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

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CERTIFICATION

This is to certify that the thesis

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

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is a record of original research carried out

by

ADELAJA, Adekunle Omolade
in the Department of Mechanical Engineering

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External Examiner's Name	Signature	Date
SPGS Representative	Signature	Date

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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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 is 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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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_p	Surface area of pipe
A'	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_f	Mass per unit length of the transported fluid inside 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
$\dot{U}$	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
$\tilde{u}^F$	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
$\tilde{w}^F$	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

$\overline{[.]}$ 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

$\varpi_{n(1)}$ Transverse natural frequency

$\varpi_{n(2)}$ 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

χ_1–χ_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 Temperature

Θ' gradient

Θ_f	Dimensionless temperature of fluid
Θ_f^F	Dimensionless temperature of fluid in Fourier plane
$\overline{\Theta}_f^F$	Dimensionless temperature of fluid Fourier-Hankel plane
Θ_p	Dimensionless temperature of pipe
Θ_p^F	Dimensionless temperature of pipe in Fourier plane
$\overline{\Theta}_p^F$	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