# HYDRODYNAMIC MODELLING OF A SEA-CROSSING BRIDGE IN THE MALDIVES

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# DEDICATION

This project report is dedicated to my late father, who taught me to persevere and prepared me to face the challenges with faith and humility. It is also dedicated to my mother for her ongoing love and support. And my wife who always had confidence in me and offered me encouragement and support in all my endeavours. Finally, I dedicate this project report to my daughter.

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# ABSTRACT

'Gaadhoo Koa Channel' is an atoll pass located in the southern tip of Malé Atoll, Maldives, which separates the capital city, Malé and the main international airport Hulhulé island. The Gaadhoo Koa channel is known for its strong tidal flow and strong swell waves and is located in a strategic area which includes the main shipping lane for Malé port and also marine traffic lanes connecting both Malé and Hulhulé with nearby inhibited islands and tourist resorts. Recently, a water crossing bridge has been constructed across the channel connecting these two islands. As a result, 21 bridge piers have been built across the channel which can result in potential changes of the flow regime in the vicinity of the bridge. This project report presents a numerical modelling study to investigate the hydrodynamic impact of the bridge piers in the Gaadhoo Koa channel. Various different software used for hydrodynamic modelling were explored and Delft3D-FLOW software was chosen. The model results were calibrated against water level data from Hulhulé station and finally model simulations were run to assess the hydrodynamic impact of the bridge piers. The results indicated that the flows in the close vicinity of the bridge were reduced with the introduction of bridge piers. Also, the magnitude of flow velocity reduced around bridge piers and increased in between bridge piers. Furthermore, the overall velocity distribution in the northern region from the bridge axis showed a decreased pattern while the southern regions showed an increased pattern: peak velocity in the northern region decreased by 7.3 % 500 m from bridge axis while peak velocity in the southern region raised by 33% 500 m from bridge axis. Based on these findings, it can be considered that the introduction of bridge piers can have a considerable impact on the hydrodynamic conditions of Gaadhoo Koa atoll pass.

# ABSTRAK

Terusan ‘Gaadhoo Koa’ adalah satu saluran terumbu karang yang terletak di selatan Malé Atoll di Maldives, yang mana memisahkan ibu negeri iaitu Malé dengan lapangan terbang antarabangsa utama di pulau Hulhulé. Terusan Gaadhoo Koa terkenal dengan aliran pasang surut dan ombak yang kuat dan terletak di kawasan strategik termasuklah laluan perkapalan utama untuk pelabuhan Malé dan laluan trafik marin yang menghubungkan Malé dan Hulhulé dengan rizab pulau berhampiran dan tempat peranginan. Terkini, satu jambatan telah dibina menyeberangi saluran dan menghubungkan dua pulau tersebut. Dengan itu, sebanyak 21 buah tiang jambatan telah dibina dan boleh menyebabkan perubahan pada regim aliran di sekitar kawasan jambatan tersebut. Laporan projek ini mengemukakan satu kajian pemodelan berangka untuk mengenalpasti kesan hidrodinamik terhadap tiang jambatan di Terusan Gaadhoo Koa. Beberapa perisian telah digunakan untuk pemodelan hidrodinamik dan perisian Delft3D-FLOW telah dipilih. Keputusan daripada model itu ditentukur terhadap data paras air daripada stesen Hulhulé dan akhirnya simulasi dijalankan untuk menilai kesan adanya tiang jambatan terhadap hidrodinamik. Dapatan kajian menunjukkan kadar aliran di sekitar kawasan jambatan menurun dengan adanya tiang jambatan tersebut. Selain itu, magnitud halaju aliran menurun di keliling tiang jambatan dan meningkat di antara tiang-tiang jambatan tersebut. Tambahan lagi, agihan halaju keseluruhan menunjukkan pengurangan di kawasan utara jambatan dan peningkatan di kawasan selatan jambatan di mana halaju puncak di utara menurun sebanyak 7.3%, 500 m daripada paksi jambatan dan halaju puncak di selatan meningkat sebanyak 33%, 500 m daripada paksi jambatan. Berdasarkan hasil kajian ini, kesan hidrodinamik daripada pembinaan jambatan ini masih boleh diterima bagi terusan Gaadhoo Koa.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| RMSE | - | Root Mean Square Error |
| GEBCO | - | General Bathymetric Chart of the Oceans |
| SI | - | Scatter Index |
| GUI | - | Graphical User Interface |
| SW | - | South West |
| NE | - | North East |
| SE | - | South East |
| NE | - | North East |
| FM | - | Flexible Mesh |
| ADCP | - | Acoustic Doppler Current Profiler |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| $U, V$ | - | the depth averaged velocities in horizontal and vertical direction |
| $Q$ | - | Contributions per unit area due to the discharge or withdrawal of water, precipitation and evaporation |
| $q_{in}, q_{out}$ | - | The local sources and sinks of water per unit of volume |
| $P$ | - | The non-local source term of precipitation |
| $E$ | - | Non-local sink term due to evaporation |
| $\upsilon_V$ | - | Vertical eddy viscosity coefficient |
| $F_x$ , $F_y$ | - | Force in the momentum equations representing unbalance of horizontal Reynolds stresses. |
| $M_x$ and $M_y$ | - | Contributions due to external sources or sinks of momentum |
| $t$ | - | Time |
| $h\bar{u}$, $h\bar{v}$ | - | Depth average values of the velocity components in the $x$, $y$ directions |
| $S^{HD}$ | - | Magnitude of discharge due to point sources |
| $f$ | - | Coriolis parameter |
| $g$ | - | Gravitational acceleration |
| $P_a$ | - | Atmospheric pressure |
| $\rho_0$ | - | Reference density of water |
| $\rho$ | - | Density of water |
| $u_s$, $v_s$ | - | Velocity components at which the water is discharged |
| $S_{xx}$, $S_{xy}$, $S_{yx}$, $S_{yy}$ | - | Radiation stress components |
| $T_{xx}$, $T_{xy}$, $T_{yx}$, $T_{yy}$ | - | Lateral stresses |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Problem Background

Water-crossing bridges are known to have an impact on the hydrodynamic environment of coastal areas. However, the majority of hydrodynamic modelling studies carried out in this field are limited to coastal environments comprising bays. There are a wide variety of coastal environments that need to be considered to better understand the nature of the impact that water crossing bridges have on the hydrodynamic processes.

There has been a number of studies carried out to understand the nature of the impact of water-crossing bridges on the surrounding hydrodynamic. Guo et al. (2016) simulated the changes in the tidal flow field in Quanzhou Bay due to a newly constructed sea crossing bridge and found that slow flow areas were present in front of bridge piers due to the influence of rising and falling tides. Likewise, slow flow areas were also formed at the back of the piers after the rising and falling tides passed the piers. The upstream and downstream flow along the bridge was found to be influenced over a distance extending approximately one kilometre. Similarly, Li et al. (2014) simulated the hydrodynamic processes in Jiaozhou Bay, China, due to a cross-bay bridge and found that the bridge significantly affected the hydrodynamics at the entrance, waterways and north side of the bridge. Despite these findings, the hydrodynamic modelling of the Hangzhou Bay Bridge (Pang et al., 2008) indicated that the impact of bridge piers on the hydrodynamic setting was limited to a small region surrounding the bridge suggesting that the relative size of the bridge span and surrounding water area could affect the degree of the impact. Moreover, the impact of flow changes due to piers will be much greater if the bridge lies in a channel subjected to strong current and complex terrain (Zhao et al., 2015).

The proposed study will model the hydrodynamic impact due to a water-crossing bridge located in the *Gaadhoo Koa*, which is an atoll pass in the Malé atoll, Maldives, separating the capital city, Malé, and the main international airport Hulhulé island. Unlike most of the previous studies which concentrates on modelling hydrodynamic impacts on bay environments, this study will model the impact on an atoll environment which is a different coastal setting. The Gaadhoo Koa channel which is known for its strong tidal flow and strong swell waves is located in a strategic area which includes the main shipping lane for Malé port and also marine traffic lanes connecting both Malé and Hulhulé with nearby inhibited islands and tourist resorts. In addition, in the Malé side the bridge will pass over a prominent surfing site. Hence it is important to understand potential adverse effects the bridge piers may have on the hydrodynamic processes. The Delf3D programme will be used for the modelling which is a cell-centred finite difference based integrated flow and transport modelling programme of Deltares for the marine environment.

## 1.2 Statement of the Problem

The Gaadhoo Koa atoll pass separating Hulhulé and Malé Island in Maldives is the main shipping lane for Malé port. The channel experiences strong tidal flow and receives strong swells from the southeast (SE) direction. In particular, the wave conditions on the SE reef corner of Malé, which is a prominent surf spot, and on the southern tip of Hulhulé Island are particularly strong. Recently a mega infrastructure project was undertaken in the area, which involved the construction of an overwater bridge covering an overwater length of 1.39 km. There is a concern that the bridge may impact the currents and wave conditions across the atoll pass. Some studies (Guo et al., 2016) has shown that the hydrodynamics of overwater bridges has caused notable changes in the flow fields over a domain that can extend as far as 1 km along bridge sites. These changes were most prominent in the vicinity of bridge piers. However, these studies were conducted to model impact of water-crossing brides in bays or rivers and there is limited literature on the effect of overwater bridges in atoll environments. Hence, it is essential to predict potential hydrodynamic changes in order to assess the physical impact of the overwater bridge on the flow field along Gaadhoo Koa.

## 1.3 Research Objectives

The objectives of the research are:

(a) To develop a numerical model to simulate the hydrodynamics of *Gaadhoo Koa* region, Maldives.

(b) To assess the hydrodynamic impact of sea-crossing bridge across the channel.

## 1.4 Research Scope

This study will involve building a two-dimensional hydrodynamic model for the Gaadhoo Koa region passing between Malé and Hulhulé island which comprises gentle reef slopes on either side of a deep oceanic channel. Only the flow module of the model programme, which focuses on unsteady flows due to tidal and meteorological forces, will be considered in this study. Model will be calibrated only based on water level data recorded at the Hulhulé tide station. After setting up model, simulations will be run to assess the hydrodynamic impacts in relation to current and tidal flows of a sea-crossing bridge across the channel. The wave and morphological conditions will not be assessed in this project.

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