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Investigation on egg-shaped pressure hulls

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ABSTRACT

Spherical shells are presently the most extensively used shapes for pressure hulls in the deep manned submersible. However, it is known that the spherical pressure hull has disadvantages of difficult interior arrangement/low space efficiency, and is highly sensitive to geometric imperfections. These limitations have prevented further developments of the deep manned submersible to some extent. In order to overcome these limitations, two egg-shaped pressure hulls respectively with the constant and variable thickness are proposed in this paper, where the equivalent spherical pressure hull is also presented for comparison. Buckling of these pressure hulls with geometric imperfections are further studied using numerical analyses at a given design load. It is found that, with respect to hull strength, buoyancy reserve, and space efficiency etc., egg-shaped pressure hulls could be optimally coordinated, which appear to be leading to overall better performance than the spherical pressure hull. Especially, the egg-shaped pressure hull is quite less sensitive to the geometric imperfections, making it more convenient and low costly to form the hull in manufacturing or to open holes in applications. It is anticipated that egg-shaped pressure hulls will play a key role in the future development of deep-sea manned submersibles.

1. Introduction

The deep-sea manned submersible plays an important role in oceanic exploration and deep-sea research. As one of the most critical components in a deep manned submersible system, the pressure hull provides a safe living and working space for crews and some non-pressure-resisting/non-water-repellent equipment. The weight of the manned pressure hull accounts for almost 1/3 of the total weight of a submersible. Therefore, the pressure hull should be designed to optimally coordinate safety, buoyancy reserve, space efficiency etc. [1–4].

As is well known, due to its efficiency to bear the external high hydrostatic pressure in deep sea, spherical pressure hull is the most extensively used structure for the deep manned submersibles, where the stresses and strains are equally distributed throughout when the pressure hull is subjected to high hydrostatic pressure in deep sea. In brief, the spherical pressure hull has advantages of good mechanical properties, low buoyancy factor and efficient material utilization [5,6]. However, the spherical pressure hull is meanwhile with difficult interior arrangement, and especially it is a highly imperfection-sensitive structure [7,8]. Any small changes in geometry such as a tiny imperfection may lead to a significant drop of the buckling load.

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Abbreviations and glossary

EPHC	egg-shaped pressure hull with the constant thickness
EPHV	egg-shaped pressure hull with the variable thickness
SPH	spherical pressure hull
KDF	ratio of buckling loads of imperfect and perfect pressure hull

Notation

$R_1(x)$	meridional radius of curvature of EPHC/EPHV
$R_2(x)$	circumferential radius of curvature of EPHC/EPHV
R_m	middle radius of SPH
R_{i}	internal radius of SPH
$\overline{R_1}$	meridional mean radius of curvature of EPHC/EPHV
$\overline{R_2}$	circumferential mean radius of curvature of EPHC/EPHV
P_s	design load
P_{s1}	yielding load of EPHC
P_{s2}	yielding load of EPHV
P_{s3}	yielding load of SPH
P_q	critical elastic buckling load
P_{q1}	critical elastic buckling load of EPHC
P_{q2}	critical elastic buckling load of EPHV
P_{q3}	critical elastic buckling load of SPH
$\sigma_\varphi(x)$	meridional stress
$\sigma_\theta(x)$	circumferential stress
$\sigma_{r4}(x)$	von Mises equivalent stress
$[\sigma]$	allowable stress
t	shell thickness
t_1	thickness of EPHC
$t_2(x)$	thickness function of EPHV
t_0	thickness normalization function of EPHV
T_2	maximum thickness of EPHV
t_3	thickness of SPH
$\bar{t}$	mean thickness of EPHV
V_0	water displacement volume of EPHC/EPHV
V_{s0}	water displacement volume of SPH
V_1	material volume of EPHC
V_2	material volume of EPHV
V_3	material volume of SPH
δ_1	buoyancy factor of EPHC
δ_2	buoyancy factor of EPHV
δ_3	buoyancy factor of SPH
ρ_w	seawater density
ρ_T	material density
S_1	meridional area of EPHC/EPHV
S_2	meridional area of SPH
x	distance between a point on the egg-shaped curve and the sharp end
L	length of EPHC/EPHV
B	width of EPHC/EPHV
K	safety factor
K_d	factor reflects the deviation
h	water depth
σ_y	yield strength
σ_b	tensile strength
E	Young's modulus
μ	Poisson's ratio
g	gravitational acceleration
Δ	imperfection size