LEMBAR
HASIL PENILAIAN SEJAWAT SEBIDANG ATAU *PEER REVIEW*
KARYA ILMIAH : PROSIDING

Judul Karya Ilmiah : The effect of initial imperfection on buckling strength for straight and curved pipe under pure bending load
Jumlah Penulis : 2 Orang (**Hartono Yudo**,Takao YOSHIKAWA)
Status Pengusul : Penulis ke-1
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Surabaya, 12 Oktober 2021

Reviewer 1

Prof. Dr. Ketut Buda Artana, S.T., M.Sc.
NIP. 197109151994121001
Unit Kerja : T. Sistem Perkapalan FTK ITS

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NIP. 197102071995121001
Unit Kerja : Teknik Mesin FT UNDIP

LEMBAR
HASIL PENILAIAN SEJAWAT SEBIDANG ATAU *PEER REVIEW*
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Total = (100%)	**27,00**	**28,00**	**27,50**
Nilai Pengusul = (60% x 27,50)= 16,50			

Semarang,

Reviewer 2

Prof. Dr. Moh. Djaeni, S.T., M.Eng.
NIP. 197102071995121001
Unit Kerja : Teknik Mesin FT UNDIP

Reviewer 1

Prof. Dr. Ketut Buda Artana, S.T., M.Sc.
NIP. 197109151994121001
Unit Kerja : T. Sistem Perkapalan FTK ITS

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The effect of initial imperfection on buckling strength for straight and curved pipe under pure bending load

Yudo H.[a, b], Yoshikawa T.[c]

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[a] Dept of Maritime Engineering, Graduate School of Engineering, Kyushu University, Fukuoka, Kyushu, Japan
[b] Diponegoro University, Indonesia
[c] Dept of Marine System Engineering, Kyushu University, Fukuoka, Kyushu, Japan

Abstract

The effect of initial imperfection on the buckling strength of a straight pipe under bending has been investigated by nonlinear FEA, considering the effect of a cross sectional oval deformation by changing the variables of pipes, that is, L/D varying from about 2.5 to 20 and D/t varying from about 50 to 200.

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The Effect of Initial Imperfection on Buckling Strength for Straight and Curved Pipe Under Pure Bending Load

Hartono Yudo
Doctoral course student
Dept of Maritime Engineering, Graduate School of Engineering
Kyushu University, Fukuoka, Kyushu, Japan
Lecturer, Diponegoro University, Indonesia

Takao Yoshikawa
Professor, Dept of Marine System Engineering
Kyushu University, Fukuoka, Kyushu, Japan

ABSTRACT

The effect of initial imperfection on the buckling strength of a straight pipe under bending has been investigated by nonlinear *FEA*, considering the effect of a cross sectional oval deformation by changing the variables of pipes, that is, *L/D* varying from about 2.5 to 20 and *D/t* varying from about 50 to 200. Furthermore also the buckling strength of curved pipes (*D/t* = 200) have been investigated by changing *R/D* from 50 to 200. Not only the elastic buckling but also the elasto-plastic buckling was investigated. From the numerical results, the followings were found. The buckling strength reduced more in longer pipes than shorter pipes due to pre-buckling oval deformation. But, the reduction of buckling strength due to imperfection is larger in shorter pipes than in longer pipes. Moreover, the buckling strength reduces more by the imperfection of buckling mode than by that of oval mode. The effect of imperfection on buckling strength in plastic region was smaller than in elastic region. The buckling moment of curved pipes reduces more when the curvature of pipe increases in both original and imperfect pipes, especially for longer pipes.

KEY WORDS: Buckling strength; initial imperfection; straight pipe; curved pipe; oval deformation; elastic buckling; elasto-plastic buckling.

NOMENCLATURE

D : *Pipe diameter*
E : *Young's modulus*
M : *Applied Moment*
M_a : *Maximum moment in elasto-plastic analysis*
M_b : *Buckling moment obtained by nonlinear calculation in elastic analysis.*
M_{cr} : *Critical bending moment under axial compression*
M_o : *Maximum moment in elastic analysis pipe without imperfection*
M_p : *Ultimate (plastic) moment*
M_y : *Yield moment*
r : *Pipe radius*
R : *Radius of curvature in curved pipe*
t : *Nominal wall thickness*
δ : *Oval deformation*
δ_o : *Maximum imperfection amplitude*
ν : *Poisson's ratio*
σ_{cr} : *Critical buckling stress under axial compression*
σ_y : *Yield stress*

INTRODUCTION

To predict the buckling strength of straight and/or curved pipes is important for designing the offshore pipelines. The various kinds of loads, such as axial compression, external pressure and bending are applied to the offshore pipelines. The buckling strength of a pipe is much reduced due to the initial imperfections. The effects of initial imperfections on the buckling strength of pipes under axial compression and pressure are investigated by many researchers, but the research for buckling strength of pipes under bending is still limited. Therefore, in this study, the comprehensive study for the buckling strength of pipes under bending is performed by utilizing *FEA.*

First, the previous researches for estimating the buckling strength of pipe under pure bending moment are briefly explained.

The maximum bending stress of cylinder under the critical (buckling) moment M_{cr} can be expressed by equation (1).

$$\sigma_{cr} = \frac{M_{cr}}{\pi r^2 t} \tag{1}$$

Where, r is the pipe radius, and t is the wall thickness.

If the critical buckling stress of a cylinder under bending is same as the buckling stress of a cylinder under uniform compression, the critical stress can be expressed by Eq. 2.

$$\sigma_{cr} = \frac{E}{\sqrt{3(1-\nu^2)}}\left(\frac{t}{r}\right) \tag{2}$$

From Eqs. 1~2, the critical moment can be estimated as follow.

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Integrate Pipe-Soil Interaction Model with the Vector Form Intrinsic Finite Element Method-Nonlinear Analysis of Free-Span

Leige Xu, Mian Lin
Institute of Mechanics, Chinese Academy of Sciences
Beijing, China

ABSTRACT

A practical model is developed by integrating pipe-soil interaction model with the vector form intrinsic finite element (VFIFE) method. The soil resistance in axial direction of pipeline is taken into account by elasto-frictional method. The soil reactions in the lateral and vertical directions of pipeline are simulated by a force-resultant model (so-called bubble model). An automatic method is developed to simulate pipe-soil contacting and separating phenomenon in dynamical analysis. A series of cases are studied. The displacements of simulation compare well with DNV. The static moment formula of DNV is modified by contrast with simulation results, which are appropriate for interaction of the studied pipeline with sandy seabed.

KEY WORDS: pipeline; tension; bending moment; VFIFE; bubble model; soil resistance; pipe-soil contacting and separating .

INTRODUCTION

Submarine pipeline is a critical infrastructure in exploration and transportation of marine oil and gas. There are always free-span submarine pipelines due to unevenness of seabed, scouring or pipelines crossing (Bijker, Staub et al. 1991, Choi 2001, Soreide, Paulsen et al. 2001, DNV-RP-F105 2006, Jin 2011). The concerned pipeline in South China sea passes through very irregular topography and has span length larger than 200m(L/D>300). However, the general formulas recommended by DNV are just feasible in situations of L/D<120 (Soreide, Paulsen et al. 2001). Therefore, the present study aims at developing a robust numerical model with which the following several points are taken into consideration in this paper to accurately simulate response of free-span pipeline. 1. The geometry nonlinearity and extra-large displacement of the long-span pipeline (DNV-RP-F105 2006). 2. Soil reaction force to pipeline as the pipeline embedded into soil. 3. The axial soil resistance in long-span case. 4. The pipe-soil contacting and separating phenomenon in dynamical analysis.

PIPE-SOIL INTERACTON MODEL

As mentioned above, the response of free-span pipeline is affected by pipe-soil interaction. Traditionally, restraint of seabed to pipeline is assumed as pinned-pinned, fixed-fixed, springs (Nielsen, Kvarme et al. 2002) or frictional (Lyons 1973, Wantland, O'Neill et al. 1979, Lambrakos 1985, Hong, Liu et al. 2004). But the influence of seabed to response of pipeline is just partly reflected by the above simplifications.

Three increasingly sophisticated force-resultant models (Elasto-plastic Model, Bounding Surface Model and Bubble Model) are introduced by Tian and Cassidy(2008). The bubble model is adopted in this paper because it simulates the force-displacement constitution best. Issues about numerically implementing several kinds of force-resultant pipe-soil interaction models in the analysis of pipelines are discussed in Tian and Cassidy(2010). The efficiency and accuracy of several time integration methods are discussed. The Euler-Modified method is proved to be the most time-saving one meeting engineering accuracy and is therefore chosen by us with adopted model accuracy of 10^{-4}.

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Interpretation of the South Stream Ring Collapse Test Program Results

Ruud Selker
INTECSEA
Delft, The Netherlands

Pedro M.C. Ramos
INTECSEA
Delft, The Netherlands

Ping Liu
INTECSEA
Delft, The Netherlands

ABSTRACT

A comprehensive study was conducted on the collapse mechanism of rings cut off from line pipe specimens. It was theoretically established that a ring without end restraints should have a lower collapse pressure value than an equivalent full-scale joint. However, similar collapse pressure test results were obtained for both rings and joints. Ring tests differ from joint tests in end restraint, but both capture collapse resistance integrally, while coupon tests (production tests) only capture the influence of material properties. The 'length effect' and the 'end cap effect' increase the collapse resistance of a joint, while radial end restraints increase the collapse resistance of a ring. These effects are found to be of same order of magnitude for the investigated combination of parameters (thermally aged SAWL 450 and D/t of approximately 20). Further, influence of the out-of-roundness shape and material properties on the collapse behaviour of rings was assessed.

KEY WORDS: South Stream; collapse; pipelines; ring; length effect; end cap effect; seal friction; out-of-roundness.

NOMENCLATURE

Symbols

D	Outside diameter (m)
D_{max}	Maximum measured outside diameter (m)
D_{min}	Minimum measured outside diameter (m)
D_{nom}	Nominal specified outside diameter (m)
E	Young's modulus (Pa)
N	Number of data points (-)
f_0	Ovality (%)
f_y	Specific minimum (uniaxial) yield stress (SMYS, Pa)
k_R	Radial foundation stiffness (Pa/m)
n	Circumferential wave number (-)
p	Contact pressure (Pa)
p_c	Collapse pressure (Pa)
p_e	Elastic collapse pressure (Pa)
p_p	Plastic collapse pressure (Pa)
t	Wall thickness (m)
Δ_n	Fourier ovality with respect to wave number n (%)
α_{fab}	Fabrication factor (-)
β	End cap pressure toggle factor (-)
δ	Push distance (m)
ε	Strain (m/m)
μ	Friction factor (-)
ν	Poisson's ratio (-)
ξ	Ramberg-Osgood shape factor (-)
σ	Stress (Pa)
$\sigma_{0.23}$	Material strength corresponding to 0.23 % strain (Pa)
$\sigma_{0.5}$	Material strength corresponding to 0.5 % strain (Pa)
σ_a	Axial (longitudinal) stress (Pa)
σ_c	Compressive stress (Pa)
σ_h	Hoop (circumferential) stress (Pa)
σ_t	Tensile stress (Pa)
τ	Shear stress (Pa)

Abbreviations and Acronyms

CoV	Coefficient of variation
FEA	Finite element analysis
FEED	Front end engineering design
FEM	Finite element model
JCOE	J-ing, C-ing, O-ing and expansion (production method)
Linopot	Linear potentiometer
OOR	Out-of-roundness
RO	Ramberg-Osgood
SAWL	Longitudinally submerged arc-welded pipes
UOE	U-ing, O-ing and expansion (production method)

INTRODUCTION

For the South Stream Offshore Pipeline project, four 32-inch (outside diameter, D) subsea pipeline strings, having 39 mm nominal wall thickness (t) and approximately 930 km length each, will be installed in the Black Sea from the Russian shore, through Turkish waters, to the Bulgarian shore, in water depths ranging up to 2200 m.

To confirm the collapse resistance of offshore pipelines, usually full-scale tests are conducted. As it is inconvenient to transport large pipe joints around the world, it was decided to conduct ring collapse tests as

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Probabilistic Lateral Buckling Assessment

Carlos Sicilia
INTECSEA
Woking, Surrey, UK

Emilien Bonnet
INTECSEA
Perth, WA, Australia

Philip A. Cooper
INTECSEA
Woking, Surrey, UK

ABSTRACT

This paper presents a probabilistic method to assess the lateral buckling response of a pipeline. The method is based on a Monte Carlo simulation in which the lateral buckling response is predicted using a surrogate model that uses artificial neural networks calibrated from non-linear FE analyses. The method presented intends to improve on current industry best practice by directly considering the limit states relevant to global buckling to produce designs with consistent levels of reliability.

KEY WORDS: Pipelines; Lateral Buckling; Probabilistic; Neural network; Safebuck; Reliability; Monte Carlo

NOMENCLATURE

ANN	: Artificial neural network
CoV	: Coefficient of variation
ESF	: Effective section force
FEA	: Finite element analysis
GLBSM	: Global lateral buckling surrogate model
ILT	: In-line tee
IMR	: Inspection maintenance and repair
JIP	: Joint industry project
LLBSM	: Local lateral buckling surrogate model
LRFD	: Load and resistance factor design
OOS	: Out of straightness
UR	: Utilization ratio
VAS	: Virtual anchor spacing
μ_L^{BO}	: Breakout lateral pipe-soil friction factor

INTRODUCTION

In the design of offshore pipelines, it is often convenient and sometimes necessary to allow the formation of lateral buckles. This relieves the axial compression, but can sometimes lead to severely localized bending deformations. In such designs, the lateral buckles are often subjected to the most onerous loading conditions and govern the mechanical design of the pipeline.

The response of a pipeline at a lateral buckle can be modeled in great detail using sophisticated non-linear finite element analysis. However, these advanced models require detailed information that is not available at the design stage. This information includes the pipe-soil interaction response, which could be quantified at the design stage but is subjected to significant uncertainty, and the as-laid geometry of the pipe in the vertical and horizontal planes, which can only be established once the pipeline has been constructed. The uncertainty in these two parameters leads to an additional unknown, which is where the buckles form and more importantly how far apart buckles are from each other, as this governs the level of load (axial feed-in or expansion) that goes onto each buckle location.

The uncertainty in design is normally accounted for by using safety (Load and Resistance) factors, calibrated to achieve a certain probability of failure. In the case of the lateral buckling response of a pipeline, this would seem impractical, given the very high level of uncertainty and the inter-dependence between the global response of the pipeline, i.e. where buckles form, and the local response at each lateral buckle. Under these circumstances, a pipeline-specific probabilistic assessment appears to be a suitable approach.

This type of approach was proposed by the Safebuck JIP (Bruton and Carr, 2011), which developed the Buckfast software, available to the participants of the JIP. This approach, however, is based on the concept of the characteristic VAS (virtual anchor spacing), which requires a calibration, implicit in the Safebuck methodology/guidelines, to obtain the required probabilities of failure.

The purpose of this paper is to present a probabilistic assessment of the lateral buckling response of a pipeline that is based on the actual limit states and therefore requires no calibration. The proposed strategy is intended to achieve probabilities of failure in line with those required for the rest of the design of the system and therefore produce a design that is better optimized.

The ultimate goal is thus to propose a method that allows reducing costs, whilst maintaining the required levels of safety.

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The Numerically Exact 6 Degree of Freedom Procedure for Geometrically and Physically Nonlinear Saint-Venant's Problem for a Moderately Thick Shell With Circular Axis

Igor Orynyak, Andrii Bogdan, Sergii Radchenko
IPP-Centre ltd.
Kyiv, Ukraine
and
Sergii Okhrimchuk
TECHDIAGAS Centre for Technical Inspection
Kyiv, Ukraine

ABSTRACT

An original numerical procedure for treating the Saint-Venant's problem for toroidal shells of arbitrary cross section under pressure and bending moment is suggested.

The main attention of investigators is given to geometrically nonlinear effects. Two of them have a direct relation to Saint-Venant's problem. The first is so called Brazier's effect, which deals with a nonlinearly increasing ovalization of cross section of an initially straight elastic pipe with growth of bending moment. This phenomenon is of practical importance for a thin-walled shell.

Another manifestation of geometrically nonlinear effects consists in an additional action of external or internal pressure. The external pressure promotes the ovalization while the internal one resists it. The current rules of designing submarine pipelines consider it as a possible limit state that requires due analysis for the substantiation of their integrity.

In the paper, two auxiliary tasks are considered separately: the loading in the plane and the loading in the axial direction of the shell. The plane section hypothesis for both tasks is used. The model proposed in the paper allows taking into account the plasticity effect as well as the distribution of the radial and shear stresses acting in the plane of the cross section.

The procedure implies the fine meshing of the cross section along the circumferential as well as the radial directions. In spite of very large number of unknowns the application of the sweeping (transfer matrix) method allows the procedure to be technically reduced to the solution of 6 linear equations at each step of iteration. The main idea consists in introducing at each iteration the Basic set of looking for parameters which are redefined by taking into account the Correction solution. The last one presents itself the numerical solution of all governing equations (equilibrium, physical, geometrical) based on current Basic geometry and taking into account the Basic stresses and deformations.

The results of comparison of the proposed procedure with known geometrically and physically nonlinear analytical and numerical solutions show the perfect accuracy of the method.

KEY WORDS: Moderately thick shell; beam; ring; outer pressure; in-plane bending; method of initial parameters.

INTRODUCTION

The ideas of work. This paper is a continuation of our previous work (Orynyak, 2009) which was devoted to thin-walled elastic shell (Fig. 1). It is intended to account for the plasticity effect as well as the distribution of the radial and shear stresses acting in the plane of the cross section. Thus we will use the same notions, designations and ideas as were expressed in (Orynyak, 2009). Most important among them are:

1. The definition of the Saint –Venant problem (Petrov, 1998) for beam structures, according to which each cross section of shell is in the same stress-strain state as others. This means that a) the form of cross sections is constant along axial coordinate; b) the shell has circular axis; c) the loading can not be given by arbitrary distribution of stress but can be presented only by some generalized parameters (bending moment, pressure).

2. The main idea of solution implies that the problem can be separated into two independent subproblems: a one for the irregular ring (curvilinear closed beam) (in the plane of cross section) and that for a beam (in axial direction) with specific Saint Venant's boundary conditions, which satisfy the outer loading (pressure and in-plane bending).

3. The plane section hypothesis. In fact it is used twice – for each of two subproblems. This allows characterizing each section of the curvilinear beam (first subproblem) as having only two degrees of freedom: uniform deformation (axial elongation) and linearly changed deformation (rotation). Similarly, second subproblem is characterized by two deformational parameters. Thus in fact our method of solution is "beam-beam" method.

4. The procedure is iterative one and two sets of solution is used: Basic solution and Correction one. Basic solution characterizes the adopted level of the stresses, strains and the geometry change at given iteration step. The Correction one was calculated for the adopted Basic geometry from all governing equations. It is used for adjusting the Basic one. In