LOCAL SCOURING AND SCOUR COUNTERMEASURE IN MALAYSIA

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ABSTRACT

The paper presents information pertaining to the design and maintenance of bridges in Malaysia. It also outlines the procedure on how bridges are inspected, and eventually how remedial actions are taken in the event that failure is detected. Three bridge sites, that is Pukin River Bridge, Keratong River Bridge and Plentong River Bridge are cited as recent case history on how local scouring affected the integrity of the bridge, and how the local authority tackled the problem. The data also reveal that a certain scour countermeasure appears to be successful when applied to a particular site, but fails miserably when used in a different location.

INTRODUCTION

Bridges are normally built to span either a valley or a stretch of water. In the latter case, it forms a link between two land masses across a river, a bay or a strait. The bridge needs to be designed to satisfy not only the structural, but also the hydraulic requirements. The hydraulic design includes considerations of both the capacity of the flood peak through the bridge opening as well as the ability of the bridge foundation to withstand the loading imposed on the bridge. The integrity of the bridge is often jeopardized when scouring occurs at its foundation. Studies reported in the literature (Smith 1976) have shown that most of the bridge failures in the United Kingdom and USA are due to scouring at its foundation. This is reinforced by the experience in Malaysia. Ng and Razak (1998) reported that bridge failure due to structural damage is very rare in the country. The main cause of bridge failure is over-topping of the bridge deck or washout of embankment during major floods.

Despite having so much data that clearly point towards the important correlation between bridge failures and hydraulic requirements, practicing engineers often overlook its importance in their design. This is especially so with the lack of proper considerations of the fluid-sediment-

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structure interaction, which is the main cause of foundation failure around the structure. One of the main reasons that the hydraulic aspects are often neglected is because structural engineers, who are tasked to design bridges, are often unsure of the implications.

The main objective of this paper is show how the hydraulic aspect of bridge design is tackled in Malaysia. The effect on foundation scour on the integrity of the bridge is highlighted. Three different bridge sites, that is Pukin River Bridge, Keratong River Bridge and Plentong River Bridge were chosen as examples to illustrate how remedial actions were taken to arrest erosion, although success is not always guaranteed.

HYDRAULIC DESIGN PRACTICES IN THE PUBLIC WORKS DEPARTMENT (PWD) MALAYSIA

Because hydraulic considerations are extremely important to ensure the integrity of a bridges and culverts, the Malaysian authority has placed high emphasis in the hydraulic design of bridges. In the Public Works Department, Malaysia, the design philosophy builds upon the considerations that bridges may fail due to:

(a) inadequate flow capacity leading to over-topping of the bridge deck or the approach embankments;
(b) increased loading on the structure from water, sediment or debris; and
(c) failure of the foundations or supports as a result of bridge scouring.

The solution to the first problem involves the determination of the design discharge and the flow capacity, and to ensure that the former is less than or equal to the latter. The design discharge can be calculated using either the measured stream flow data or rainfall records. In Malaysia, guidelines for the procedures to calculate this value are contained in a series of documents published by the Drainage and Irrigation Department (DID) under the Ministry of Agriculture. Some of these publications are Heiler (1973, 1974), Heiler and Chew (1974), Lewis et al (1975) and Taylor and Toh (1980). The Public Works Department (PWD) in Malaysia utilizes a 100-year storm for bridge design and a 50-year storm for culvert design.

To counteract the second problem, the department proposes the provision of a freeboard, which is the vertical distance between the highest water level and the soffit level of the bridge deck. A value ranging from 0.3 m to 1.0 m is used, with the lower value for channels that are not expected to have debris or floating logs. However, if debris and floating logs are expected in the river, the force exerted by these objects on the piers must also be considered in the design of the pier. The standard practice by the Public Works Department (Public Works Department Malaysia, 1982, 1985) to calculate these forces is as follows:

<u>For debris</u>:

- the force shall be computed based on a minimum depth of 1.22 m (4 feet) of debris; and
- the force shall be computed based on the assumption that the length of the debris is equivalent to half the sum of the adjacent spans.

For floating logs:

- the force shall be computed based on the assumption that the log weighs 2 tonnes, and travels at the normal stream velocity; and
- the log shall be assumed to stop at a distance of 30.5 cm (12 inches) for timber piers, 15.2 cm (6 inches) for column-type concrete piers, and 7.6 cm (3 inches) for solid-type concrete piers.

The third problem involves failure of the structure due to scouring at its foundation. The local authority does not normally estimate the probable depth of scour for short and medium bridges. The common practice is to use only piled foundation. No guideline for scour protection such as riprap is available.

Recently, the Public Works Department in Malaysia, in collaboration with the Japan International Cooperation Agency has undertaken two studies (JICA and PWD 1992, 1996) and identified many "hydraulic defects" in Malaysian bridges. These are summarized as follows:

(a) Inadequate bridge opening;
(b) Inadequate slope protection around abutment;
(c) Unsuitable bridge siting at sharp bends;
(d) Piers skewed to river flow;
(e) Obstacles like old bridge piers remain under bridge;
(f) Floating logs or debris not removed; and
(g) Rivers and mining activities near the bridge sites.

The main causes of the above defects are attributed to both design and maintenance. The level of uncertainty associated with hydraulic designs far exceeds those associated with structural design. For example, the ability to accurately predict flood levels is much more difficult than to predict the effect due to vehicular loads. Furthermore, the design location is normally subjected to changes that occur both upstream and downstream of the bridge site, but the designer is often unaware of future changes or unable to control such changes. With this in mind, a proper design of hydraulic structures involves not only the necessity of an accurate set of hydraulic calculations, but also a good conceptual design of the structure as well as the entire waterway. In this respect, the Public Works Department in Malaysia has adopted the following recommendations from the Drainage and Irrigation Department in the country:

- the bridge structure should cross the river perpendicularly;
- abutments should not protrude into the waterway;
- the number of piers in the river should be minimized;
- the shape of bridge piers should, as far as possible, be oval; and
- the pile caps should be buried by at least 1.2m below the expected scoured depth.

BRIDGE INSPECTION

To ensure the integrity of a bridge, it is necessary that an accurate prediction of the hydraulic parameters and an appropriate measure to prevent any adverse effect on the hydraulic structure are carried out at the design stages. In addition, it is also crucial that a system of surveillance exists to identify hydraulic problems in existing bridges so that immediate remedial actions can be activated. In Malaysia, the traditional approach is that the PWD district offices undertake inspection of bridges and culverts after each flood season.

Generally, Malaysia's rivers flow in abundance, a result of the high rainfall in the country, with an annual average rainfall of 2420 mm in Peninsular Malaysia, and 2630 mm and 3830 mm for Sabah and Sarawak, respectively. The flooding season normally takes place during the North-East Monsoon, which lasts from November to February. During this period, very heavy rainfall occurs, with as much as 600 mm in 24 hours in extreme cases, along the east coast of Peninsular Malaysia, Sabah and Sarawak. Yusof (1996) reported that the inspection exercise has been expanded to include condition survey and this has become mandatory since 1995. The inspection is essentially visual and involves the assignment of a numerical rating to each bridge or culvert to indicate its condition. A rating of "1" represents excellent condition whereas a rating of "5" means critical condition (Public Works Department Malaysia 1995). Table 1 shows an example of the checklist used in the country. Only items related to hydraulic problems are indicated. A description of the damages and proposed maintenance activities is recorded in the checklist accordingly.

Table 1. Partial Inspection Checklist used for Bridges in Malaysia

Bridge Components	Ratings		Damages	Maintenance
	Old	New		
Slope Protection				
Pier				
etc.				

With regard to scouring problem, the annual mandatory bridge inspection would only be able to detect erosion problems above the waterline, such as slope protection around the abutment. The present scheme is not able to reveal potential scouring problem at the piers beneath the waterline. To overcome this drawback, the department occasionally engages specialist divers to carry out underwater inspection. The obvious predicament with this tactic is that the divers often do not have adequate knowledge in bridge engineering. Besides, visibility is normally very poor under water. The PWD Malaysia has recently acquired an echo depth-sounding device called Fathometer (from Raytheon, USA). It can be used to measure water depth and determine the extent and severity of scouring.

REMEDIAL ACTIONS

Remedial actions play an essential role in the total management of a bridge against failure. An adequate design and frequent inspection may be futile without appropriate remedial actions to arrest deterioration of the bridge due to adverse hydraulic effects. Ng and Razak (1998) have identified the following remedial actions:

- replacement of the bridge;
- modification of the bridge;
- replacement of the scoured material;
- provision of armor material; and
- provision of flow control.

Replacement or reconstruction of the entire bridge with due considerations of the current hydraulic requirements may be very effective in arresting deterioration of the bridge. However, this involves high cost and disruption to traffic flow. Modification of the bridge is a step towards cost reduction as compared to replacing the entire bridge. This includes altering the foundation, such as adding piles; underpinning and construction of relief culverts.

Replacement of scoured material involves placement of erosive resistance material such as crushed aggregates or riprap stones. In the light of recent investigations by Chiew (1995) and Chiew and Lim (2000) on the failure behavior of riprap layer at bridge piers, this method is likely to require recurrent maintenance, especially under live-bed conditions where bedforms are present. In addition, the replacement of scoured material is often not done in accordance with specifications and the replaced material may protrude into the river and cause obstruction to the flow, aggravating the erosion problem. In the local context, the provision of armor material refers to the construction of a revetment to protect the sub-structure of the river bank. The commonly used material are gabions, riprap, grouted riprap, bagged concrete, sand bags and precast concrete blocks. Finally, the provision of flow control refers to the training of rivers in such a way as to eliminate the undesirable hydraulic effect on the bridge structure. This involves the construction of spur dikes and sheet piles.

All the above methods, except the construction of spur dikes, had been used by the Public Works Department in Malaysia. Table 2 shows a summary of some of the projects undertaken by the department. Ng and Razak (1998) reported that the department tends to favor using a flexible revetment system, such as sand bags, over a rigid system like concrete blocks. In many instances, a change to the main flow direction of the river has been identified as the main cause

Table 2 PWD Cases of Scouring at Bridges in Malaysia

River Name	Defects/Problems	Remedial Actions
Pukin River, Pahang	General and local scour	Armor using precast concrete interlocking blocks (flex-slab system)
Keratong River, Pahang	General and local scour	Gabions and sand bags (proprietary products)
Plentong River, Johor	General and local scour; earlier protection work washed out	Armor using gabions, sheetpiles and precast concrete interlocking blocks (flex-slab system)
Trolak River, Perak	Collapse of approach embankment	Reconstruction of approach embankment using RE system with gabions
Buloh River, Selangor	Pier on footing scoured and settled	Replacement with a bridge
Salor River, Kelantan	General and local scour	Armor using sand bags (proprietary products)
Geliga River, Terengganu	General and local scour	Underpinning and replacement with a bridge

of the problem at the bridge site. The department is currently contemplating doing some river training works as a longer-term solution.

The seven bridge sites in Table 2 are some recent examples of scour-related problems that have occurred in Malaysia. In order to illustrate how these problems are tackled, the first three bridge sites, that is, Pukin River Bridge, Keratong River Bridge and Plentong River Bridge are presented in more detail in this paper. A site visit to the three bridges was made between January 3-4, 2000 by the writers. During the site visit, assistance was rendered by PWD Senior Technician, Mr Tan Chee Kean, and personnel from the district office of the Public Works Department in Johor Bahru. The aim of the visit is to ascertain the success or failure of the countermeasure used in each of these bridge sites.

PUKIN RIVER BRIDGE

Pukin River Bridge, which was built around 1983, spans across the river with the same name. It serves as a vital road link between the Kuantan-Segamat Highway and the Selancar Felda Scheme. The overall length of the bridge is approximately 55 m, and it consists of three equal-distance spans. The superstructure of the bridge is in the form of prestressed I-beams, supported on two 910-mm diameter cylindrical piers. Official reports from the Public Works Department Malaysia recorded that severe scouring and erosion of the slope embankment around both the abutments has occurred as early as 1992. The failed slope embankment was reinstated using the flex-slab slope protection system (a type of precast concrete blocks) in 1993.

Approximately two years after actions were taken to remedy the failure of the slope embankment, another flood in June 1995 has further aggravated the slope embankment at one of the bridge abutments. The personnel from the Bridge Unit of the Public Works Department Malaysia and the District Office had carried out a detailed joint inspection after the flood to investigate the defects at the bridge. Observations showed that the slope embankment at the bridge abutment had collapsed partially although the majority of the slabs were intact. They reported that "the flex-slab at the toe of the slope embankment was slightly crumbled". The original manufacturer of the flex-slab system laid in 1993 carried out an independent inspection of the site on June 21, 1995. They reported that the main cause of the failure of the flex-slab system is earth movements due to seepage. It was unfortunate that no detailed information is available on any scouring that may have formed at the toe of the abutment. Hence, one is unable to determine whether there is a correlation between failure of the flex-slab system along the embankment and scouring that could have occurred at the toe of the abutment.

The recommendation by the authority was to reinstate the failed slope embankment to avoid further loss of fill material and disintegration of the flex slab. To that end, the following steps were recommended:

- The existing flex slab at the abutment shall be dismantled and stored at a separate location. The broken slabs shall be removed and disposed;
- The existing ground profile shall be trimmed to a minimum depth of 300 mm and a geotextile filter fabric with a minimum weight of 180 g/m^2 shall be laid;

- The material loss at the slope embankment shall be replaced with crush stones ranging from 50-100 mm;
- The crush stones shall be compacted to build up the slope to the existing profile in preparation for laying the flex slab; and
- The new slope shall be protected using the flex-slab protection system.

Figure 1 shows the sectional view of the abutment and the proposed scour countermeasure at Pukin River Bridge. The new slope embankment was completed at the end of 1996. On the day of the site visit (January 4, 2000), the flex-slab system was still in place, and no defects were apparent.

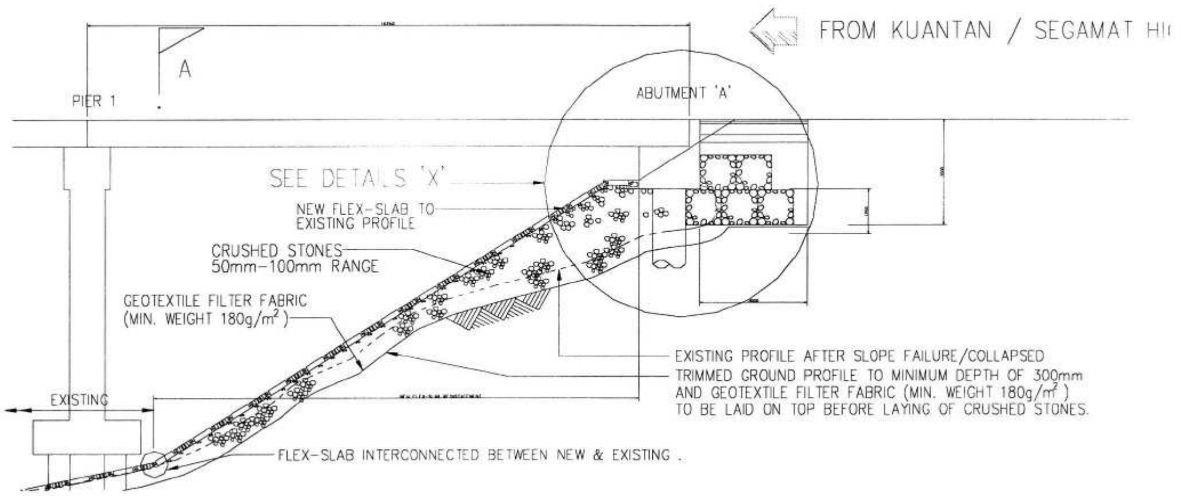

Figure 1 : Sectional View of Bridge Abutment at Pukin River Bridge

KERATONG RIVER BRIDGE

Keratong River Bridge links the towns of Bahau to Keratong in Pahang, Malaysia. The bridge is located at a curved section of the river, and it is supported on six rectangular piers each with a size of 0.914 m x 8.54 m on a pile cap with a size of 4.27m x 9.14m. Figure 2 shows the alignment of the bridge to the river, and the supporting structures. Pier 2 is located on the outer bend of the river, with its pile cap protruded slightly into the waterway. As such the protrusion will cause local scouring at the toe of Pier 2 (Lim, 1997; Lim and Cheng, 1998). In addition, its location at the bend further aggravates the extent of localized scouring at the abutment.

During a recent flood, severe river bank erosion has occurred, causing slope failure along a 50 m stretch on the upstream bank of the abutment. This realignment of the channel geometry

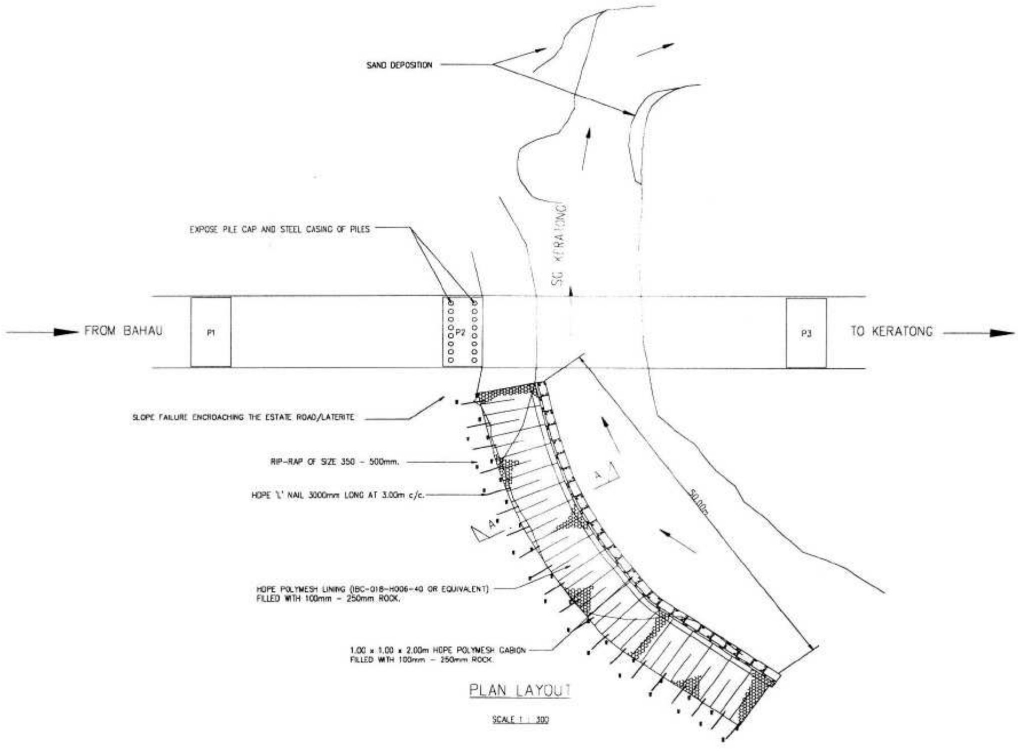

Figure 2 : Plan View of Keratong River Bridge

may have caused the shifting of the thalweg of the channel bed, and thereby directing the main flood flow towards Pier 2. Consequently, the toe of the approach fill slope was eroded, and undermining of the fill material occurred causing slope failure at Pier 2. The result is that the pier pile cap and steel casing of the piles have been exposed, and the flow encroached all the way onto the estate road. The damage can be attributed to the increased velocity of the river flow during the flood and the migration of the channel flow towards Pier 2.

The scour protection measures for this bridge is to use tubular gabions filled with sand to protect the toe of Pier 2 and conventional box gabions for the river banks. The tubular gabions are fabricated using high-density polyethylene (HDPE) mesh. They can be filled mechanically or manually with gravels or sand to form tubular bags. The tubular sand bags used in this case is 0.636m in diameter and of varying length to suit the site condition. They are arranged in a longitudinal and transverse direction, interlocking using HDPE 'T'-nail (see Figure 3). The site visit showed that the scour countermeasure worked well for this bridge and no apparent defects were detected. However, it must be pointed out the HDPE material is flammable, evident from the burnt marks on the material observed during the site visit. Apparently, local residents have used the site as a picnic location, hence the burnt marks on the tubular sand bags.

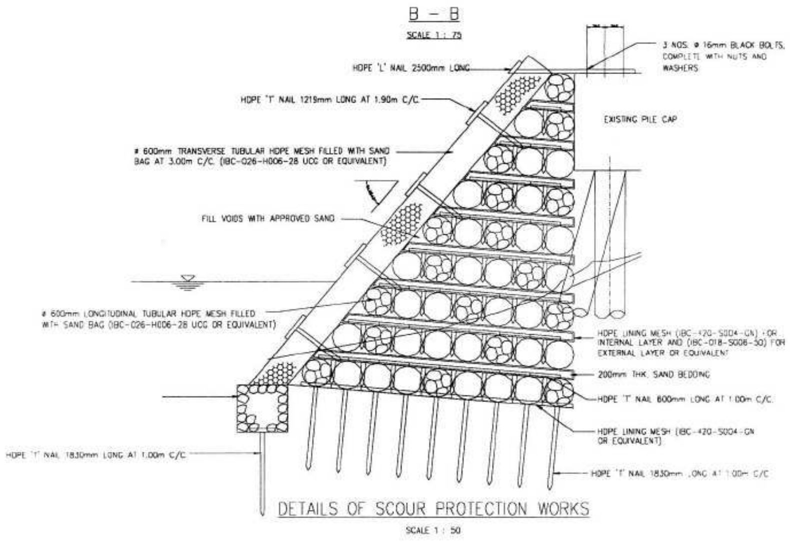

Figure 3 : Details of Scour Protection Works Using Tubular Gabion at Keratong River Bridge

PLENTONG RIVER BRIDGE

Plentong River Bridge is a dual carriage road linking Johor Bahru to Pasir Gudang Port along Federal Trunk Route 17 in the state of Johor, Malaysia. The bridge, which was constructed in 1983, consists of two separate structures each carrying two lanes of traffic in one direction. The structures comprise a three-span bridge of pretension inverted T-girders, and the length of the spans are 11.25m, 15.75m, and 11.25m, respectively. Two cylindrical bridge piers with diameter = 1.32 m support each of the two structures (see Figure 4).

Scour problems at Plentong River Bridge were reported very early in the life of the bridge, and sheet piles were used to protect one of its abutments (see Figure 5). However, this countermeasure did not seem to arrest erosion completely. In 1995, the flex-slab system was used as a more permanent solution after the apparent success of the method for Pukin River Bridge. However, this system did not work as anticipated and failed. To arrest further erosion, the District Office of the Public Works Department used gabions and rubbled pitching type of protection as a temporary measure (see Figure 6). The scouring problem at this bridge is now continuously being monitored to check that it is not detrimental to the overall safety of the superstructure.

On the day of the site visit (January 3, 2000), observations clearly showed that erosion had occurred along the riverbank at the bridge site. Sheet piles and a grade-control structure were apparent on the upstream end of the bridge. The upstream grade-control structure appeared to have re-directed the flow towards the pier and the abutment (see Figure 4). It is envisaged that during flood flows in the preceding monsoon season, scouring at both the pier and abutment

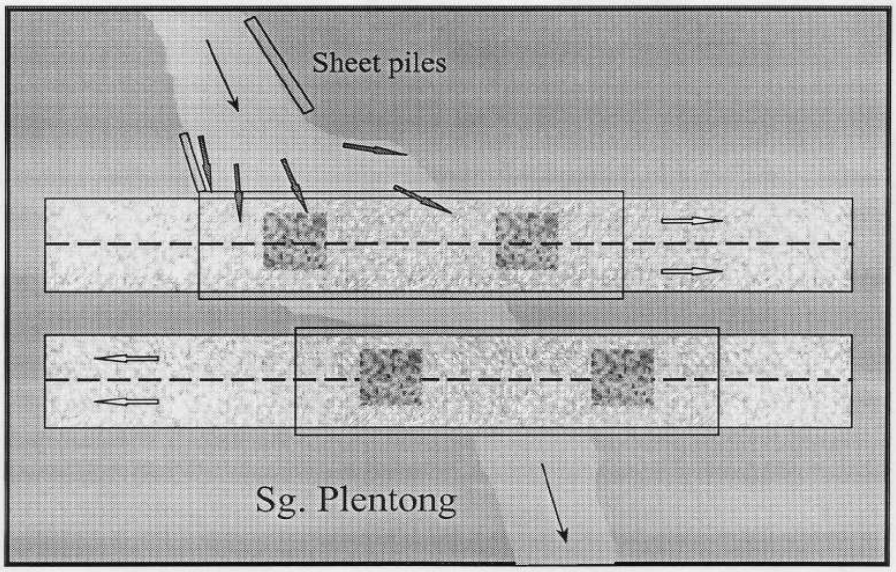

Figure 4 : Plan View of Plentong Bridge

Figure 5 : Plentong River Bridge (flow from top right to bottom left)

Figure 6 : Use of Gabions as a Temporary Scour Countermeasure at Plentong River Bridge (looking downstream)

would have been substantial, contributing to the failure of the flex-slab system. This can be seen in Figure 6, which shows that severe erosion has taken place along the abutment, and the flex-slab system on the abutment has collapsed. The photograph in Figure 5 also shows severe scouring at the pier, damaging the flex-slab system on the approach fill slope. It can be seen that the flex-slabs are lying around the site of the pier.

It is interesting to note that the same scour countermeasure method, vis-à-vis the flex-slab system, which appears to work reasonably well for Pukin River Bridge, fails miserably in the case of Plentong River Bridge. This conflicting performance of a particular scour countermeasure at different bridge sites is not only confined to Malaysia, but is also confirmed by an extensive site visit program of many bridges in the U.S.A. by Parker et al. (1998). The search for a comprehensive method of scour protection, suitable for varying site conditions, is top most in the mind of bridge engineers.

CONCLUSIONS

Despite the many bridge failures due to scouring at their foundation, the search for an all-encompassing scour countermeasure method is still elusive. One of the main reasons for such a poor record on bridge failure is the lack of a systematic research investigation on scour countermeasure at bridges. A cursory search of published literature will immediately reveal that little has been done to examine the performance of scour countermeasure on bridge foundations, even for the most commonly used scour countermeasure, vis-à-vis riprap protection. Many of the previous studies on riprap protection were confined to determining riprap sizing for bridge pier applications. As far as the writers are aware, no specific study has been devoted to bridge abutment. Furthermore, most of these studies were conducted under a clear-water condition, and their validity when applied to a live-bed condition remains unproven. Only recently, the study by Chiew and Lim (2000) has ventured into riprap protection under a live-bed condition. Even so, riprap protection around an abutment continues to remain in uncharted territories.

In addition, the experience gained on the success or failure of a particular scour countermeasure under a given flow condition often remains the "property" of a particular agency or company. This knowledge is often not shared although blame should not be levied so quickly on the practitioners. Generally, there are not many platforms on which such experience and knowledge can be disseminated. It is hoped that the information on how bridge design is conducted in Malaysia, and the three examples cited above will encourage discussion for mutual benefits amongst researchers and practitioners in this area.

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