PERFORMANCE EVALUATION OF PORTABLE BRIDGES USING NUMERICAL SIMULATIONS AND LABORATORY TESTS

A G U S R I L

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DEDICATION

"Especially for ayah and mak, Syamsir and Alm Naimah.
My beloved wife and sons, Vivi Anggraini, Muhammad Athar Al Rafee, and Muhammad Arkaan At Tariq".
You give me strength to carry on.

ABSTRACT

Portable bridges are important for ground mobility to transport troops and vehicles through gaps like rivers, valleys, and lakes, or when an existing bridge gets damaged because of natural disaster or being attacked by enemy. Imported and expensive portable bridges have been deployed in such situation. The objectives of this research are to design and evaluate the performance of locally produced CFRP, AA 6061 T6 and Hybrid beams and their steel connectors. The available materials in this country were selected in order to produce affordable beams and also to reduce dependency on imported portable bridges. Aluminum design manual (ADM) and trilateral design and test code for military bridging and gap-crossing equipment (TDTC) were used in designing and testing of beams. Detailed design of the beam was carried out by numerically simulating the beams using MSC Patran/Nastran finite element software. The simulations were constrained by allowable strength of material and vertical displacement limit of L/180. Wet hand layup method was selected in fabrication of CFRP and Hybrid beams prototype, while AA 6061-T6 beam prototype was fabricated using welding method. Strains and displacements were recorded during structural testing of the beam. Maximum load that can be supported by CFRP beam is 11.3 kN which is lower than design load of 12.7 kN due to preliminary failure of CFRP layers at compression joints. AA 6061-T6 and Hybrid beam have shown good performance that they are able to support load up to the ultimate load (U). Addition of CFRP layers at the bottom flange of beam has reduced tensile strains and vertical displacements of beam by 38 % and 9 %, respectively against AA 6061-T6 beam. Production cost of AA 6061-T6 and Hybrid beam is only at 33.3% of imported LEGUAN bridge. It can be concluded that the joints of CFRP beam need to be redesigned in order to improve performance of the beam. The redesigned joints were used successfully in AA 6061-T6 and Hybrid beam that show good performance as designed. The beams can be produced locally using available materials and technology in Malaysia at a much lower cost than the imported product.

ABSTRAK

Jambatan mudah alih penting untuk mobiliti di darat bagi mengangkut anggota dan kenderaan merentasi halangan seperti sungai, lembah, dan tasik atau apabila jambatan sedia ada menjadi rosak disebabkan oleh bencana alam atau serangan musuh. Jambatan mudah alih yang mahal dan diimport biasanya akan digunakan pada keadaan sedemikian. Objektif penyelidikan ialah untuk mereka bentuk dan menilai prestasi rasuk CFRP, AA 6061 T6 dan Hybrid dan penyambung-penyambung keluli mereka. Bahan-bahan sedia ada di Negara ini dipilih untuk menghasilkan rasuk mampu milik dan juga mengurangkan ketergantungan kepada jambatan-jambatan mudah alih yang diimpot. ADM dan TDTC digunakan untuk rujukan dalam merekabentuk dan ujian struktur terhadap rasuk Rekabentuk terperinci keatas rasuk telah dijalankan termasuk mensimulasikan kesan sudut-sudut dinding rasuk dan jenis pengukuh melintang dinding rasuk. Simulasi ini dikekang oleh kekuatan bahan dan had lenturan yang dibenarkan iaitu L/180. Kaedah ‘wet hand-layup’ telah terpilih dalam pembinaan prototaip rasuk CFRP dan Hybrid, sementara prototaip rasuk AA 6061-T6 difabrikasi menggunakan kaedah kimpal. Ketegangan dan lenturan telah direkodkan semasa ujian struktur keatas rasuk. Muatan maksimum yang boleh disokong olek rasuk CFRP ialah 11.3 kN yang mana lebih rendah dari beban rekabentuk iaitu 12.7 kN disebabkan kegagalan lapisan-lapisan CFRP di sendi-sendi mampatan. Rasuk AA 6061-T6 dan Hybrid mempertunjukkan prestasi yang baik yang mampu menyokong

beban sehingga beban muktamat (U). Tambahan lapisan CFRP di permukaan bebibir rasuk telah mengurangkan ketegangan tegang dan sesaran tegak rasuk sehingga 38 % dan 9 %, masing-masing. Kos pengeluaran rasuk AA 6061-T6 dan hybrid ialah pada 33% berbanding kos jambatan Leguan yang diimpot. Ia boleh disimpulkan bahawa sendi perlu direkabentuk semula supaya meningkatkan prestasi rasuk. Sendi sendi yang direkabentuk semula digunakan dengan jayanya di rasuk AA 6061 T6 dan Hybrid. Rasuk-rasuk ini boleh dihasilkan tempatan menggunakan bahan-bahan dan teknologi sedia ada dengan kos lebih rendah daripada produk yang diimport.

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APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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LIST OF ABREVIATIONS

AA	-	Aluminum Alloy
ADM	-	Aluminum Design Manual
AISI	-	American Iron and Steel Institute
AMCB	-	Advance Modular Composite Bridge
AVLB	-	Armor Vehicle Launched Bridge
CAB	-	Composite Army Bridge
CFRP	-	Carbon Fiber Reinforced Polymer
FM	-	Field Manual
FRP	-	Fiber Reinforced Polymer
GFRP	-	Glass Fiber Reinforced Polymer
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAB	-	Heavy Assault Bridge
MCB	-	Module Composite Bridge
MLC	-	Military Load Class
TDTC	-	Trilateral Design and Test Code for Military Bridging

LIST OF SYMBOLS

E_{11}	-	Elastic modulus in fiber direction (longitudinal)
E_{22}	-	Elastic modulus in transverse direction
v_{12}	-	Poisson's Ratio
G_{12}	-	Shear modulus
λ_s	-	slenderness ratio of an element with an intermediate stiffener
I_o	-	moment of inertia of element
t	-	Thickness of element
S_1	-	Slenderness ratio at the intersection of the equations for yielding and inelastic buckling
B_c	-	Buckling constant intercept for compression in columns and beam flanges
F_{cy}	-	Compressive yield strength
D_c	-	Buckling constant slop for compression in columns and beam flanges
F_e	-	Elastic buckling stress
λ_{eq}	-	equivalent slenderness ratio for alternate determination of compressive strength for flexure or axial compression
B_{br}	-	Buckling constant intercept for bending compression in flat elements
D_{br}	-	Buckling constant slop for bending compression in flat elements
F_{ty}	-	Tensile yield strength
P_n	-	Nominal tensile strength
A_g	-	Gross cross-sectional area
Ω_t	-	Safety factor for tension (1.85 for bridge-type structure)
σ_t	-	Tensile stress of bottom flange
$\boldsymbol{I_x}$	-	Moment of inertia of the beam's cross-section