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Analytical behavior of carbon steel-concrete-stainless steel double-skin tube (DST) used in submarine pipeline structure

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ABSTRACT

One type of submarine composite pipeline structure, with carbon steel-concrete-stainless steel (CCS) double-skin tube (DST), was introduced in this paper. This composite pipeline was expected to make optimal use of the three types of the materials, and provide significant structural and internal corrosion resistance. This study investigated the compressive and flexural behavior of the composite pipeline under internal content pressure and external hydrostatic pressure through finite element analysis (FEA). Finite element models were developed, where non-linear material properties of stainless steel and composite actions between constituent parts were considered. The models were verified through the comparisons between the numerically and experimentally determined results, in terms of load-deformation histories, failure modes and ultimate strength. Structural behaviors of the composite pipeline under pressures were compared with those without content and hydrostatic pressure. Parametric studies were carried out to investigate the effects of the outer carbon steel strength, inner stainless steel strength, concrete strength and hollow ratio on the compressive and flexural behaviors of the composite pipelines subjected to pressures.

1. Introduction

Pipe-in-pipe (PIP) systems have been widely used in offshore oil and gas industry due to its significant structural resistance and their superior thermal insulation performance [1]. The PIP system generally consists of an outer carbon steel pipe, withstanding external loadings and an inner carbon steel pipe carrying hydrocarbons, where the annulus in-between is filled with non-structural insulation materials. PIP systems have been systematically studied in terms of thermal expansion, lateral buckling, upheaval buckling, propagation buckling, installation, impact loading.

In recent years, to provide better structural resistance to the increasingly harsh environmental conditions such as anchor impact, pull-over and free spanning, concrete filled double-skin tubular (DST) cross-section was proposed for submarine pipeline and the structural performance was studied accordingly. An et al. [2] investigated and found well structural behaviors of pipe-in-pipes filled with steel fiber reinforced concrete under combined external pressure and bending. Cement filled pipe-in-pipes were proposed and studied. Impact tests on lightweight cement composite filled pipe-in-pipe composite structures [3] were conducted and the results clearly demonstrated superior impact resistance of the cement filled specimens than those of hollow ones. Outer pipes were found playing significant roles in determining the structural resistance of the cement filled PIP system, while the minor correlation of the inner pipe to the structural resistance was observed [4]. However, systemic studies on the effect of the internal and external pressures on the composite actions and the structural behavior of the concrete filled DST were somewhat limited.

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Nomenclature

A_c	Cross-sectional area of concrete
A_{ce}	Nominal cross-sectional area of concrete
A_{si}	Cross-sectional area of inner carbon steel tube
A_{so}	Cross-sectional area of outer stainless steel tube
CCS	Carbon steel-concrete-stainless steel
CFST	Concrete-filled steel tubular
CFDST	Concrete-filled double skin steel tubular
d	Outer diameter of inner steel tube
D	Outer diameter of outer steel tube
DST	Double-skin tubular
$E_{0.2}$	Modulus of stainless steel at 0.2% proof stress
E_c	Elastic modulus of concrete
f_{b0}	Concrete compressive strength under biaxial loading
f_c'	Concrete cylinder strength
f_{ck}	Characteristic concrete strength (f_{ck} = 0.67f_{cu} for normal strength concrete)
f_{cu}	Concrete cube strength
f_{Mises}	Von Mises stress of steel
f_{syi}	Yield stress of inner stainless steel
f_{syo}	Yield stress of outer carbon steel
f_y	Yield stress of steel
N_{FE}	Observed ultimate strength of column in FE simulation
N_u	Measured ultimate strength of column
p_e	Applied external pressure
p_i	Applied internal pressure
p	Interaction stress
p_u	Interaction stress at ultimate strength
t	Wall thickness of steel tube
t_{so}	Wall thickness of outer steel tube
t_{si}	Wall thickness of inner steel tube
χ	Hollow ratio, given by d/(D-2t_{so})
ξ	Nominal confinement factor (=$A_{so}f_{syo}/A_{ce}f_{ck}$)
ψ	Dilation angle of concrete
e	Flow potential eccentricity of concrete
γ	Poisson's ratio

In addition, to provide better internal anti-corrosion property, stainless steel has been increasingly used in submarine pipeline applications. For instance, corrosion resistance alloy (CRA) clad pipeline has significant anti-corrosion properties to CO_2 and H_2S, contents of which became noticeable. A carbon steel-concrete-stainless steel (CCS) double-skin tubular (DST) cross-section is subsequently proposed to be used in submarine pipeline structures, as illustrated in Fig. 1.

The CCS DST cross-section is consistent of one outer carbon steel tube, one inner stainless steel tube and the annulus between them is filled with concrete as shown in Fig. 1. Hollow ratio χ and the nominal confinement factor ξ can be expressed by Eqs. (1) and (2), respectively.

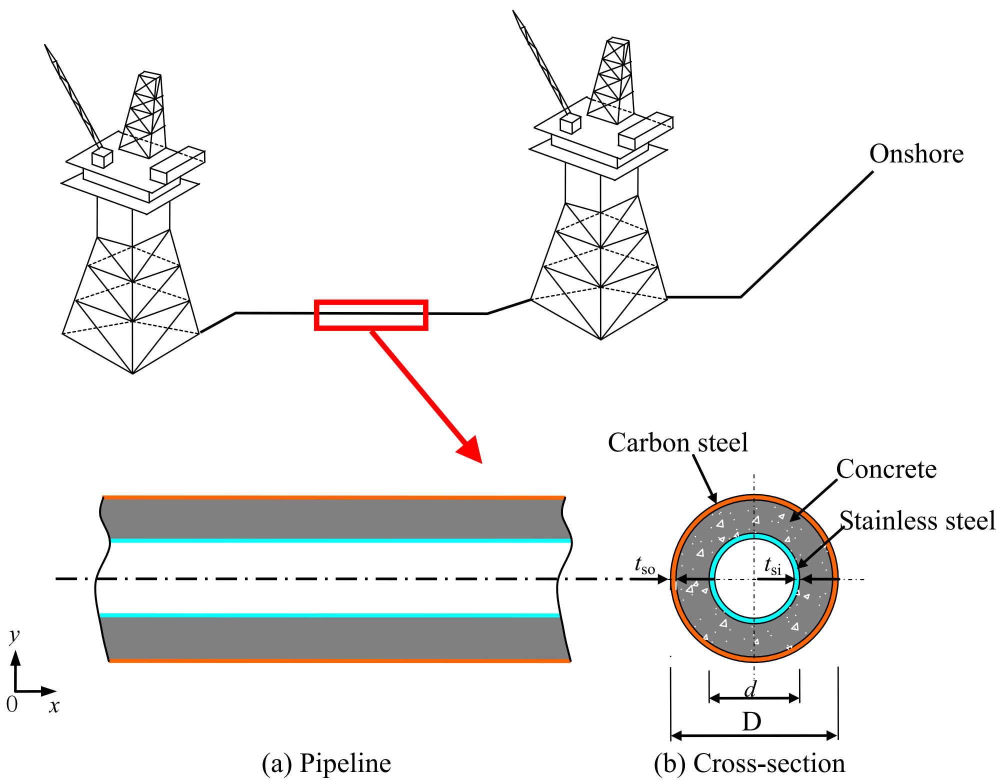

Fig. 1. Schematic view of CFDST with external stainless steel sections.