DETERMINATION OF FLOOD LOAD ON BRIDGE DECK

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By

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ABSTRAK

Banyak jambatan telah dirosakkan semasa banjir di seluruh dunia termasuk banjir yang terkini di pantai timur Semenanjung Malaysia pada Disember 2014. Punca utama yang menyebabkan kerosakan jambatan semasa banjir telah dikaji. Objektif utama kajian yang berasaskan simulasi berangka ini adalah untuk menentukan kesan pelbagai kedalaman aliran, halaju aliran dan ketinggian geladak jambatan yang terdiri daripada lima galang terhadap beban hidraulik pada jambatan semasa banjir berlaku. Selain itu, hubungan antara pekali seret (C_D), pekali daya angkat (C_L), dan pekali momen (C_M) berkenaan dengan nisbah pembanjiran (h^*), nisbah kehampiran (P_r) dan nombor Froude (Fr) telah dikaji. Julat halaju banjir di antara 1 m/s hingga 8.22 m/s telah digunakan dan kedalaman aliran 5 m hingga 14.3 m telah dipertimbangkan. Kelegaan geladak jambatan adalah dalam julat 1.5 m hingga 6.0 m. Eksperimen fizikal yang terdiri daripada kes tenggelam penuh dan separa penuh telah dilakukan untuk mengesahkan keputusan daripada simulasi berangka. Untuk hubungan dengan nisbah pembanjiran, pekali seret dan pekali daya angkat, mempunyai julat kira-kira 0.3 hingga 5.2 dan -2.4 ke hampir 0, masing-masing. Pekali momen yang diperolehi daripada kajian ini adalah dalam julat 0.3 hingga 14.1. Pekali daya angkat dan pekali momen berkenaan dengan nisbah kehampiran kebanyakannya dalam julat -2 hingga 2 dan -6 hingga 15. Pekali seret mempunyai nilai positif dalam julat 0.5 hingga 5 untuk hubungan dengan nisbah kehampiran. Graf menghubungkaitkan pekali seret, pekali daya angkat dan pekali momen dengan nisbah pembanjiran, nisbah kehampiran dan nombor Froude telah dihasilkan. Keputusan kajian adalah berguna untuk jurutera untuk menganggarkan beban hidrodinamik ke atas jambatan yang ditenggelami penuh atau separa penuh semasa banjir.

ABSTRACT

Many bridges were damaged during flood worldwide including the recent flood happened in East Coast of Peninsular Malaysia in December 2014. The fundamental causes of bridge failure during flooding are reviewed. The main objective of this numerical simulation based research are to determine the effect of various flow depths, flow velocities and elevations of the five-girder bridge deck to the hydrodynamic loading on bridge deck during flood events. Moreover, the relationship between the drag coefficient (C_D), lift coefficient (C_L), moment coefficient (C_M) with respect to the inundation ratio ($h*$), proximity ratio (P_r) and Froude number (Fr) were developed. The range of the flood velocity simulated in this study was 1 m/s to 8.22 m/s and the flow depth of 5 m to 14.3 m was considered. The vertical clearance of the bridge deck is within the range of 1.5 m to 6.0 m. A physical experiment consisting partially submerged and fully submerged cases was conducted to validate the numerical results. From the numerical analysis, the graphs of the drag coefficient, lift coefficient and moment coefficient with respect to inundation ratio and Froude number were plotted. For the relationship with inundation ratio, drag and lift coefficient have a range of about 0.3 to 5.2 and -2.4 to nearly 0, respectively. Moment coefficients obtained from this study are in the range of 0.3 to 14.1. Lift and moment coefficient with respect to the proximity ratio are mostly in the range -2 to 2 and -6 to 15. The drag coefficient have all positive value in the range of 0.5 to 5 for the relationship with proximity ratio. The results of this study are useful for engineers to estimate the hydrodynamic loadings on bridge deck in designing new or retrofitting existing bridge so that it can withstand the hydrodynamic forces under partially or completely inundated cases.

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LIST OF ABBREVIATIONS

AASHTO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
ASCE	**A**merican **S**ociety of **C**ivil **E**ngineers
ARI	**A**verage **R**ecurrence **I**nterval
CFD	**C**omputational **F**luid **D**ynamics
FHWA	**F**ederal **H**ighway **A**dministration
LES	**L**arge **E**ddy **S**imulation
NAASRA	**N**ational **A**ssociation of **A**ustralian **S**tate **R**oad **A**uthorities
NS	**N**avier-**S**tokes
RANS	**R**eynolds-**A**veraged **N**avier-**S**tokes
REDAC	**R**iver **E**ngineering and Urban **D**rainage Research **C**entre
STL	**ST**ereo**L**ithography
3D	**T**hree **- D**imensional
UK	**U**nited **K**ingdom
UN-SPIDER	**U**nited **N**ations Platform for **D**isaster Management and **E**mergency **R**esponse
USA	**U**nited **S**tates of **A**merica
UCS	**U**niversal **C**oordinate **S**ystem
USM	**U**niversiti **S**ains **M**alaysia
VOF	**V**olume of **Fl**uid

NOMENCLATURES

A	Frontal area of the bridge body
C_D	Drag coefficient
cg	Center of gravity
C_L	Lift coefficient
C_M	Moment coefficient
F_D	Drag force
F_L	Lift force
Fr	Froude number
F_{RES}	Resultant force
g	Gravitational acceleration
h^*	Inundation ratio
M	Overturning moment
P	Pressure
P_o	Free stream mean dynamic pressure
P_r	Proximity ratio
Re	Reynold number
s	Bridge deck height
t	Time
W	Bridge width
z	Vertical clearance height of the bridge deck

Greek Letter

h	Water depth

v	Velocity of water flow
θ	Angle
ρ	Fluid density (or water density)
τ	Shear stress

CHAPTER 1

INTRODUCTION

1.1 Background

Flooding is a natural disaster, and it is common in many places where heavy rainfall occurs. This natural disaster is extremely dangerous and has the potential to wipe away an entire city, coastline and cause great damage to property and loss of life. It has high erosive power and can be extremely destructive to the embankments, roads and bridges and paralyzed transportation for long periods. The extent, magnitude and duration of the storms could cause flood waters to overtop numerous bridges, roads and levees. Kilometres of roadway will be submerged and eroded, and portions of roadway will be covered with sediment deposits after flood waters recede. According to UN-SPIDER (2006), flooding means a general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland or tidal waters from the unusual and rapid accumulation or runoff of surface waters from any source.

Parola et al. (1998) reported that the floods that destroyed the upper Mississippi River and Missouri River basins (a place in the Southern region of the United States) in 1993 were abnormal in terms of magnitude, severity of damage, and season of occurrence. The severe rainfall events were coupled with wet antecedent conditions over large areas. This flooding caused large-scale damage to embankments, roadways and bridge, and also damage to slopes, drainage facilities as well as pavements. The U.S. Federal Highway Administration (FHWA) has allocated more than 158 million dollars for repair and/ or replacement of elements of the federal aid highway system in roughly 2305 sites (Parola et al., 1998).

The drastic change of global environments in recent years induces a significant increase of natural hazards, both in magnitude and frequency. Catastrophic damages of important infrastructures, especially the heavy concrete bridges, have been reported frequently (Chen et al., 2014). Bridges playing an important role in connecting the community. Based on Guo et al. (2009), numerical simulations were carried out at the Argonne National Laboratory to examine the hydrodynamic forces experienced by an inundated bridge deck as it is considered as an important input in the design of bridges. The evaluation of bridge stability after flooding events, including the integrity of the bridge itself and the erosion of the riverbed surrounding bridge support structures, is critical to highway safety. During a big flood, a highway bridge above the sea or waterway may be submerged partially or completely. Such flows add significant hydrodynamic loading on bridge deck, possibly resulting in the turnover of the bridge decks and failure of the bridge superstructures (Guo et al., 2009).

In December 2014, the massive floods that hit the Kelantan state in East Coast of Peninsular Malaysia have left behind a trail of destruction. It was the worst in the past history confirmed by the National Security Council (NSC). According to the council's report, the water level of Sungai Kelantan at Tambatan Diraja, which has a danger level of 25 m, reached 34.17 m compared to 29.70 m in 2004 food and 33.61 m in the 1967 flood. In addition, the existing bridges and infrastructures were damaged due to the flooding would be estimated up to RM 932 million for the state of Kelantan. Figure 1.1 shows the collapse of the Pulau Setelu Bridge across the 300 m wide Nenggiri River due to the extraordinary water levels. Figure 1.2 and Figure 1.3 shows the high speed currents had destroyed properties and infrastructures in the region of Kelantan and Pahang, respectively.

Figure 1.1: Wash Away of the Decks of Pulau Setelu Bridge in Kelantan
(Thestar, 2015)

Figure 1.2: Debris Accumulated at Bridges in Kelantan During the Recent Flood
(Straitstimes, 2014)

Figure 1.3: The Partially Collapse of Aur Gading Bridges in Pahang
(Astroawani, 2015)

Damages of bridges due to flood also happens worldwide recently. In the northwest region of Pakistan, a bridge linking Peshawar and Sheikhan in Lower Dir, dramatically collapsed on 5 April 2016 after torrential rains triggered flash floods as shown in Figure 1.4. At least 47 people have been killed and 37 of others injured in this flood event, as reported by the country's Provincial Disaster Management Authority. For the infrastructures, at least 141 houses have been damaged that yielded severe losses and casualties were beyond the expectation. The rescue actions have been blocked by the collapse of a bridge in the Khyber Pakhtunkhwa Province. The rains started lashing the northwest and other parts of Pakistan on Saturday, causing flooding in the Khyber Pakhtunkhwa Province (BBC, 2016).

Figure 1.4: Bridge Collapse During the Flood Event in Lower Dir
(BBC, 2016)

Furthermore, a huge suspension bridge was swept away by flash flooding in Nepal on 25 July 2016. The bridge, which crossed part of the Tinau River in the city of Butwal was completely destroyed due to the continuous monsoon rains (The Telegraph, 2016). According to the Nepal's government, at least 58 people have been killed, while another 20 people were missing. Hundreds of flood victims have lost their house and properties due to this horrify flood. The dramatic moment of the suspension bridge collapse during deadly Nepal floods is shown in Figure 1.5.

Figure 1.5: The Collapse of the Suspension Bridge due to the Flash Flood
(The Telegraph, 2016)

Similarly, a 44-year-old bridge in Himachal Pradesh's Kangra district in India collapsed on 11 August 2016 afternoon due to the heavy flow of flood water and rain. Figure 1.6 shows a large portion of the 160 m bridge and its pillars collapsing and getting swept away in the heavy current. According to the officials report, a total 76 m of the bridge on 10 pillars were washed away by flood waters. This old bridge links the villages of Himachal's Nurpur Tehsil with neighbouring Punjab area (NDTV, 2016).

Figure 1.6: The Bridge Collapsed in Heavy Rain in Kangra District of Himachal
Pradesh on 11 August 2016 (Newscrunch, 2016)