Conference Paper, Published Version

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Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/100074

Vorgeschlagene Zitierweise/Suggested citation:
Sidek, Faridah J.; Wahab, Ahmad K. A. (2006): Revisiting the Study to assess Scour around a Prototype Bridge in Malaysia. In: Verheij, H.J.; Hoffmans, Gijs J. (Hg.): Proceedings 3rd International Conference on Scour and Erosion (ICSE-3). November 1-3, 2006, Amsterdam, The Netherlands. Gouda (NL): CURNET. S. 607-613.

REVISITING THE STUDY TO ASSESS SCOUR AROUND A PROTOTYPE BRIDGE IN MALAYSIA

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This paper will focus on a Study which has been carried out to evaluate scour development around piers supporting an existing bridge which plies 13.5 km across coastal waters ten years on after construction. The Study was first undertaken in 1996. It was also the first of its kind to be executed in Malaysia at that time, where computer simulation exercises using the computer model TELEMAC to evaluate the hydrodynamic processes at the site and projections concerning bridge pier stability were made.

Generally, the paper will outline several work components that have been undertaken for the Study which covers tasks such as field data collection works and data appraisal, hydrographic survey works of the area, computer simulations to evaluate the hydrodynamic processes at the site and projections made to predict potential scour evolutions around the bridge over a specified period of five years. The paper will then present a summary of the results yielded and highlight several recommendations which have been drawn to ensure hydraulic stability of the bridge in light of limitations faced and assumptions made to complete the Study.

I. INTRODUCTION

The long term functioning of bridges require that bridge owners continually attend to hydraulic safety issues in particular the stability of bridge abutments and piers that are perpetually in contact with the water. Attention is needed not only prior to bridge construction but also during bridge operation and their maintenance periods. When bridges have been planned to traverse water, bridge engineers will need to make early evaluations to determine potential scour severity in the pre-design and design stages of the bridge supports; assess whether there exist instability from scour of its piers and foundations after construction and also during bridge operation or maintenance stages; and likewise identify other future threats which may affect bridge safety apart from that which could be caused by potential scour related failures mentioned. On top of this if signs of concern existed, engineers may be required to recommend and implement remedial measures in the event of protecting the hydraulic structures from damage.

In order to substantiate decisions with regards to confirmations of bridge stability, it is essential that bridge engineers well-plan the bridge operation and maintenance works. The engineers could opt for operations to send divers for underwater inspections as is the norm, or choose to carry out computer simulations to provide the needed information to support their engineering judgments, or even use both options to complement each other. If computer simulating exercises were chosen, then the engineers will need to first establish the hydraulic parameters present in the surrounding water regime. These parameters could include that which describe the existing flow processes namely, wave climate (wave heights, wave periods and water depths) in the coastal area, water level fluctuations, flow characteristics (velocities and discharges), bathymetric information which characterizes the flow pattern and shoreline dynamics which may affect bridge abutments. This will be continued with the conduct of a detail hydraulic data analysis of the compiled data and also the need to choose as well as use relevant computer models to simulate the hydrodynamic processes in the project area and subsequently make projections to gauge the extent of potential bed movement around the bridge supports. Only after undertaking these activities would the engineer be more technically equipped to identify factors which could potentially destabilize the bridge and to recommend mitigating measures to minimise potential damage. If underwater inspection is selected as a means of evaluation, then the engineer must be able to identify the particular support of the bridge requiring the attention. When the bridge is particularly long and is supported by many piers, this could be a more expensive exercise.

This paper highlights an investigation which has been undertaken to determine potential scour magnitudes that might have evolved around the piers of an existing bridge which traverses a coastal strait in Malaysia. As part of the routine tasks that has been undertaken by the bridge owner to maintain and safeguard the bridge, the owner has opted to apply a computer model as a tool to evaluate the stability of the prototype bridge. Information described in this paper has been obtained from experiences derived by the authors from the conduct of the Study [1] which was carried out to evaluate potential scour evolutions around the bridge supports so as to confirm that the developed scour holes have been designed-for ten years after their construction.

II. PROJECT BACKGROUND

Penang Straits is an elongated water channel of about 25 km which is bounded by Peninsular Malaysia to its east and Penang Island to the west. The Straits is connected to the Straits of Malacca to its north and south. An existing bridge that is, the Penang Bridge, a significant landmark in Malaysia, forms the only physical link between the two land masses. The bridge has been constructed as an elevated cable stayed concrete girders, with a dual carriageway and three lanes at the Main Span. Figure 1(a) and (b) illustrate the location of the bridge.

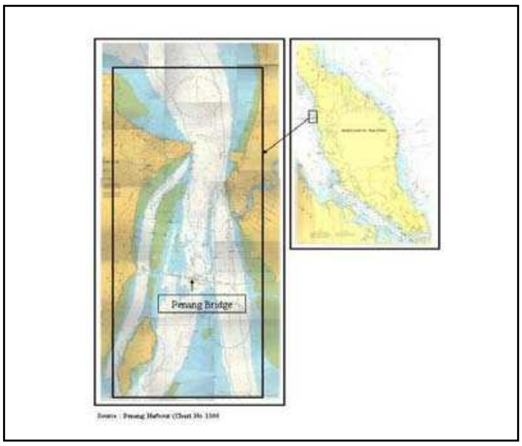

Figure 1(a). Extend of the Study Area

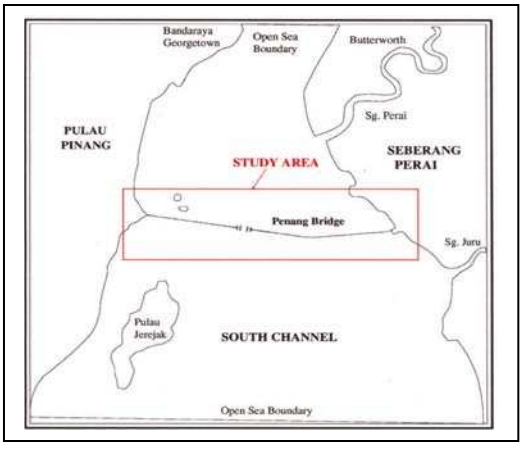

Figure 1(b). Location of the Bridge in the Straits

The crossing was built in 1985 as an alternative to using the ferry as a mode of transfer to cross the Straits. It was also built to escalate economic development on the Island. The bridge is supported by 517 piers with approximately 197 of the supporting piers lying in the straits water. The Main Span is about 225 m in length. It is supported by 4 main piers. The other piers are in turn supported by individual groups of raker piles ranging in number from 11 to 40, which have been well embedded into the sea bottom at various reduced levels. Four of the piers in the Main Span are each covered and protected by rock berms. Exact depths to which each of the individual piles was founded into the bed was not known with certainty at the time the scour assessment study was carried out in 1996. It has been reported that they could have been piled down to more than the recommended RL-49.7 m and potential scour related failure of the piers has been accounted for in the design. In spite of this, it was decided in 1996 that a scour assessment study be undertaken as part of routine checks to confirm bridge support stability by the bridge owner.

III. THE SCOUR ASESSMENT STUDY

Three work stages were adopted to evaluate scour development around the piers. They were :

- Stage 1 – Initial Scour Assessment Works
- Stage 2 – Detail Scour Assessment Works
- Stage 3 - Recommendations and Suggestions for Future Works

The first stage involved examining past and existing reports, information and drawings for gathering of general information and details of activities relating to the construction of the bridge and other related works. Initial identification of piers showing indications of local bed lowering was evaluated from the many hydrographic survey drawings produced by surveyors who carried out survey works especially for the project in 1996.

The second stage included works to execute computer models to describe the flow conditions in the straits and quantitative magnitudes of potential scour around the bridge. In this stage, extensive data collection of environmental parameters in the water body making up the Straits was required and planned for. Thereafter, the morphological module of the computer model was applied to yield computer simulated outputs to identify potential piers at risk to scour and also project potential scour hole magnitudes around each individual pier.

The final stage of the Study documented recommendations which should be adopted by the bridge owners. This was to ensure that consistent hydraulic checks were made and that they form part of the routine inspection works for the bridge.

Overall, the completed Study was deemed to be useful in assembling baseline hydraulic information and generating initial estimations and projections of scour hole magnitudes a decade after bridge completion. It assisted in recognizing and identifying the piers which should be constantly inspected more regularly than others along the bridge length. The Study also resulted in laying out recommendations for monitoring works which should be undertaken by the bridge owners to confirm overall stability of the bridge from the hydraulic aspects in particular.

IV. ESTABLISHING THE TOPOGRAPHIC AND HYDRAULIC PARAMETERS

A review of past and present data, records, reports, drawings, chronological information available with respect to the pre-design, design and construction stages of the bridge were important in order to generate a comprehensive understanding of the events that took place over the past ten years prior to the Study being undertaken. Some information on early feasibility study reports [2] and [3], an underwater inspection report and a set of structural drawings were found available for use for the Study. Compiled hydraulic data were not readily available for the second stage of works which required the set-up of a computer model for the surrounding waters where the bridge was located.

The authors were faced with several difficulties to initiate the Study in the early stages. This arise particularly from the lack of information made available to describe the flow conditions in the straits, the absence of past survey drawings of the area to provide reference details of the seabed levels in relation to the location of the piers underwater that is, during the before- and after-bridge construction periods, and there was no clear indication of what allowable maximum scour hole depth values have been finally used in the design of the supporting structures. These reasons therefore justified the necessity to plan and carry out hydrographic survey works of the surrounding area particularly in the vicinity of the bridge in order to initiate the Study. Survey information was also required for use in the computer model to establish first the flow pattern in the existing area before projections of bed movement could be made. Thus, an extensive field data collection program was implemented. Data collected from the field measurements were used to serve as the boundary conditions to execute the computer model. The data collection task therefore consisted of collecting the following much needed environmental parameters.

A. Hydrographic Survey Works

The site was surveyed using side scan sonar with an approximately 5 metres sounding interval very close to the piers and at greater intervals further away from the bridge area. The drawings were useful in providing the exact locations of the bridge supports underwater and an early description of immediate bed lowering details around individual supports.

From visual evaluations of the drawings, it was noted that the sea bed has been lowered down to depths of 0.6m to 0.9 m around some piers when compared to the surrounding bed. Review of limited past structural drawings made available to the authors indicated that most piers have been founded very deeply in the sea bottom. It has also been reported in [2] and [3], that beds should be expected to be lowered in total by about 5 m to 6 m as a result of bridge construction. It was not possible to confirm the significance of the values shown by the drawings due to the absence of previous reference levels of the seabed. From limited data made available and the knowledge that the piles have been founded to more than the RL-50m, it was safe to assume that the value has not exceeded the maximum pre-designed and designed value.

B. Water Surface Elevations

For the Study, two tidal gauges were setup in the field in order to capture water level variations over the spring and neap tidal cycles. The data collected compared well with published predictions made for the area. They were then used as inputs to drive the computer model used in the simulations. The reliability of computed water surface elevations produced by the model was also checked against measured water levels generated over a time series in the field. Comparisons made gave good agreement.

C. Tidal Currents

There were no readily available current data for use for the Study and thus on-site measurements were made. Three current meters were deployed to obtain records of simultaneous readings of current magnitudes at several locations during spring and neap tides. Readings were recorded at every 15 minutes interval. Since tidal current data is important to generate flow distribution and bed movement in the area, sufficient data is needed to calibrate and verify the computer model to simulate the current distribution pattern characterizing the coastal strait. Good agreement of the field measured and computed currents was to be found when calibration and verification works were carried out by the computer model.

From in-situ readings obtained, flood currents were recorded to flow southwards with a peak current reaching 0.85 m/s during spring tide in the straits. Lower currents ranging from 0.3 m/s to 0.5 m/s were recorded during neap. Ebb currents were comparatively lower and flowed northwards.

D. Wave Climate

The bridge lie in a sheltered area of the straits from offshore waves and is relatively unaffected by the offshore wave climate. Thus, wave data was excluded from the Study.

E. Bed Material

Bed samples were measured for use to define bottom roughness in the computer model. Twenty-two samples were collected around the site, coarse sand with a maximum d_{50} size of 1.0 mm was found to occur around the central regions of the water channel and finer materials ranging from 0.001 to 0.06 mm (fine silt to fine sand) were found along the coastlines. Sensitivity tests were applied in the model computation works using several roughness values in order to ensure that outputs of bed movement obtained did not vary too widely.

V. COMPUTER SIMULATION WORKS

In order to obtain a description of the flow conditions and quantitative estimates of bed lowering around the piers, the computer model TELEMAC 2D and its sediment module were used. TELEMAC 2D is a two-dimensional finite element model developed by *Laboratoire Nationale d' Hydraulique, Electricite de France*. There existed several assumptions and limitations which the authors have had to accommodate during the application of the two-dimensional computer model to simulate bottom bed movement. One of them as mentioned earlier was the absence of original sea bed level description before or after bridge construction to use as reference to compare and justify the lowering captured in the 1996 survey drawings. Therefore, actual scouring extent of the bed and the piles could not be ascertained from the period of bridge completion up to 1996 when the Study was initiated. Due to these uncertainties, the authors have had to execute the computer model based on the assumption that the bed description provided by the 1996 survey works was the existing bed condition to be found in the area. Potential projections of bed depressions over a period of five years were then initiated from there henceforth. Other assumptions made in the Study are described in the sub-sections below.

A. Computer Model Set-Up, Execution and Assumptions

The model boundary covered an area of about 15 km by 14.2 km. In the modeling exercise, the size of the pile cap of each pier was used as an effective pier width to depict the dimensions of each of the individual piers supporting the length of the bridge as several big columns due to model limitations. It was anticipated that this assumption could result in more conservative scour magnitudes. Each raker pile which supported the bridge pier was less than 1 metre in size and was inclined in various numbers and grouping arrangement. They were not possible to be modelled individually in the computer model to gauge bed movement. A comparison of modelled and observed current measurements obtained from the current pattern output generated by the model indicated good agreement and that the model has been well calibrated and validated.

B. Generated Computer Model Outputs

Samples of computational outputs produced by the model are illustrated in Figures 2 to 6. Figure 2 shows the mesh generated by the computer model. The element size of the mesh varied from 1 km in the study area to approximately less than 5 m around the bridge piers. Figure 3 shows a close up of the digitized bed bathymetry adjacent to selected bridge piers. Flow pattern in the surrounding bridge area is illustrated in Figure 4. Samples of the projected bed movement around the piers are shown in Figure 5. Projected maximum bed stresses in the model domain are illustrated in Figure 6.

From the exercise, it was possible to identify piers which were expected to be more susceptible to greater scour capability. These identified piers were located mainly in the areas which possessed the higher bed stress values and flow strengths. These piers were then used to quantify estimates of scour magnitudes that might develop around the piers in a five years time frame.

C. Results and Analysis

In the Scour Assessment Study, flow was shown to be influenced by the tidal cycle in the Straits. Water movement around the piers (discharge and velocity magnitudes) have been well computed and can be used as a basis for comparison should there be flow variations in the straits. It was found that generally currents moved

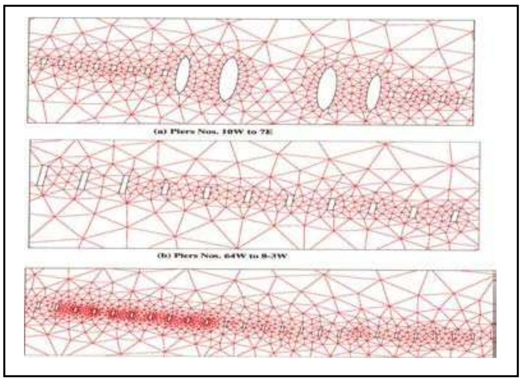

Figure 2. Mesh Generated by the Computer Model

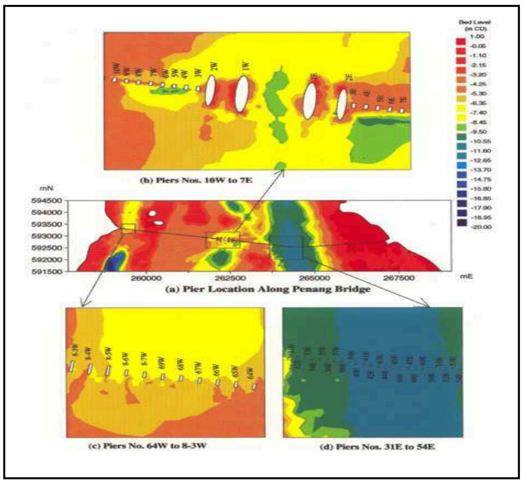

Figure 3. Digitised Bed Bathymetry

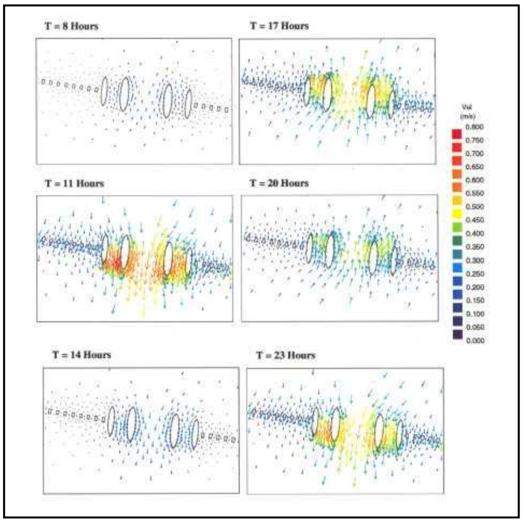

Figure 4. Flow Distribution Around the Piers

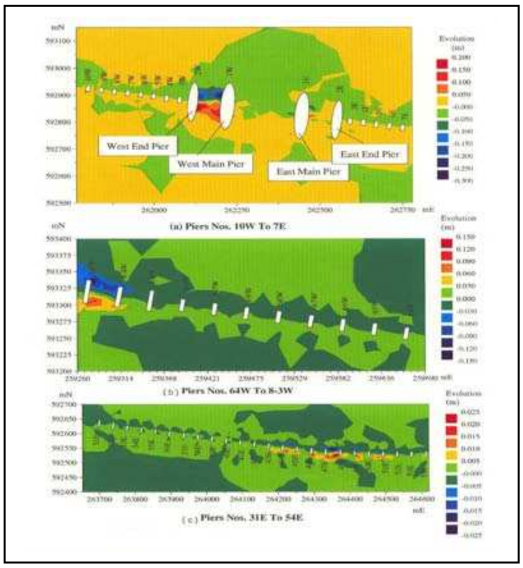

Figure 5. Projected Maximum Bed Stresses in Model Domain

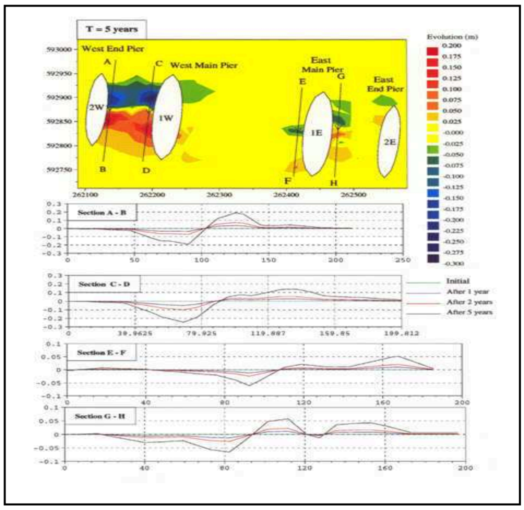

Figure 6. Projected Bed Evolution around the Main Piers

northwards during ebb and the reverse upon flood tide. A peak of 0.75 m/s in speed was attained in the deeper sections of the Straits and also at bridge mid-span. Lower values of 0.55 m/s was reached during ebb tide at the same location. Flow distribution around mid-span moved smoothly around the streamline shaped of the rock berms. At other locations, flow around piers in the deeper water developed stronger currents than those located in the shallower areas.

Bed shear stresses were computed in order to determine potential sediment transport around the piers. Peak stresses were observed to occur in the deeper sections of the water channel with lower stress values generated in shallower regions. In the tests conducted to simulate scour development, it was assumed that the 1996 survey drawings were taken as the reference to describe the original bed level to start the potential scour projections over a five years period. From the results of the bed evolution, it was found that maximum erosion could potentially occur towards the northern end of the piers reaching a magnitude of 0.3 m. Accretion tended to occur on the southern end reaching a value of 0.2 m. A rate of 0.3 m in five years could be generated around the edges of the rock berms at mid-span. From analysis made, the values obtained from the computations were considered to be insignificant to cause risks since the piers were reported to be generally well embedded and founded in the seabed. With information made available then, the authors have concluded that the piers were not expected to undergo excessive scouring. However, it was advisable to monitor potential of the piers to scour over the long term and a review be made whenever new data become available so that predictions made in this Study could be confirmed through further computational exercises.

The computer simulation outputs were treated as that providing a baseline from which future investigations on scour projections could be initiated from. Detail information of flow was important in providing the basis for comparison in a changed scenario. Information obtained from the documented Scour Study could also be used as a reference to determine potential risks afforded by new changes in the coastal straits making up the bridge surroundings in future. Identified bridge piers which were embedded in locations with higher capability to scour could then be routinely checked through regular underwater inspections and scour monitored periodically to confirm stability.

D. Recommendations and Future Computations

It is always advisable to ensure that checks and appropriate measures have been undertaken to ensure that there existed some level of security in order to avoid high risks when operating and maintaining a bridge. In the scour assessment study, some recommendations have been made to safeguard the bridge. These included the following:

- the conduct of another study in the near future for example, within an ideal span of the next three to five years to confirm local bed movement around the piers; or when new data become available; or in the event of changes in the straits from activities such as future dredging or sand extraction works which may change the flow distribution pattern.

- to undertake further hydraulic investigations for example, before reclamation activities along the coastline are planned since these may constrict flow movement in the straits or before the construction of other infrastructures namely, a new bridge or underwater tunnel which may indirectly impact the existing bridge.

- to carry out regular inspection for scour related failures accordingly not longer than a period of one year and shorter when the need arise. It has been recommended that all information collected and monitored be properly archived for future use. These included information made available by divers, surveyors or bridge engineers through routine checks of piers namely, reports/drawings/charts/data etc. by providing full details of structure foundation and levels, sea bed material, hydraulic parameters, details of previous and future inspection checks.

- the need for underwater divers to work very closely with the bridge engineers to note if any, for example the nature and location of any serious defects, the extent of defects for comparison with previous and subsequent reports, existing extent of scour, information of the location and value of horizontal and vertical reference datums, data of previously measured bed levels, etc. so that appropriate action could be followed up by the engineers if necessary.

- the need for specialist surveyors to provide reports to bridge engineers such as to include location and contour plans of associated bridge structures, cross-sections of seabeds especially around the piers which have been identified in the priority checklist from the present study, photographs or multi-media display of evidences to confirm bed depressions which could create concern

- piers that were especially noted to be higher up in the priority risk checklist as provided in the study should be periodically checked.

- regular updating of the information archived and computer model already set-up for the straits should be made.

- a long term monitoring study so that scour risks could be more meaningfully rated should be periodically undertaken by the bridge owners.

VI. ADAPTATION OF THE COMPUTER MODEL TO INCORPORATE FUTURE PHYSICAL CHANGES AROUND THE BRIDGE

It has been reported by the local media that there might be on-going physical changes in the Straits in the future. It is expected that the coastline on both sides of the Straits may undergo changes where plans to build coastal roads on new reclaimed coastal land could materialize. There is the possibility of a new bridge being constructed to support the traffic congestion already being felt daily during peak periods on the existing bridge. Also, bridge expansion of the existing link is to be anticipated. With such plans, it is envisaged that there will be new data available. Thus, there arises the need to provide further detail information of the physical impact of these projected new developments in the straits to the existing bridge structure.

A model of the straits has been set-up from the Scour Assessment Study described herein. It is therefore not difficult to include the new features into the model to gauge these changes and predict their potential impacts on the existing bridge. It is reassuring to know that a hydraulic data baseline is already in existent and is accessible for use whenever required.

VII. CONCLUSIONS

The following conclusions have been drawn :

- Computer models can be used as decision tools during bridge maintenance works to project scour development around piers. Outputs generated by the models could aid engineers in identifying piers which needed more regular inspection.

- In the scour assessment study undertaken, it has been shown that though data made available was found to be limited, evaluations carried out were useful in providing general information on the hydraulic stability of bridge supports up to a certain extent. However, continual monitoring of the bridge should be undertaken periodically over the long term so that more new data could become available for use to confirm findings already made in the present study.

- A baseline for the gauging of future physical impacts near the bridge surroundings have been derived through the setting up of the computer model for the straits.

ACKNOWLEDGMENT

The authors wish to acknowledge the Coastal and Offshore Engineering Institute of Universiti Teknologi Malaysia for allowing the use of the computer modelling outputs. We wish to extend our gratitude to the same organizations also for providing the financial support to present this paper at the Conference. Our utmost appreciation is especially extended to Penang Bridge Sdn. Bhd for having the confidence to engage the authors to undertake the Scour Assessment Study.

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