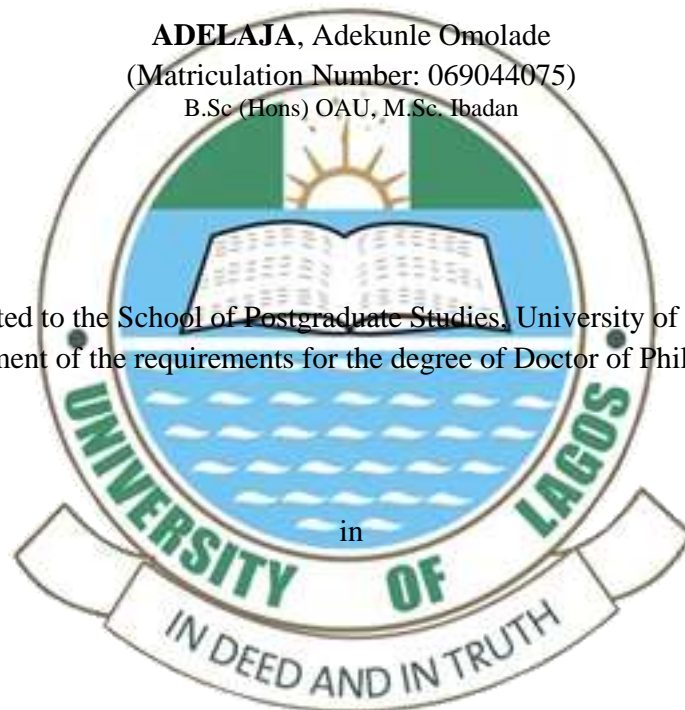


**THE RESPONSE OF PIPELINES IN HIGH PRESSURE, HIGH TEMPERATURE
OFFSHORE ENVIRONMENT**

by

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Thesis submitted to the School of Postgraduate Studies, University of Lagos in partial
fulfilment of the requirements for the degree of Doctor of Philosophy



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Department of Mechanical Engineering
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**SCHOOL OF POSTGRADUATE STUDIES
UNIVERSITY OF LAGOS, AKOKA, LAGOS, NIGERIA**

CERTIFICATION

This is to certify that the thesis

**“THE RESPONSE OF PIPELINE IN HIGH PRESSURE, HIGH TEMPERATURE
OFFSHORE ENVIRONMENT”**

Submitted to the School of Postgraduate Studies, University of Lagos for the award of the
degree of

Doctor of Philosophy (Mechanical Engineering)
is a record of original research carried out

by

ADELAJA, Adekunle Omolade
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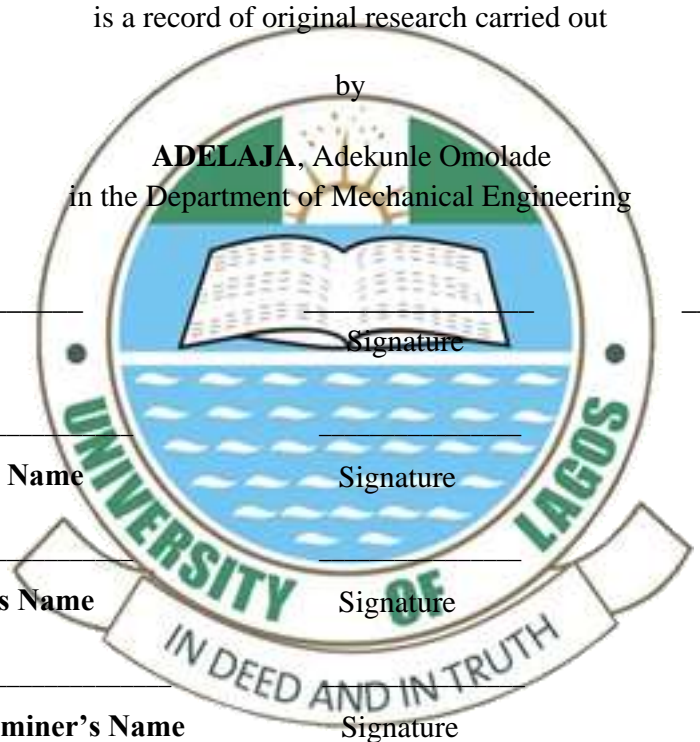
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DEDICATION

This work is dedicated

Firstly, to GOD, the only wise one, the Alpha and Omega, the Beginning and the End, Who Was, and Who is, and Who is to come, the Almighty

and, to my late mother, Mrs. Felicia Modupe ADELAJA whom GOD used to raise my siblings and me after the death of my father twenty nine years ago



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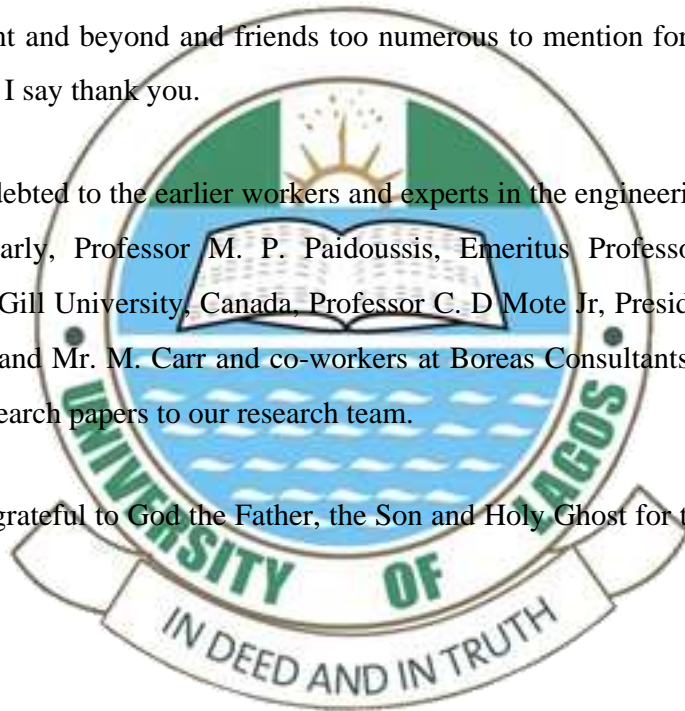
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ABSTRACT

This thesis explores the application of Euler-Bernoulli beam theory to derive the equations of motion of fluid conveying pipelines subjected to high pressure, high temperature offshore conditions. The vibration responses show that the higher the density of the transported fluid, the lower the critical velocity at which resonance will take place, hence heavier fluid should be pumped at lower velocity than lighter ones whereas heavier surrounding fluid (as in the case of salty and muddy swamp) behaves as a damper. In addition, the higher the inlet temperature, the higher the period of oscillation but the lower the critical velocity required to initiate resonance. The study also provides theoretical bases for the popular practice of burying of pipeline as a means of controlling buckling and further justifies the same means for the control of pipe walking where the geology permits it. Deformations such as pipeline buckling and pipe walking are found to be enhanced by increase in inlet temperature which is a function of the well condition. Furthermore, the study shows that the hitherto central role attributed to transient response may not be the main driver for pipe walking since the magnitude of steady state is higher and may after all be responsible. Also, the results of the order of the contributing factors indicate that oscillatory strain, pressure, temperature, tension and friction among others play a significant role in the phenomenon of walking.

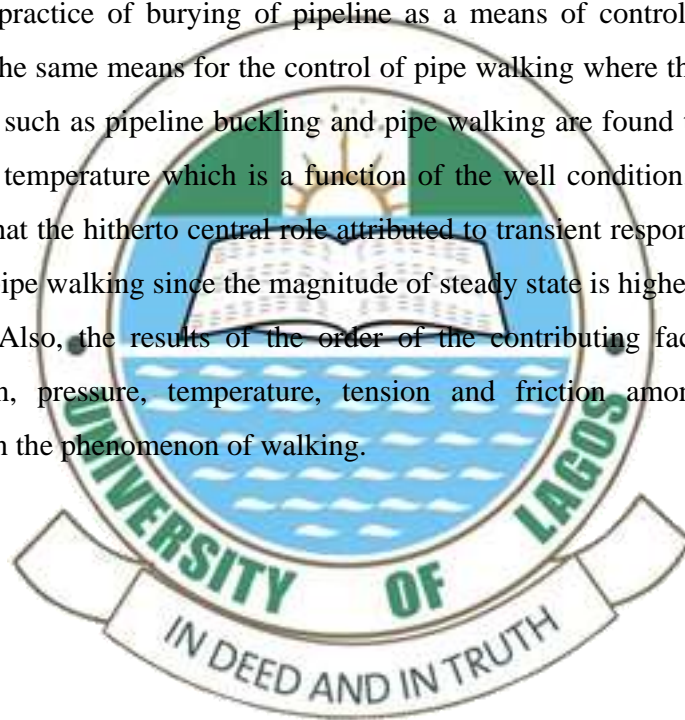


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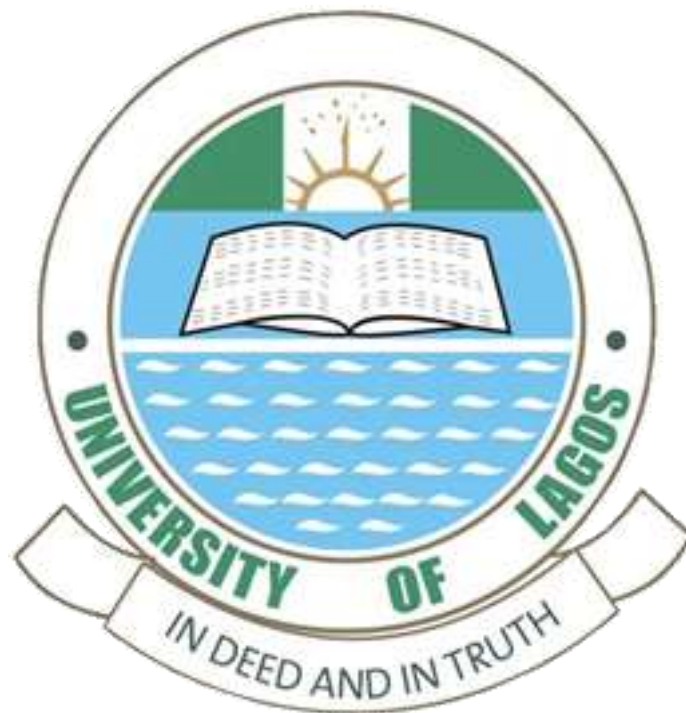
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- Figure 5.35c: Transient-state longitudinal response \bar{u} to polynomial order for case 110
 $R_i = 0.4m, L = 2km, \kappa = 1.0, \gamma = 0.02, \bar{U} = 2.5, \delta_1 = 0.3721, \delta_2 = 0.3111$
 $n = 1, m = 3$
- Figure 5.35d: Transient-state longitudinal response \bar{u} to polynomial order for case 111
 $R_i = 0.4m, L = 2km, \kappa = 1.0, \gamma = 0.02, \bar{U} = 2.5, \delta_1 = 0.3721, \delta_2 = 0.3111$
 $n = 1, m = 4$

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$$n = 1, m = 7, \delta_0 = 2.0r_0$$

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NOTATIONS

Pipe Motion Analysis

A	Pipe internal cross sectional area
A_o	Original cross sectional area of pipe at inlet
A_t	Pipe cross sectional area
A	Surface area of pipe
A'^p	Change in the surface area of the pipe
C_1	Damping force per unit velocity in the transverse direction
C_2	Damping force per unit velocity in the axial direction
C_D	Hydrodynamic drag coefficient
E	Young's modulus of elasticity
M	Bending moment
Q	Shearing force
f_n	Normal force per unit length
f_t	Tangential frictional force at fluid-pipe interface
δx	Elemental length
$\frac{D}{Dt}$	Material derivative
$F_1(t)$	External force in the transverse direction
$F_2(t)$	External force in the longitudinal direction
g	Acceleration due to gravity
h	Depth of pipe below sea level
I	Moment of inertia
k_b	Stiffness of the sea bed
L	Length of pipe
m	Mass per unit length of the transported fluid inside the pipe
m_f	Mass per unit length of the pipe
m_p	Mass per unit length of the pipe
m_w	Mass per unit length of sea water displaced by pipe during transverse motion

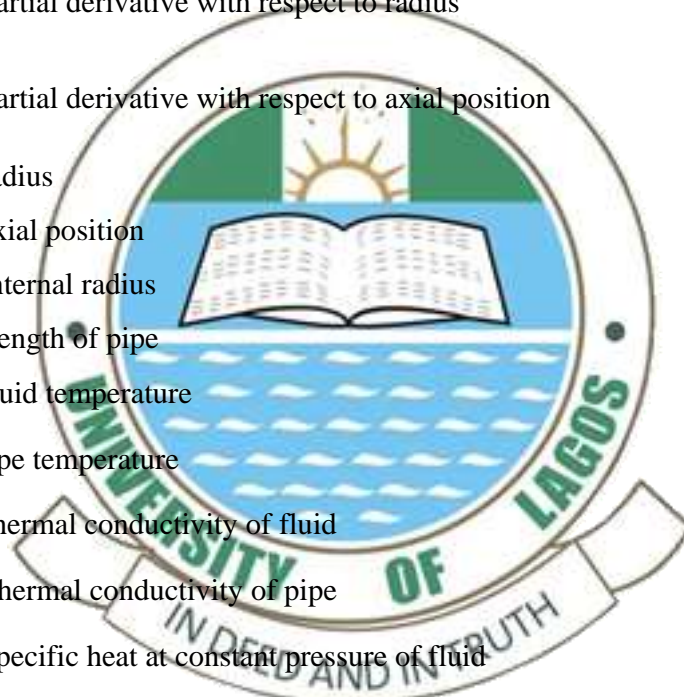


m	Sum of the masses per unit length of pipe and fluid
M	Sum of masses per unit length of pipe, fluid in pipe and external fluid displaced by pipe
p	Fluid pressure
P_h	Hydrodynamic effect of the ocean
p	Pressure drop
T_o	Tension in pipe
t	Time
U	Velocity of fluid flowing inside pipe
U'	Differential of velocity with respect to x
$\frac{dU}{dt}$	Differential of fluid velocity with respect to time
u	Longitudinal displacement
u'	First order derivative of longitudinal displacement wrt x
u''	Second order derivative of longitudinal displacement wrt x
u'''	Third order derivative of longitudinal displacement wrt x
u^{IV}	Fourth order derivative of longitudinal displacement wrt x
\tilde{u}	Longitudinal response in Laplace plane
u^F	Longitudinal response in Fourier plane
$u^{\sim F}$	Longitudinal response in Fourier-Laplace plane
w	Transverse displacement
w'	First order derivative of transverse displacement wrt x
w''	Second order derivative of transverse displacement wrt x
w'''	Third order derivative of transverse displacement wrt x
w^{IV}	Fourth order derivative of transverse displacement wrt x
$w_o(t)$	External excitation displacement
\tilde{w}	Transverse response in Laplace plane
w^F	Transverse response in Fourier plane
$w^{\sim F}$	Transverse response in Fourier-Laplace plane
x	Axial displacement coordinate
z	Transverse displacement coordinate

r_i	Internal radius of pipe
r_o	External radius of pipe
$[\cdot]$	Dimensionless quantities

Energy Transport Analysis

$\frac{D}{Dx}$	Material derivative
$\frac{\partial}{\partial t}$	Partial derivative with respect to time
$\frac{\partial}{\partial r}$	Partial derivative with respect to radius
$\frac{\partial}{\partial x}$	Partial derivative with respect to axial position
r	radius
x	axial position
R	Internal radius
L	Length of pipe
T_f	Fluid temperature
T_p	Pipe temperature
k_f	Thermal conductivity of fluid
k_p	Thermal conductivity of pipe
c_{pf}	Specific heat at constant pressure of fluid
c_{pp}	Specific heat at constant pressure of pipe
Bi	Biot number
Nu	Nusselt number
Pe	Peclet number
Fo	Fourier number
h_i	Heat transfer coefficient for the inner surface of the pipe
h_o	Heat transfer coefficient for the external surface of the pipe



U_i	Overall heat transfer coefficient
q_w	Heat flow through the wall of the pipe
p_i	Hankel roots/eigenvalues of the fluid equation
b_i	Hankel roots/eigenvalues of the pipe equation
m_i	Fourier transforms roots
H_n	Hankel transform of order n
J_n	Bessel function of the first kind of order n
K_n	Bessel function of the third kind

Greek letters

α	Coefficient of thermal expansivity
γ	Coefficient of area deformation
ω_n	Transverse natural frequency
$\omega_{n(1)}$	Transverse natural frequency
$\omega_{n(2)}$	Complimentary transverse natural frequency
Ω_1	Longitudinal natural frequency
Ω_2	Complimentary longitudinal natural frequency
θ	Angle between pipe element position and the x-axis
φ	Orientation of the system
ε	Axial strain
Ω_1	Environmental fluid domain
Ω_2	Fluid in pipe domain
Ω_3	Soil domain
$\chi_1-\chi_7$	Coefficients of the polynomial approximation
$\Delta\Theta$	Temperature change from inlet to outlet
p	pressure change from inlet to outlet
Θ	Temperature of the flowing fluid
Θ'	Temperature gradient



Θ_f	Dimensionless temperature of fluid
θ_f^F	Dimensionless temperature of fluid in Fourier plane
$\bar{\theta}_f^F$	Dimensionless temperature of fluid Fourier-Hankel plane
Θ_p	Dimensionless temperature of pipe
θ_p^F	Dimensionless temperature of pipe in Fourier plane
$\bar{\theta}_p^F$	Dimensionless temperature of pipe Fourier-Hankel plane
δ_1	$\frac{m_f}{m}$
δ_2	$\frac{m_w}{M}$
μ	Coefficient of sliding friction
μ_s	Sliding frictional coefficient of the interface of pipe sediment layer
∇_2	Laplacian operator
∇	Gradient operator
ρ_w	Density of water
Φ	Velocity potential
ρ_f	Fluid density
ρ_p	Pipe density
α_f	Thermal diffusivity for fluid
α_p	Thermal diffusivity for pipe

