

TABLE OF CONTENTS

| | |
|---|-----|
| TITLE PAGE | i |
| APPROVAL SHEET | ii |
| LEGALIZATION SHEET | iii |
| STATEMENT SHEET | iv |
| PREFACE | v |
| TABLE OF CONTENTS | vi |
| LIST OF FIGURES | x |
| LIST OF TABLES | xii |
| ABSTRACT | xiv |
| CHAPTER 1 INTRODUCTION | 1 |
| 1.1 Background | 1 |
| 1.2 Problem Statement | 2 |
| 1.3 Research Objectives | 3 |
| 1.4 Research Limitation | 3 |
| 1.5 Research Benefit | 3 |
| CHAPTER 2 LITERATURE REVIEW | 4 |
| 2.1 Jetty Structure..... | 4 |
| 2.2 Pile System on Jetties..... | 5 |
| 2.2.1 Dolphin Structure | 5 |
| 2.2.2 Pile Foundation | 5 |
| 2.2.3 Pile Subjected to Lateral Load | 6 |
| 2.3 Pile on Slope..... | 7 |
| 2.3.1 Slope stability..... | 7 |
| 2.3.2 Pile behavior on riverbank slope | 8 |
| 2.4 Previous Studies | 9 |
| 2.4.1 Pile on slope behavior due to lateral load | 9 |
| 2.4.2 Post-failure analysis of the port using PLAXIS 2D staging construction..... | 10 |
| 2.4.3 Importance of soil model selection on PLAXIS 2D | 10 |
| 2.5 Analysis of dredging effect using PLAXIS 2D modelling..... | 11 |
| 2.6 Comparative study of two soil models for 2D and 3D PLAXIS modelling | 11 |



| | |
|--|-----------|
| 2.7 Combining SAP2000 and PLAXIS 2D for structural and geotechnical analysis | 11 |
| 2.8 Novelty of Research | 11 |
| CHAPTER 3 THEORETICAL FRAMEWORK | 12 |
| 3.1 Structural Loads on Jetty Design | 12 |
| 3.1.1 Dead load..... | 12 |
| 3.1.2 Live load..... | 12 |
| 3.1.3 Berthing force..... | 12 |
| 3.1.4 Mooring force..... | 14 |
| 3.1.5 Current Force..... | 15 |
| 3.1.6 Wind drag force | 16 |
| 3.1.7 Earthquake load..... | 16 |
| 3.1.8 Load combination..... | 18 |
| 3.2 Soil Mechanics and Parameters..... | 19 |
| 3.3 Bearing Capacity of Pile Foundation | 21 |
| 3.3.1 Axial load | 21 |
| 3.3.2 Lateral load..... | 22 |
| 3.3.3 Deflection criteria and safety limit..... | 24 |
| 3.4 Slope Failure Mechanism..... | 25 |
| 3.5 Finite Element Method Program | 25 |
| 3.5.1 SAP2000 Overview | 26 |
| 3.5.2 PLAXIS Overview | 28 |
| 3.6 Soil Constitutive Models | 30 |
| 3.6.1 Mohr-Coulomb..... | 30 |
| 3.7 Structural Elements | 31 |
| 3.7.1 Plates | 31 |
| 3.7.2 Node-to-node anchors | 32 |
| 3.7.3 Embedded beam rows | 32 |
| CHAPTER 4 RESEARCH METHOD | 35 |
| 4.1 Research Location | 35 |
| 4.2 Research Procedure | 35 |
| 4.3 Literature Review | 37 |
| 4.4 Research Data..... | 37 |
| 4.5 Structural Modelling in SAP2000 | 37 |



| | |
|--|-----------|
| 4.6 Geotechnical Modelling in PLAXIS 2D | 40 |
| CHAPTER 5 RESULTS AND DISCUSSION..... | 44 |
| 5.1 General Description of Research Site | 44 |
| 5.1.1 Soil profile and classification | 46 |
| 5.1.2 Soil parameters and overburden stress | 48 |
| 5.2 Calculation of Applied Loads on Dolphin Structures | 49 |
| 5.2.1 Berthing Energy | 50 |
| 5.2.2 Mooring Force..... | 52 |
| 5.2.3 Current Force..... | 54 |
| 5.2.4 Wind Force | 54 |
| 5.3 Manual Analysis of Single Pile Capacity | 54 |
| 5.3.1 Axial Bearing Capacity | 54 |
| 5.3.2 Lateral Resistance | 57 |
| 5.3.3 Deflection Analysis | 60 |
| 5.4 Numerical Modelling Using SAP2000 | 62 |
| 5.4.1 Soil Spring Values | 62 |
| 5.4.2 Modelling Procedure | 64 |
| 5.4.3 Output results | 66 |
| 5.5 Numerical Modelling Using PLAXIS 2D | 70 |
| 5.5.1 Model geometry and soil layers | 70 |
| 5.5.2 Plate elements with embedded beam row | 71 |
| 5.5.3 Embedded beam row with node-to-node anchor..... | 74 |
| 5.5.4 Output interpretation | 76 |
| 5.6 Structure Internal Forces Output Comparison | 81 |
| 5.6.1 Between SAP2000 and PLAXIS 2D programs..... | 81 |
| 5.6.2 Between manual and numerical Results..... | 86 |
| CHAPTER 6 CLOSING..... | 88 |
| 6.1 Conclusions | 88 |
| 6.2 Recommendations | 88 |
| REFERENCES..... | 90 |
| APPENDIX A..... | 97 |
| APPENDIX B..... | 98 |
| APPENDIX C | 99 |



Numerical Analysis of Breasting Dolphin Failure on Riverbank Slope: A Case Study of Jetty Construction in East Kalimantan

Bella Esfadiary Yus, Prof. Ir. T. Faisal Fathani, S.T., M.T., Ph.D., IPU., ASEAN.Eng. ; Dr.Eng. Fikri Faris, S.T., M.Eng

Universitas Gadjah Mada, 2025 | Diunduh dari <http://etd.repository.ugm.ac.id/>

UNIVERSITAS
GADJAH MADA

| | |
|-------------------------|-----|
| APPENDIX D | 100 |
| APPENDIX E | 102 |
| APPENDIX F | 107 |
| APPENDIX G | 109 |

LIST OF FIGURES

| | | |
|-------------|--|----|
| Figure 1.1 | Coal exports by major exporters from 1978 to 2020 (modified from International Energy Agency, 2021) | 2 |
| Figure 1.2 | Documentation of breasting dolphin on site | 2 |
| Figure 2.1 | Type of port (Triatmodjo, 2009) | 4 |
| Figure 2.2 | Top view of jetty structure (modified from Siliwangi et al., 2014) | 4 |
| Figure 2.3 | Load transfer of pile: (a) Axial load, (b) Lateral load (Basu et al., 2008) | 5 |
| Figure 2.4 | Rigid and flexible piles under lateral loading (Basu et al., 2008)..... | 6 |
| Figure 2.5 | Groundwater conditions when the river level is: (a) stable, (b) unstable (adapted from Wikipedia, as cited in Ubechu & Okeke, 2017) | 9 |
| Figure 2.6 | Piles in slope: (a) Active pile, (b) Passive pile..... | 10 |
| Figure 3.1 | Rotation radius around the ship's center of gravity | 14 |
| Figure 3.2 | Design response spectrum (Kementerian PUPR, 2021) | 17 |
| Figure 3.3 | PGA map (Kementerian PUPR, 2021)..... | 18 |
| Figure 3.4 | Early α correlations developed from load test databases (Doherty & Gavin, 2011) | 22 |
| Figure 3.5 | Typical 2D finite element (Potts & Zdravković, 2001) | 26 |
| Figure 3.6 | Implementation of soil springs (modified from Haskell et al., 2019)..... | 27 |
| Figure 3.7 | Positions of node and stress points in soil elements: (a) 15-node triangle (b) 6-node triangle (Bentley, 2022)..... | 28 |
| Figure 3.8 | Example of plane strain (Bentley, 2022)..... | 29 |
| Figure 3.9 | Mohr-Coulomb constitutive model (Tjie-Liong, 2014)..... | 30 |
| Figure 3.10 | Plate element (Bentley, 2022) | 31 |
| Figure 3.11 | Node-to-node anchor element (Bentley, 2022) | 32 |
| Figure 3.12 | Embedded beam row interaction with soil (Bentley, 2022)..... | 33 |
| Figure 3.13 | Embedded pile row element (Bentley, 2022)..... | 33 |
| Figure 3.14 | p - y curve for soft clay (Rocscience, 2022)..... | 34 |
| Figure 4.1 | Study area (modified from Google Earth, 2025; Pusat Penelitian dan Pengembangan Geologi, 1995; Pusat Pengembangan Infrastruktur Informasi Geospasial, 2024)..... | 35 |
| Figure 4.2 | Flowchart of research..... | 36 |
| Figure 4.3 | Tensile requirements (ASTM A252-10, 2018) | 38 |
| Figure 4.4 | Design response spectrum graph (RSA Ciptakarya, 2021)..... | 40 |
| Figure 4.5 | Geometry modelled on .dxf file | 42 |
| Figure 5.1 | Cross section layout of the jetty | 44 |
| Figure 5.2 | Drawing of dolphin structure: (a) Initial design, (b) Field implementation..... | 45 |
| Figure 5.3 | Aerial photo of site layout and displacement note | 45 |
| Figure 5.4 | Soil stratigraphy of cross section STA 0+350 | 47 |
| Figure 5.5 | Variation of SPT N-Values with depth | 47 |
| Figure 5.6 | Determining r/L value..... | 51 |
| Figure 5.7 | Example of taking the α value | 56 |



| | | |
|-------------|---|----|
| Figure 5.8 | Successful input of soil spring on SAP2000: (a) 3D-plane, (b) 2D-plane..... | 63 |
| Figure 5.9 | Side view of applied loads on the upper dolphin structure | 65 |
| Figure 5.10 | Undeformed 3D Shape: (a) Initial design, (b) Field implementation | 66 |
| Figure 5.11 | Deformed 3D shape based on ASD Combination (scaled 1:10): (a) Initial design, (b) Field implementation | 67 |
| Figure 5.12 | Axial force output: (a) Initial design, (b) Field implementation..... | 67 |
| Figure 5.13 | Shear force output: (a) Initial design, (b) Field implementation..... | 68 |
| Figure 5.14 | Bending moment output: (a) Initial design, (b) Field implementation | 68 |
| Figure 5.15 | Deformed mesh of post-construction of plate-EBR combination..... | 73 |
| Figure 5.16 | Bending moments produced on dolphin's bracings | 74 |
| Figure 5.17 | Mesh detail and quality analysis of the model..... | 75 |
| Figure 5.18 | Safety factor observed..... | 76 |
| Figure 5.19 | Plastic points produce failure point domination (slip surface) | 77 |
| Figure 5.20 | Deformation generated: (a) lateral direction, (b) vertical direction | 78 |
| Figure 5.21 | Axial forces of PLAXIS 2D..... | 80 |
| Figure 5.22 | Shear forces of PLAXIS 2D..... | 80 |
| Figure 5.23 | Bending moments of PLAXIS 2D | 81 |
| Figure 5.24 | Axial force: (a) front vertical piles, (b) rear batter piles | 82 |
| Figure 5.25 | Shear force: (a) front vertical piles, (b) rear batter piles | 83 |
| Figure 5.26 | Bending moment: (a) front vertical piles, (b) rear batter piles..... | 84 |
| Figure 5.27 | Output of axial force on bracings..... | 85 |
| Figure 5.28 | Typical displacement output | 86 |

LIST OF TABLES

| | | |
|------------|--|----|
| Table 2.1 | Allowable lateral pile loads (USACE, 1993 in Budhu, 2010). | 7 |
| Table 2.2 | Macro causing slope movement (Look, 2007)..... | 8 |
| Table 3.1 | Berthing velocity (Triatmodjo, 2009)..... | 13 |
| Table 3.2 | Drag coefficients for a circle-shaped object (Ports and Harbours Bureau MLIT / National Institute for Land and Infrastructure Management MLIT / Port and Airport Research Institute, 2020) | 16 |
| Table 3.3 | Site classification (Badan Standardisasi Nasional, 2017) | 17 |
| Table 3.4 | Load combinations (modified from American Society of Civil Engineer, 2017; Department of Defense USA, 2017; International Code Council, 2016)..... | 18 |
| Table 3.5 | Approximate variation of consistency, N , and undrained cohesion of clay (Ameratunga et al., 2016)..... | 19 |
| Table 3.6 | Value ranges for Poisson's ratio (Look, 2007) | 19 |
| Table 3.7 | Representative of dry unit weight (Look, 2007) | 20 |
| Table 3.8 | Typical values of E_u for clays (Ameratunga et al., 2016)..... | 20 |
| Table 3.9 | Value ranges for Poisson's ratio (Bowles, 1997)..... | 20 |
| Table 3.10 | Approximately typical ranges of the permeability coefficient for cohesive and non-cohesive soils (Wilun, 2013 in Wrzesiński, 2020)..... | 21 |
| Table 3.11 | Safety factor category for slope stability (Bowles, 1979)..... | 25 |
| Table 3.12 | Lateral soil resistance-deflection relationship (PileLAT, 2017) | 34 |
| Table 4.1 | Pipe pile properties on site | 37 |
| Table 4.2 | Defined material properties | 38 |
| Table 4.3 | Defined section properties | 39 |
| Table 4.4 | Design spectral acceleration parameters | 40 |
| Table 4.5 | Material properties | 41 |
| Table 4.6 | Stage construction on site..... | 43 |
| Table 5.1 | Total displacement in a month..... | 46 |
| Table 5.2 | River tide level on the project site..... | 46 |
| Table 5.3 | Soil properties of BH-01 and BH-03 based on the N-SPT test result | 48 |
| Table 5.4 | Input parameters for Mohr-Coulomb Model in PLAXIS 2D..... | 49 |
| Table 5.5 | Input parameter for fill material in PLAXIS 2D | 49 |
| Table 5.6 | Dimensions and capacity of the cylinder fender (modified from Triatmodjo, 2009)..... | 52 |
| Table 5.7 | Resume of wind drag force | 53 |
| Table 5.8 | Summary of Q_s calculation results for each layer | 56 |
| Table 5.9 | Summary of the soil spring coefficient of the initial design | 63 |
| Table 5.10 | Spring value check based on Bowles (1997)..... | 64 |
| Table 5.11 | Maximum displacement produced by design codes for LRFD..... | 66 |
| Table 5.12 | Recapitulation of the force generated by piles in the spring modelling..... | 69 |
| Table 5.13 | Resultant forces | 70 |
| Table 5.14 | EBR parameters input: embedded..... | 72 |



Numerical Analysis of Breasting Dolphin Failure on Riverbank Slope: A Case Study of Jetty Construction in East Kalimantan

Bella Esfadiary Yus, Prof. Ir. T. Faisal Fathani, S.T., M.T., Ph.D., IPU., ASEAN.Eng. ; Dr.Eng. Fikri Faris, S.T., M.Eng

Universitas Gadjah Mada, 2025 | Diunduh dari <http://etd.repository.ugm.ac.id/>

UNIVERSITAS
GADJAH MADA

| | | |
|------------|--|----|
| Table 5.15 | Plate parameters input | 72 |
| Table 5.16 | EBR parameter input: nonembedded | 75 |
| Table 5.17 | Node-to-node anchor parameters input | 75 |
| Table 5.18 | Recapitulation of manual deflection calculation results..... | 87 |
| Table 5.19 | Recapitulation of manual and numerical analysis | 87 |