supported by eligible limited field measurements for model calibration and verification, is commonly used to predict the above parameters. Hydrometric survey of water level, sediment samples (both suspended and bed sediment), velocity and bathymetry were conducted to get instantaneous field data. Based on the comparison of two bathymetry map with difference periods of measurements, it was found that the sedimentation rate, was different for high and low tide. Tank model of Sacramento and USLE were used to respectively generate synthetic river discharge and soil surface erosion rate. Hydrodynamic model of SMS 8 was used to predict annual rate of sedimentation. Good comparison of the field measurement and SMS model results was found for current and sediment pattern. The maximum sedimentation occurs during the high tide where the backwater was generated by sea intrusion. The New LRT pier increase the impact of river contractions for both maximum velocity around the Ampera Bridge up to 1.5 time and sedimentation rate behind the pier group of the bridges.

*Keywords: Sedimentation pattern, Musi River, Ampera Bridge pier, Field measurements, Mathematical model*

## 1. INTRODUCTION

Musi River is a multi-purpose river for inland waterways, water supply, water tourism, aqua culture, drainage and hydropower so that it become the most important river in South Sumatera, Indonesia (see Fig.1). However, as most of the main rivers in Sumatera Island, Musi River facing also flood, drought, erosion, sedimentation and water quality problems [1][2][3][4][5].

The Ampera bridge is built in 1965 to cross the Musi River in Palembang City (see Fig.1 and Fig.2). This bridge is located approximately 90 km from the estuary where Musi River has about 60,000 km$^2$ of catchment area, an average flow of 2,500 m$^3$/s and a backwater due tide influence. It is then obviously that most of the maximum flood and sedimentation around that bridge occur during high tide period. The highest peak discharge of Musi River occurs between February and March, and the lowest occurs between July and September. There are several stations of discharge and tide measurement along the Musi River but only a few has a long-enough data records. The Musi Riverine in the study area has a mild slope so that it becomes vulnerable to sedimentation and flood. However, lack of recorded sedimentation data drives most of previous study discuss flood more than sedimentation. JICA [4][5] addressing the requirement of mathematical model application to support the prediction of land erosion and river sedimentation due to the lack of field observation on both erosion and sedimentation rate. Previous study of JICA [4][5] conclude that the decreasing navigation capacity of Musi River is caused by sedimentation. Houterman et al. [6] concludes that the river bed rate of Musi river is raised due to more severe floods but further study is needed to quantify its correlation.

Based on two-dimensional numerical model and regardless the influence of sedimentation rate and tides, Amin et al. [2] find that the maximum flood depth in Palembang City caused by 100 years of peak discharges is about 0.00 to 3.24 m and its maximum velocity ranged about 0.00 to 0.83 m/s. Further two-dimensional numerical model (HEC-RAS 5.0) study that use more recent bathymetry data and includes tides influences find that the maximum flood depth caused by 25 years of peak discharge is 1.4 m to 3.0 m [1]. This result shows that flood depth increases significantly compared to previous study, however further analysis is required to distinguish the influences of the tides and sedimentation rate in increasing that flood depth. Sarminingsih discussed the relationship of the increasing flood depth to the increasing flood disaster risk [7]. Furthermore, in 2016, a Light Rail Transit (LRT) is developed across the Musi River just next to the downstream of The Ampera Bridge so that it is important to predict the change of the sedimentation patterns around that Bridges. This paper discusses the result of that prediction which conducted based on field measurements and mathematical model.

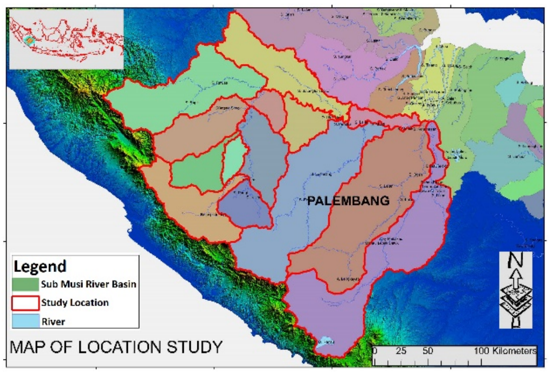


Fig.1 The Musi River catchment area at the Ampera Bridge location (in Palembang City, South Sumatera, Indonesia)

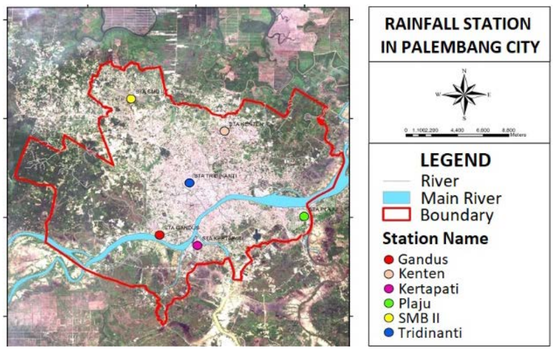


Fig.2 Palembang City, Musi River, Ampera Bridge and rainfall station distribution in the study area

Based on the statistical correlations between a set of hydro-geomorphometric parameters of 30 Italian rivers, Grauso et al. [8][9] suggested a prediction model of Suspended Sediment Yield (SSY) of ungauged river basin that worthwhile to be further improved. Based on the mathematical model study on the scour depth for several bridge pier geometry shape in Nile River, Moussa [10] proposed to use a smallest possible sharp nose pier to minimize the local and contraction scour.

Based on the experimental work on pier scouring, Zarrati et al. [11] conclude that two piers in line with the combination of continuous collars and riprap could reduce about 50% and 60% respectively for the front and rear piers. Furthermore, a combination on two piers in line with independent collars show a better efficiency compare to a continuous collar around both piers. However, it is also shown that efficiency of collars is more on a rectangular pier aligned with the flow than two piers in line. Experiments, however, indicated that collars are not so effective in reduction of scouring around two transverse piers.

## 2. METHODOLOGY

Leo C. van Rijn [12] resume that the suspended sand transport is found to be strongly dependent to the particle size and current velocity. Therefore, the sediment transport will influence the river morphology, sediment carrying capacity, its erosion/deposition rate and its hydraulic stability.

Panos Panagos et al. [13] suggested the use of Slope Length and Steepness Factor (LS-Factor) suported by GIS software based on the high-resolution (25 m) DEM to get a well enough quality result of erosion rate of a very large Catchment Area.

A good result has been achieved by Hogu et al. [14] when using Sacramento model for predicting rainfall run off discharge of a large ungauged catchment area.

Fan [15] concludes that a two-dimension mathematical model calibrated by field measurements data, could give a good enough prediction of sedimentation pattern in the riverine flow under the backwater flow influence. Salim et al. [16] had discussed the important of the erosion rate prediction of the upperpart river for estuary river sedimentation prediction. Gunawan et al. [17] demonstrate the application mathematical model based on neural network methods for river sediment load estimation, however, to achieve satisfied results, this model requires a well record data measurement which is not the case of Musi River data.

Based on previous study and site investigation, JICA [4] concludes in its project research that the source of the sedimentation in Musi River are the soil surface erosion of its catchment area and the river bank erosion of its tributary, however there is no adequate data and analysis results that could be use as referential erosion rate. Formanek et al. [18] conclude in its flood flow numerical model that the most possible maximum velocity is generated around river or channel obstruction. In Musi cases, this might not coincident with highest and or lowest water level as there is a tide influence. Kusuma et al. [19] demonstrate a low Reynold number circulation flow which is one of important flow phenomenon around an obstacle. Kusuma et al. [20] demonstrate the influence of geometry shape of concrete block to the flow dissipation energy around the blockage system but there is no scour depth measurements in its experimental work.

Based on the above discussion and regarding the Musi River condition (physical characteristic, data availability and potential previous research methods), this research was conducted using several mathematical models combined with both secondary data and limited field observation as presented in the following paragraph.

Secondary data such as rainfall, discharge, land use, topography, soil surface types, bathymetry, tides and bridges layout were collected from related stakeholder. Field measurements was also conducted to get several additional data such as bathymetry, tides, flow velocity and bed/suspended sediment samples that required for model calibration and/or comparison study.

The study scheme is presented in Fig.3. As there is no eligible field data measurement of the river hydraulic parameter, the Musi River catchment area was divided into 3 area: the upstream area, the study area and the downstream area.

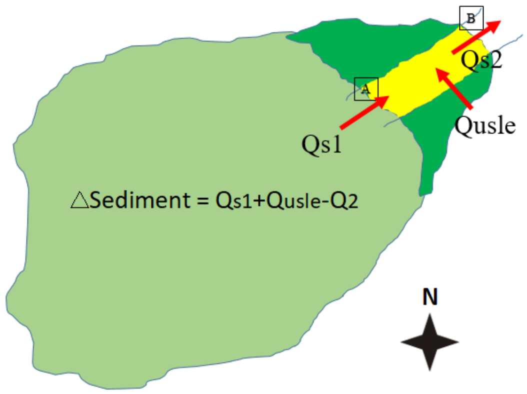


Fig.3 Scheme of evaluation study

There is no data at all in the upstream and downstream area except for hydro-climatology data (daily rainfall, temperature etc.) land use and topography (based on satellite data) and limited (one year in 2008) discharge observation in Lematang River, one of the upper part of Musi tributary. The current field measurements and more detail secondary data available only in the study area. The field measurements (see paragraph below) were conducted to provide initial and boundary condition for the mathematical model work. Meanwhile, secondary data from previous study was used for comparison study.

There are three types of mathematical model that had been used in this study: rainfall- runoff model, soil erosion model and hydrodynamic model. In the first stage, rainfall runoff of tank model of Sacramento (Model SMA-SAC, NOAA) was applied to estimate synthetic discharge of Musi River in the study area. This process is compulsory as there was no adequate/eligible field data of the Musi River discharge in the study area. The reliable rainfall data is taken from BMKG Station in Sultan Badarudin 2 Airport in Palembang (see Fig.2). The calibration model was done using the limited discharge observation data in 2008 of Lematang River which is one of Musi Tributary located in the upper part of the Ampera Bridge. (see Fig.1).

Soil erosion in this study was estimated using A (mean annual soil los, kg $m^{-2}$) based on classic USLE method [21] as follow:

$$\boldsymbol{A = RxKxLxSxCxP} \tag{1}$$

where:

R = rainfall erosivity factor (MJ mm $m^{-2}$ $m^{-2}h^{-1}$)
K = soil erodibility factor (kg h $MJ^{-1}$ $mm^{-1}$)
L = slope length factor
S = slope gradient factor
P = support practice factor.

Sediment delivery ratio (SDR) is usually used to get the net erosion from USLE method. Nevertheless, due to its uncertainties caused lack of data availability, there is still an issue regarding its assessment [8]. Therefore, in this study, we prefer to estimate the net erosion by adjusting USLE calculation to field observation data.

The Hydrodynamic model of SMS 8 was used to predict current pattern and sediment transport of Musi River in the study area.

## 3. RESULT AND DISCUSSION

### 3.1 Secondary and Field Data Analysis

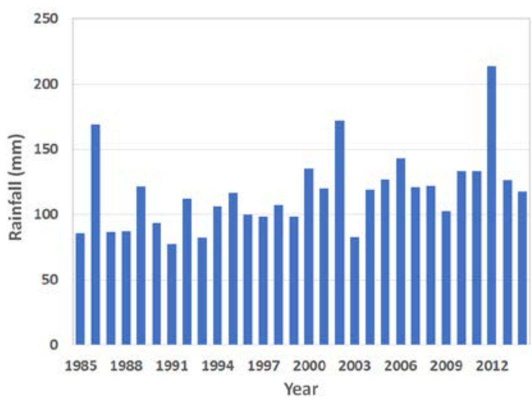


Fig.4 Annual maximum rainfall (BMKG Station)

Based on land used map in 2011, the catchment area of Musi River at Ampera Bridge is covered by paddy fields, plantation, rain forests, mangrove, ponds, small reservoir, housing, industry, mining and swamps. However, in the last two decades, some of the area had been changed into urban area and mining area, so that the erosion rate of that area is obviously already increased.

Based on the above data, the annual maximum daily rainfall recorded at that station from 1985 to 2014 is presented in Fig.4. The smallest maximum daily rainfall of 82.8 mm occurred in 2003 and the largest annual maximum rainfall of 214.1 mm occurred in 2012 based on BMKG.

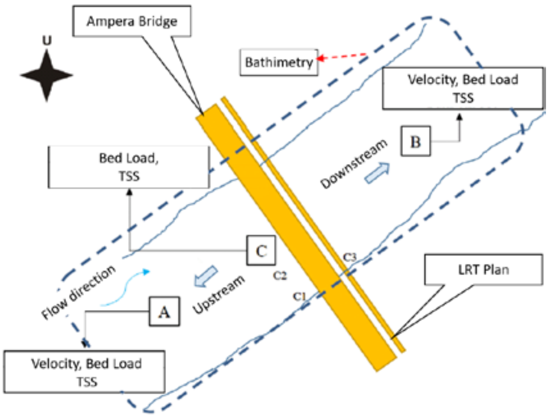


Fig.5 Resume of field measurement scheme and results around the Ampera Bridge, Palembang City

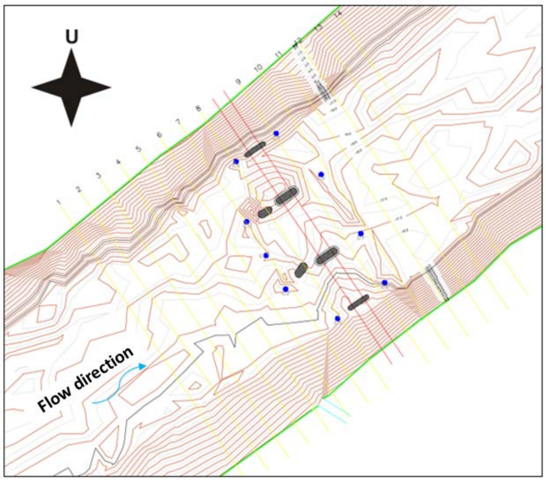


Fig.6 Bathymetry results in March 2016 and topography of study location

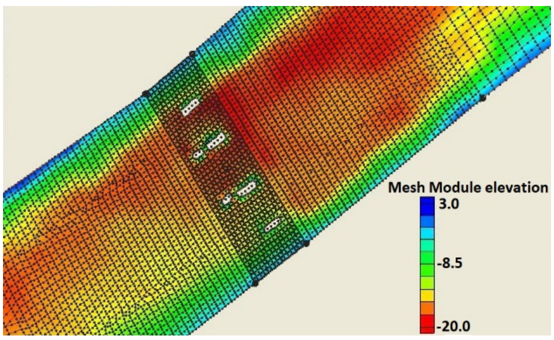


Fig.7 Bathymetry results in November 2016 and mesh modelling in study area without LRT Pier

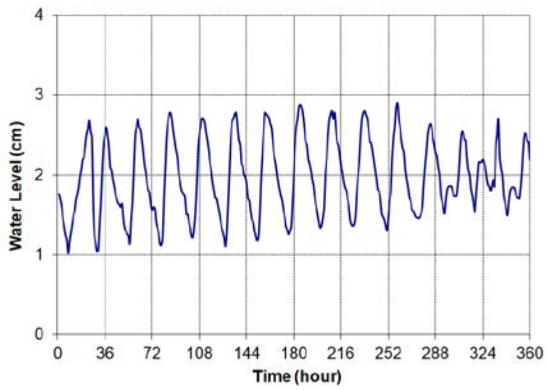


Fig.8 Water level fluctuation in Ampera Bridge under the tide influence

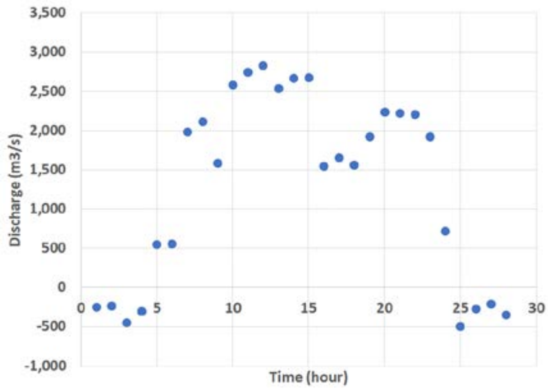


Fig.9 Result of discharge, flow and velocity

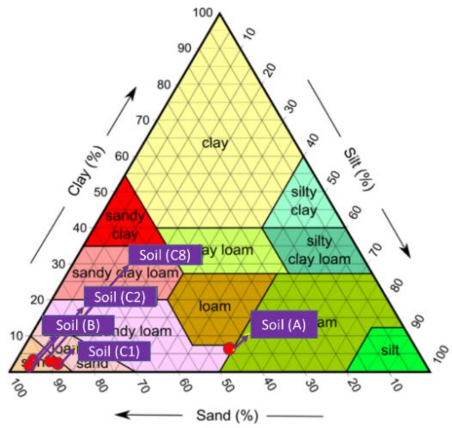


Fig.10 Bed sediment type upon USDA criteria

Field measurement of flow velocity, water level and bathymetry around the Ampera Bridge were conducted in two period of measurement: March and November 2016 (see Fig.5 to Fig.7). The water level was hourly measured at both the upstream and downstream of the bridge. The water level measurement at the downstream part of the bridge was conducted for 15 days to capture the tide influence during measurement's period of November 2016. Flow velocity was hourly measured during 30 hours of the spring tide period influences. Flow direction was identified only for downstream (low tide) and upstream (high tide) direction. River bed and suspended sediment sampling were also taken for the spring tide period influences.

These following paragraphs discuss the above field measurements results (see Fig.5 to Fig.10).

The highest tide range of 1.66 m and the lowest tide range of 0.96 m occurred respectively on November 3, 2016 and November 13, 2016. The average daily time period of tide influence to the water level is about 15 hours. The daily maximum velocity and discharge were observed at 20:00 pm and its minimum was observed at 09:00 am.

There was no lag time of water level between the upstream and downstream side of the bridge. However, 1-2 hours lag time with an irregular pattern of discharge was observed between the two measurement points. The maximum velocity and discharge were observed at 20 pm and its lowest were observed at 11 am Musi river bank was relatively stable so that there is no river bank erosion yield along the study area. The depth of the Musi River varies from + 4.0 m to -20.5 m. The deepest river body was found around the existing bridge pillar. The river depth was changed, especially around the bridge pillars. This change of depth tends to be larger around the left and right outer of bridge’s pillars (see Fig.6 and Fig.7).

The sedimentation rate was identified based on the deviation of bathymetry map of study area resulted from different measurement periods (March 2016 and November 2016).

The discharge budget found positive (outflow to the estuary) which shows the dominance of the discharge of rain fall runoff so that tide intrusion generate only backwater curve to the river flow in the study area. This is very reasonable, since the Ampera Bridge is located about 90 km from the estuary of Musi river in Bangka Strait where the maximum tide is only about 3 m, so that the tide flow is weak enough to completely reverse the existing runoff discharge.

The Structure of Ampera Bridge (especially its pier and abutment) generate a contraction impact to the river flow so that for both low tide and high tide condition, the river stream below the bridges span has the highest velocity, meanwhile the upper part of the Ampera Bridge has a higher flow velocity than that of the downstream part during low tide, and a lower velocity during the high tide.

Based on the grainsize distribution analysis of the bed sediment samples, the bed sediment around the bridge pier at points C1, C2 and C8 were classified as sand. However, the bed sediments at points C3, C4, C4, C6 and C7 were unsuccessfully taken by sediment grab so that it was concluded as silt. The bed sediment in point A and B was classified respectively as sandy loam and sand. Meanwhile, the suspended sediment concentration distributed from point A, B and C respectively 65 mg l, 214.25 mg l and 54.25 mg l for low tide and 23 mg l, 37 mg l and 23 mg l for high tide. The classification of the bed sediment remains the same for high and low tide, but it changes for the suspended sediment.

The increasing of TSS at point B compared to point A and C in the upper part indicated that a very high erosion occurred in the downstream of the bridge pier. This indication was not match to the bathymetry measurements result, therefore, it can be concluded that the suspended samples sediments was exposed to noise from the ongoing sand-mining activity around the area. The bridges contraction influence is significant only during the low tide.

Based on the above analysis the sedimentation rate of the study area was found around 433 $m^3$/day.

## 3.2 Mathematical Model

### *3.2.1 Synthetic Discharge and Erosion Rate*

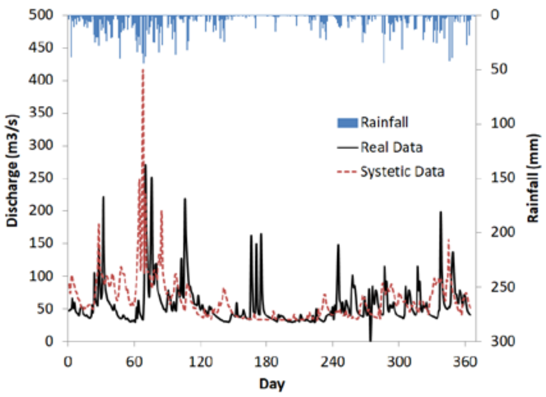


Fig.11 Comparison of Sacramento Model and observation discharge in Lematang River (Upper Musi Tributary River)

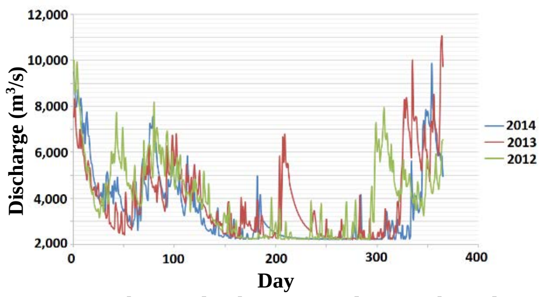


Fig.12 Synthetic discharge prediction based on Sacramento Method

The synthetic discharge and its calibration resulted from Sacramento model was presented in Fig.11 and Fig.12. A good comparison of model prediction with discharge observation was achieved. Based on this model result the average discharge of Musi River was found as large as consecutively 2,265 $m^3$/s for normal condition and 10,878 $m^3$/s for flood condition.

Based on the analysis using USLE method with NSE value about 60%, the erosion rate of Musi River stream at the Ampera Bridge in 2014 was estimated about 210,054,59 $m^3$/year or 575 $m^3$/day. This magnitude is relatively larger than the JICA [4] study results which concludes the erosion rate about 233 $m^3$/day, however this result was realistic as the rate of watershed degradation due to land use change in Musi River catchment area was also significantly increased. Sediment discharges estimated based on TSS concentrations identified from field measurements is commonly reflect the total sediment generated by erosion of erodible land surface and river bodies. Therefore, this result demonstrate that the existing land drainage capacity was not enough yet to prevent the land surface erosion yield entering the Musi River stream.

### *3.2.2 Velocity Pattern*

The flow velocity pattern modelling was conducted for two type of initial flow condition: normal flow and flood flow. The magnitude of its discharge determined based on the synthetic discharge predicted using the Sacramento method where the initial condition was defined in point A. The current pattern of normal flow was predicted for sedimentation pattern in the study area based on the RMA (current model package) of SMS 8 model, whereas the current pattern of flood flow was predicted for maximum scouring depth prediction around the pier bridge and abutment.

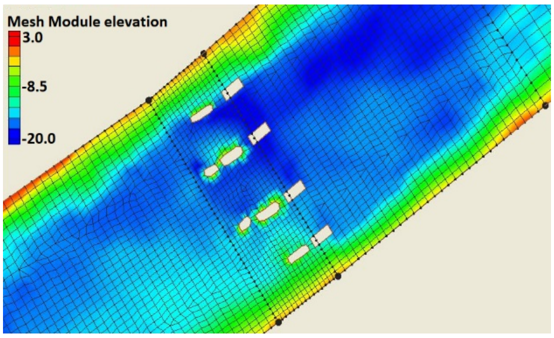

Fig.13 Bathymetry and mesh condition with additional LRT pier

The modelling was conducted for two river hydraulic condition: without LRT Pier where the mesh scheme was generated based on the observed bathymetry map (see Fig.7) and with LRT Pier (see Fig.13).

Based on the normal flow model simulation where the discharge was about 2265 $m^3$/s, the average velocity of the Musi river without LRT Pillar was found as follows:

a) about 0.55 m/s in the upstream part of the pier and about 0.25 m /s in the downstream of the pier

b) about 0.7 m/s between the pillar

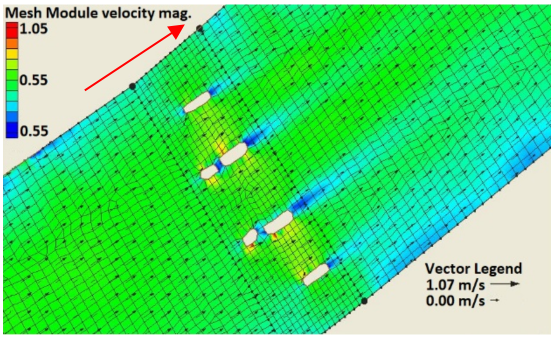

Fig.14 Flow velocity pattern without LRT pier in normal flow condition

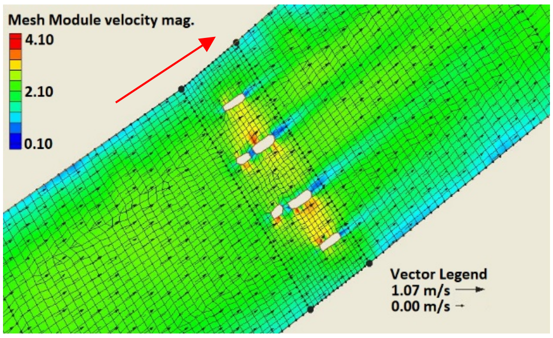

Fig.15 Flow velocity pattern without LRT pier in flood flow condition

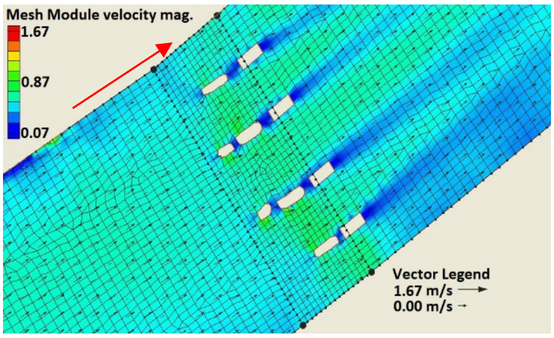

Fig.16 Flow velocity pattern with LRT pier in normal flow condition

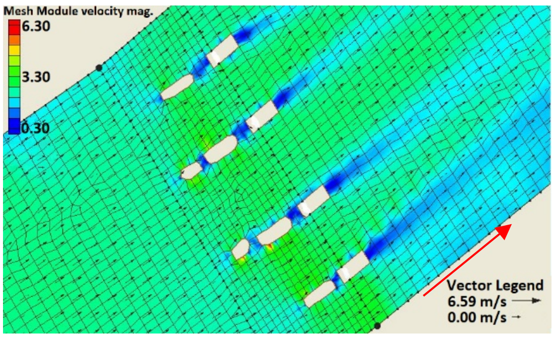

Fig.17 Flow velocity pattern with LRT pier in flood flow condition

Meanwhile, the average velocity of the Musi river with LRT Pillar was found as follows:
a) about 0.55 m/s in the upstream part of the pier and about 0.3 m /s in the downstream of the pier
b) about 0.79 m/s between the pier of the same bridges and 0.2 m/s between Piers of the Ampera Bridges and LRT Bridges

This velocity distribution for normal flow is in a good comparison with that of observation result in the second survey. The velocity around the bridge pillar is higher compare to the other area due to the contraction impact of the bridge structure. Meanwhile, the smallest average velocity is found in the wake generation of the LRT Bridges piers.

Based on the flood flow model simulation where the discharge was about 10.8781 $m^3/s$, the average velocity of the Musi river without LRT Pillar was found about 2.5 m/s in the upperpart of Ampera Bridge, 3 m/s between the bridge pier, reach its maximum of about 4.15 m/s near the end of the pier and reach its lowest velocity of about 0.6 m/s after the pier system. This result shows us that there is no significant difference of velocity pattern between normal flow with that of flood flow.

The average velocity of the Musi river with LRT Pillar was found about 2.5 m/s in the upperpart of Ampera Bridge Pier, 3.3 m/s approaching the upstream part of bridge pier, reach its maximum of about 6.5 m/s between the Ampera Bridges prier, 0.4 m/s between the Ampera pier and LRT pier and decreasing to 0.5 m/s after the pier system.

This result shows us that there is no significant difference of velocity pattern between normal flow with that of flood flow, however the velocity magnitude around the pier of flood flow condition was 1.5 time of that normal flow condition. The increasing velocity around the Ampera Bridge Pier will obviously increase the potential scour depth around that area, while the decreasing velocity between LRT bridge pier will generate the sedimentation, especially in the wake area.

### *3.2.3 Sedimentation Pattern*

Sedimentation pattern was predicted using the SED2D (Sedimentation model package) where the output of the RMA model for normal flow was applied covering both low and high tide period. The sedimentation pattern was predicted for without-LRT-pier and with-LRT-pier scenarios. The initial condition was defined also in point A where the erosion rate resulted from USLE prediction were used as the input sediment (See Fig.3, and Fig.18 to Fig.21).

The model results for predicting bathymetry changes in the existing (without-LRT-pier) conditions due to the normal flow applied for 10 hours high tides per day and 14 hours low tides per day can be seen in Fig.18 and Fig.19. It was found that the riverbed sedimentation rate was about 0.005 m/day during the high tide and was about 0.0037 m/day during the low tide.

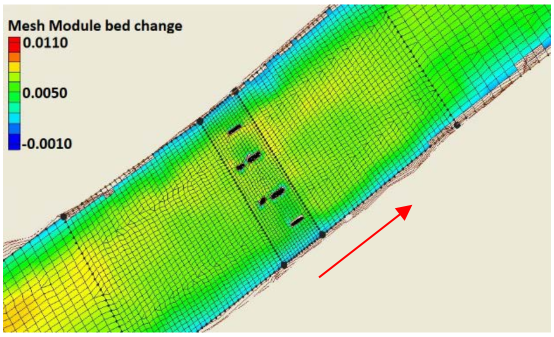

Fig.18 Sedimentation in high tide condition for without-LRT-pier condition

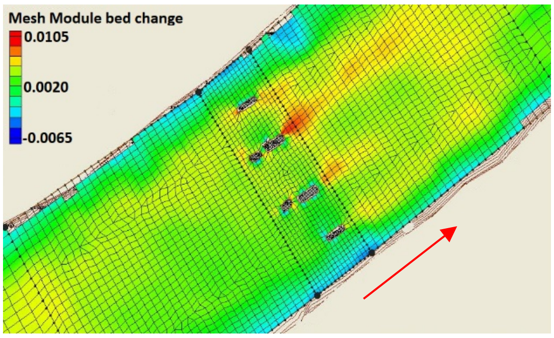

Fig.19 Sedimentation in low tide for without-LRT-pier condition

Meanwhile, the bathymetry change around the Ampera Bridge Pier was as follows:
a). Siltation rate was 0.008 m/day in the downstream (wake) area of the bridge pier.
b). Scouring was shown in the upper part of the Ampera pier bridge where its rate was about 0.0014 m /day. A secondary flow which is generated by scour protection structure in front of the pier could be suspected for this scouring phenomenon. Pagilara [22] demonstrate a simple relationships between Froude number and nonuniformity parameter of river bed sediment that can be used to estimate the maximum depth of river cross section, but the results valid only for specific hydraulic condition (especially clear water). Umesh et al. [23] conclude that a combination of sediment characteristics, approach flow velocity, and obstruction geometry could be used to predict scour around the obstacle but further research with more detail data measurement and analysis is required.
c). Scouring was also shown in along the abutment bridge of the Ampera pier bridge where its rate was about 0.0014 m/day. A secondary flow which is generated by small shipping mooring system

could be suspected for this scouring phenomenon. Mehdi Osrousha et al. [24] investigate the effects of the height and vertical position of slots on the reduction of scouring on the periphery of rectangular abutments where based on 25 experiments conducted under clear water conditions, find that the use of slots in abutments was more effective in reducing scouring than the use of bridge piers.

The model results for predicting bathymetry changes in the with-LRT-pier conditions due to the normal flow applied for 10 hours high tides per day and 14 hours low tides per day can be seen in Fig.20 and Fig.21. It was found that the riverbed sedimentation rate was increased to about 0.002 m/day during the high tide and was about 0.0026 m/day during the low tide.

Meanwhile, the bathymetry change around the Ampera Bridge Pier was as follows:

a). Siltation rate was 0.008 m/day in the downstream area of the bridge pier.

b). Siltation in the area between Ampera bridge pier and the LRT pier was found about 0.009 m /day. A wake area generated by the new LRT pier could be suspected for this phenomenon.

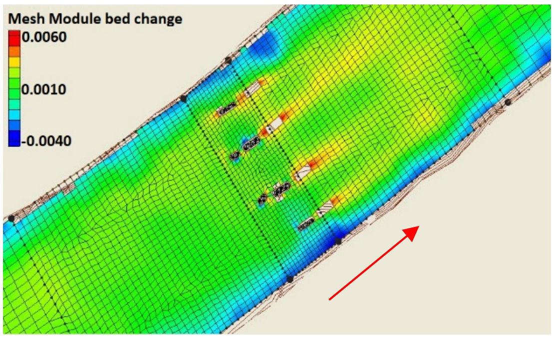


Fig.20 Sedimentation in low tide condition with LRT Condition

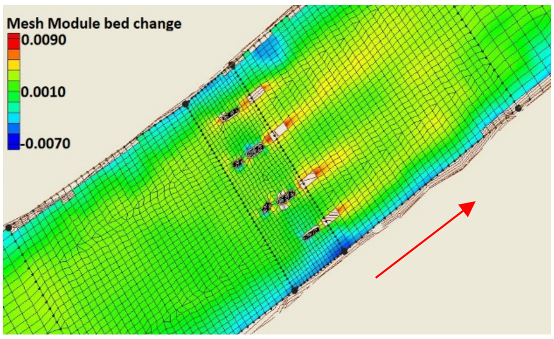


Fig.21 Sedimentation in high tide with LRT pier condition

## 4. CONCLUSION

The influence of a new bridge pier to the sedimentation pattern change of Musi River around the Ampera Bridge was predicted based on the mathematical model that calibrated with limited field observation data. Due to the additional bridge pier, the sedimentation rate, was found increasing in the downstream area, was insignificantly changed in the upperpart of the bridge peer, decreasing around the outer edge of pier group and significantly change in the area inside the pier perimeter (wake flow area). Based on the results, the model prediction showed good agreement with the observed data. However, like in every mathematical model, field data is the limitation. Therefore, more detail research particularly in getting more field observation data regarding evaluation of flow pattern around the pier and abutment can be conducted for further development of this study.

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