1. Introduction

Cylindrically curved structural plates are widely used as element members of various structural systems such as oil and gas storages for ships and offshore structures, cooling towers, and hull shell plating structures. Ship structures typically have welded plates, and design methods related to the use of flat plates as longitudinal and transverse strength members have been remarkably developed, many of which have become well established (Paik, 2018). However, as compared with a flat plate, as shown in Fig. 1, a curved plate has limited use as a structural member in deck plating cambers, side shell plating, fore and aft parts, and circular bilge parts, or for buckling strength evaluations, and is designed by taking into account only the curvature effect for a simple flat plate (Park and Seo, 2019).

Therefore, to apply a curved plate, a structural design reflecting the lightweight and high-speed characteristics of a ship structure will require a clear understanding of the precise non-linear material and geometric structural behaviors under various load conditions. In terms of the structural strength, a hull should maintain sufficient strength under longitudinal bending moments caused by its self-loading, weight, and external force distribution. In this case, the most important aspect is the compressive strength of the stiffened plates on the deck and at the bottom of the ship. In particular, it is essential to examine the ultimate compressive strength in terms of the safety of the hull girder structure. The buckling and plasticity of a stiffened plate structure with an increasing in-plane compressive load, along with a complex nonlinear behavior occurring until the ultimate strength is reached, need to be investigated. Previous studies related to this issue were reviewed for a typical stiffened curved plate applied in a bilge structure.
A study on the buckling and plastic collapse using a nonlinear numerical analysis of the development of an ultimate strength prediction equation for unstiffened curved plates used in ships was conducted, and the ultimate strength for the buckling mode and the initial deflection effect through an eigenvalue analysis for a change in curvature during elastic buckling under a compressive load was also investigated (Park et al., 2008; Kim et al., 2014). In addition, empirical equations on the aspect ratio and curvature effects have been proposed for various combined loads such as transverse compressive, shear, and longitudinal compressive loads (Kwen et al., 2004).

For stiffened curved plates, an analysis of the stiffener and curvature effect of container ships using a commercial finite element analysis (Oh et al., 2011), an empirical equation (Seo et al., 2016), an ultimate strength behavior analysis for compressive and hydrostatic loads with the initial deflection, and the residual stress based on a numerical analysis was conducted (Park et al., 2005). Cho et al. (2007) analyzed the curvature effect on the compressive load through an ultimate strength test and a numerical analysis for six stiffened curved plates.

Most recently, the quantitative curvature factor based on the curvature of stiffened curved plates was developed through an extensive numerical analysis on the curvature, slenderness ratio, aspect ratio, web height, and initial deflection effects of stiffeners for stiffened curved plates used on container ships (Park and Seo, 2019). Studies on the collapse behavior characteristics of curved plate members related to container ships on a large-scale have recently been conducted.

However, previous studies on the quantification and analysis of collapse mode patterns of stiffened curved plates have been limited. In the case of a flat stiffened plate structure, the characteristics of each of the six collapse modes have been clearly distinguished both theoretically and analytically, through which, the minimum value of the collapse modes has been identified as the ultimate strength (Paik, 2018). By contrast, in the case of stiffened curved plates, previous studies were mainly carried out through a numerical analysis of the buckling and ultimate strength according to the curvature and stiffener.

Therefore, in this study, for a clear identification of the collapse pattern of the stiffened curved plates, buckling and elasto-plastic collapse behaviors according to the change in the type of stiffener (flat bar, angle bar, tee bar), curvature (flank angle, $\theta$), and panel slenderness ratio (slenderness ratio, $\beta$) used in a ship were analyzed in detail to quantitatively analyze the collapse mode.

2. Numerical Analysis of Stiffened Curved Plate

2.1 Analysis Model Selection

To characterize the collapse mode of the curved plate for the curved plates used in a ship bilge and for various ship types, in this study, a container ship designed with the largest bilge curvature was selected and the analysis model shown in Fig. 2 was applied.

The selected stiffened curved plate has a continuous stiffened plate structure and consists of various types of surrounding members (stiffeners, large girder) around the stiffened curved plate. The boundary condition for a numerical analysis is assumed to be simply supported, and the boundary condition in which the loading edge and the non-loading edge are kept straight in the in-plane direction while the stiffened curved plate is buckled by a compressive load is applied. In addition, for the large girder effect, a one-bay (1/2 + 1/2 bay) finite element analysis model was selected by implementing symmetrical conditions at both ends.

Three shapes, as discussed above, were examined (Fig. 3). The stiffener web height ($h_w$) ranged from 50 to 400 mm, and the web ($t_w$) and flange ($t_f$) thicknesses were fixed at 12 and 15 mm, respectively, and the collapse characteristics for the web height of the stiffener were examined. The plate thickness ($t_p$) of the curved plate was determined as a variable of between 12 to 26 mm, and the collapse characteristics

![Fig. 2 Double span/double bay model of stiffened curved plate](image1)

![Fig. 3 Typical shapes of curved plate and stiffener](image2)
of the slenderness ratio of the plate were examined. The width \((b)\) and length \((a)\) of the curved plate were fixed at 1,000 and 3,000 mm, respectively, and the flank angle corresponding to the curvature was varied from 5° to 45°.

The finite element model of the plate consists of ten elements with a finite element longitudinal aspect ratio of 1.0 \((a/b)\) in the circumferential direction. The web height and flange width of the stiffener used to describe the local buckling phenomenon are 6 and 4, respectively (Table 1).

A nonlinear analysis was conducted by considering the material and geometric nonlinearities. In an analysis of a large deflection, which is a geometric nonlinearity, the arc-length method for describing the secondary buckling phenomena is used. For the nonlinearity of the material, a perfect plastic model was assumed, and a bilinear isotropic hardening model was considered. The material properties are as shown in Table 2.

### Table 2 Material properties for stiffened curved plate

| Material                | High tensile steel |
|-------------------------|--------------------|
| Elastic modulus \((E)\) | 205.8 GPa          |
| Poisson ratio \((\nu)\) | 0.3                |
| Yield stress \((\sigma_y)\) | 352.8 MPa          |

2.2 Initial imperfection

A fillet welding is commonly used to fabricate stiffened curved plates used in ship and offshore structures. Consequently, a residual stress and an initial deflection are inevitably generated from the welding. In particular, an initial deflection is known to be a major cause of a geometrically nonlinear behavior.

In an existing flat stiffened plate, Eq. (1), which is a deflection equation of a plate, and Eq. (2) applied for a stiffener, are assumed for application to a buckling mode shape.

However, the deflection equation for the curvature of a curved plate differs from that of a flat plate. Therefore, the eigenvalue characteristics need to be examined, and in this regard, the initial deflection shape is applied through a mode analysis using an eigenvalue analysis.

\[
\begin{align*}
    w_{op} &= \sum_w \sum_n A_{on} \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{b} \\
    w_{oa} &= 0.00025 a \sin \frac{\pi x}{a}
\end{align*}
\]

The size of the initial deflection comes from the welding, as shown in Eqs. (3) and (4), using the size of the initial deflection proposed by Smith (1988), when applying a flat stiffened plate and stiffener in the structure.

\[
\begin{align*}
    \text{Plate: } \frac{w_{op}}{t} &= \begin{cases} 
    0.025/\beta^2 & \text{for slight level} \\
    0.1/\beta^2 & \text{for average level} \\
    0.3/\beta^2 & \text{for severe level} 
    \end{cases} \\
    \text{Stiffener: } \frac{w_{oa}}{a} &= \begin{cases} 
    0.00025 & \text{for slight level} \\
    0.0015 & \text{for average level} \\
    0.0046 & \text{for severe level}
    \end{cases}
\end{align*}
\]

Here, \(w_{op}\) represents the initial deflection of the plate, \(w_{oa}\) is the deflection of a column-type stiffener, \(w_{oa}\) is the deflection of a sideways-type stiffener, and \(m\) and \(n\) represent the buckling half wave number in the \(x\)-(length) and \(y\)-directions (width). The initial deflection size was applied using the mean value of the stiffened curved plates as a function of the plate slenderness ratio and thickness (ISO, 2007). In this study, the welding residual stress arising from the welding was not considered.

2.3 Eigenvalue Mode

To analyze the buckling mode, an eigenvalue analysis was conducted using the general-purpose finite element analysis program (ANSYS, 2015). The eigenvalue mode can predict the collapse mode through the geometric characteristics and can be used as a numerical deflection equation or analysis of the initial deflection shape according to the geometric characteristics of the stiffened curved plate, as described above.

In the stiffened curved plate model included in most basic flat-bar stiffeners used in ship structures, the elastic buckling strength characteristics according to the curvature are compared, as shown in Fig. 4, based on the change in the web height of the stiffener. As the curvature (flank angle) increases, the buckling strength tends to...
increase, and when the curvature is lower than 10° at the same elastic buckling strength, it can be seen that the increase in buckling strength with a change in the stiffener height is not large. However, according to the shape characteristics of a flat-bar stiffener, owing to the weak torsional rigidity against a compressive load, the elastic buckling strength is estimated to be lower as the web height of the stiffener is increased. The main reason for this can be explained by the tripping collapse phenomenon in which buckling occurs in the web as the web height increases.

The buckling mode determined through an eigenvalue analysis can be classified into four characteristics, as shown in Fig. 5. (1) As indicated in Fig. 5 (a), an overall stiffener buckling is observed in the longitudinal direction, and this lateral buckling mode occurs when the web height is large. (2) Fig. 5 (b) shows that the typical curved plate and stiffener are in local buckling mode, as in the case of a flat stiffened plate, when subjected to axial compression. (3) When the stiffener is relatively weak compared to the plate, the plate shows the overall column type buckling mode, as indicated in Fig. 5 (c). (4) Finally, as shown in Fig. 5 (d), a local buckling phenomenon occurring in a curved plate and stiffener was observed when the web height and torsional rigidity were both high.

The existing flat stiffened plate demonstrated six collapse modes (Paik, 2018). Mode I shows the collapse of a stiffener and panel with a small stiffener size, whereas mode II shows a collapse by a plate, and only the panel collapses when a biaxial pressure is applied. Modes III–V indicate a collapse by the stiffener; mode III shows a stiffened plate collapsing in a beam-column shape, mode IV shows a collapse with a buckling in the web of the stiffener, and mode V shows a tripping phenomenon in which the stiffener lies sideways. Finally, mode VI indicates a collapse occurring from the plasticity of the shear surface. Theoretical and numerical solutions for each collapse mode were derived, and the minimum value is defined as the ultimate strength of the flat stiffened plate.

Therefore, the collapse mode of a stiffened curved plate, which is similar to the collapse mode of a conventional flat stiffened plate, can be identified in the eigenvalue analysis. As a follow-up, investigations into the elastic buckling and elasto-plastic buckling behavior are required to identify the ultimate strength collapse mode characteristics when considering the material and geometrical nonlinearities.

2.4 Elastic Buckling Behaviour

Through an investigation into the elastic buckling behavior under the assumption of a stiffened curved plate as an elastic body and considering the geometric nonlinearity, various geometric collapse characteristics can be analyzed according to the curvature effect of the curved plate. Therefore, the buckling behavior of the stiffened curved plate was analyzed through a large deflection analysis for a geometric nonlinearity and under the assumption of an elastic material.

For three types of stiffener, the web height ($h_w = 400$ mm) was fixed to show the dimensionless elastic buckling strength and strain according to the curvature change, as summarized in Fig. 6.

In general, as the curvature increases, the elastic buckling strength increases regardless of the stiffener shape. As shown in Fig. 6 (b), when the flange angle of the angle-bar stiffener is 20°, the elastic
buckling behavior changes rapidly. This is a secondary buckling phenomenon, which can be explained by the sharp change in deflection mode with an increase in load.

It can be stated that the geometric instability caused by the relationship between the shape of the stiffener and the curvature differs from that of an existing flat plate. The flat- and angle-bar stiffeners did not show a secondary buckling phenomenon within the applicable strain range when the curvature was 45°. This is because a curvature of more than 45° indicates a cylindrical curved shape, and the geometrical characteristics of a cylindrical curved plate dominate over the stiffener characteristics. In addition, in the case of flat stiffened plates, a secondary buckling phenomenon generally occurs when the slenderness ratio is large at a specific aspect ratio, whereas in the case of a curved plate, it is highly likely that such a curvature effect will bring about a secondary buckling phenomenon according to the change in the geometric buckling mode.

2.5 Elastic / plastic Buckling Behaviour

The collapse mode characteristics of a curved stiffened plate were examined through a large elasto-plastic deflection analysis when considering a material nonlinearity. In the same way as in an elastic buckling behavior analysis, the buckling strength and collapse behavior characteristics were investigated based on the slenderness ratio of the plate, curvature, and web height of the stiffener.

Fig. 7 shows the results of the elasto-plastic buckling strength behavior for three different stiffeners. With the use of a perfect elasto-plastic model, which is a bilinear isotropic hardening material model, similar characteristics as in the elastic buckling strength are shown. However, owing to the material plastic effect, a secondary buckling phenomenon did not occur, unlike with the elastic buckling behavior. This can be explained as a yield occurring before a secondary buckling occurs, and the material yield region spreading to surrounding members such that the initial eigenvalue mode is maintained without changing the buckling mode.

In addition, as shown in Table 3, five types of collapse modes were identified through a total of 75 series analyses. This is similar to the four characteristics derived through an eigenvalue analysis and can be classified as follows.

(A-mode) overall collapse mode: In this mode, a stiffened curved plate with a flat-bar stiffener shows a stiffener collapsing into a column type buckling shape before the local buckling of the curved plate occurs when the stiffener height is low or the flank angle is large. This mode is shown in Fig. 8 (a).

Fig. 8 Typical collapse modes of stiffened curved plates (Continued)
(d) Stiffener induced collapse by tripping
\( (h_w = 400 \text{ mm}; \beta = 2.30; \theta = 20 \, d) \)

(e) Local stiffener collapse- Stiffener induced
\( (h_w = 400 \text{ mm}; \beta = 2.76; \theta = 45 \, d) \)

Fig. 8 Typical collapse modes of stiffened curved plates

Table 3 Collapse modes of stiffened curved plates

| \( \beta \) (mm) | 5 \( d \) | 10 \( d \) | 20 \( d \) | 30 \( d \) | 45 \( d \) | 5 \( d \) | 10 \( d \) | 20 \( d \) | 30 \( d \) | 45 \( d \) | Angle-bar | 5 \( d \) | 10 \( d \) | 20 \( d \) | 30 \( d \) | 45 \( d \) | T-bar |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1.59            | 150    | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      | D      |
|                 | 200    | A      | C      | C      | C      | A      | A      | A      | D      | D      | D      | A      | A      | A      | D      | B      | A      | A      |
|                 | 250    | A      | A      | C      | C      | A      | A      | D      | D      | D      | A      | D      | A      | A      | A      | C      | A      | C      |
| 1.97            | 300    | C      | C      | C      | C      | A      | A      | A      | C      | A      | A      | A      | A      | A      | A      | C      | A      | C      |
|                 | 400    | C      | C      | C      | C      | A      | A      | A      | C      | A      | A      | C      | A      | A      | A      | C      | C      |
| 2.30            | 150    | A      | A      | A      | A      | D      | A      | A      | A      | D      | D      | A      | A      | A      | A      | B      | A      | A      |
|                 | 200    | A      | A      | A      | C      | C      | A      | A      | A      | A      | A      | D      | A      | A      | A      | A      | A      | A      |
|                 | 250    | A      | A      | C      | C      | A      | A      | A      | A      | B      | A      | A      | A      | A      | A      | A      | A      |
|                 | 300    | A      | A      | A      | C      | C      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      |
|                 | 400    | A      | C      | C      | C      | C      | A      | A      | A      | A      | A      | A      | A      | A      |
| 2.76            | 150    | A      | A      | A      | A      | A      | A      | A      | A      | D      | D      | A      | A      | A      | A      | D      | A      | A      |
|                 | 200    | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      |
|                 | 250    | A      | A      | C      | C      | A      | A      | A      | B      | A      | A      | A      | A      | A      | A      |
|                 | 300    | A      | T      | C      | C      | A      | A      | A      | A      | A      | A      | A      | A      | A      |
|                 | 400    | A      | C      | C      | C      | A      | A      | A      | C      | A      | A      | C      | A      | C      |
| 3.45            | 150    | A      | A      | A      | A      | A      | A      | A      | D      | D      | A      | A      | A      | A      | D      | A      | A      |
|                 | 200    | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      | A      |
|                 | 250    | A      | A      | C      | C      | A      | A      | A      | B      | A      | A      | A      | A      | A      |
|                 | 300    | A      | T      | C      | C      | A      | A      | A      | A      | A      | A      | A      | A      | A      |
|                 | 400    | A      | C      | C      | C      | A      | A      | A      | C      | A      | A      | C      | A      |

Note: A is Local collapse, B: Local stiffener collapse, C is Overall stiffener collapse, D is overall panel collapse, T is stiffener collapse by tripping.
Estimation of Buckling and Ultimate Collapse Behaviour of Stiffened Curved Plates under Compressive Load

As in the case of the plate shown in Fig. 9, when the slenderness ratio is low and the curvature is similar to that of a flat plate (less than 10° flank angle), it was found that the ultimate strength of a stiffened curved plate is estimated to be smaller than that of an unstiffened curved plate. This can be explained through the collapse mode (A: overall collapse mode) of the overall buckling of the stiffened curved plate in a column shape before the local buckling, as shown in Fig. 8(a).

In the case of a flat-bar stiffened curved plate, the highest ultimate strength was shown in the stiffened curved plate with the same slenderness ratio of the plate at the stiffener height ($h_w = 250$ mm). This suggests that the bending rigidity of stiffeners with a low web height is low and that the stiffener with a high web height has a low torsional rigidity, and thus for a stiffened curved plate under this condition, the ultimate strength is estimated to be rather low even though the effective longitudinal cross section area is large.

In the case of an angle-bar, the web is rotationally restrained owing to the flange effect of the stiffener, as shown in Fig. 10. As a result, in the case of the same curvature and slenderness ratio of the plate, the ultimate strength of the stiffened curved plate increases with an increase in the stiffener height. This can be regarded as the typical difference from a flat-bar stiffener. However, the ultimate strength of a flat-bar stiffened curved plate shows the reverse behavior. This can be explained based on the collapse mode (C: overall stiffener collapse-stiffener induced mode) characteristics in which the stiffener shows columnar buckling before a local buckling of the plate occurs.

In Figs. 10 and 11, the ultimate strengths of the angle- and T-bar stiffeners show similar strengths. However, under the same collapse mode, the angle-bar stiffener shows a low ultimate strength. This difference is caused by the rotationally restrained flange.

**Fig. 9** Ultimate compressive strength of stiffened curved plate with flat-bar stiffener under axial compression

**Fig. 10** Ultimate compressive strength of stiffened curved plate with angle-bar stiffener under axial compression

**Fig. 11** Ultimate compressive strength of stiffened curved plate with tee-bar stiffener under axial compression

Characteristics. The ultimate strength for the in-plane compression of a stiffened curved plate is shown in Figs. 9-11 based on the stiffener type according to the curvature, stiffener height, and slenderness ratio of the plate. In addition, to examine the ultimate strength characteristics under the impact of a stiffener, the ultimate change in strength was comparatively analyzed for a case with a stiffener and for a case with an unstiffened curved plate, which considers a curve plate only.
4. Conclusion

In this study, the large elastic/plastic deflection behavior, ultimate strength, and collapse characteristics were determined through a precise nonlinear numerical analysis to identify the buckling and collapse modes of stiffened curved plates. For a stiffened curved plate, the following conclusions were drawn for three types of stiffeners applied to a ship bilge according to the curvature, stiffener height, and plate slenderness ratio.

(1) In general, the increases in the stiffener height and curvature increase the elastic and elasto-plastic buckling strengths of the stiffened curved plate, and in the case of elastic buckling, a complex secondary buckling behavior occurs, whereas in the case of elasto-plastic buckling when considering the material plastic effect, the secondary buckling behavior does not occur. This indicates that, because a stiffened curved plate has a geometrically unstable structure compared to a flat stiffened plate, a design based on elasto-plastic buckling when considering the material nonlinearity is required.

(2) A large series elasto-plastic deflection analysis was conducted to derive the collapse mode characteristics. Based on the analysis results, the collapse mode of the stiffened curved plate was categorized into five modes similar to the collapse mode of a conventional flat stiffened plate: the (A) overall collapse mode, (B) local collapse mode-curved plate induced mode, (C) overall stiffener collapse mode-stiffener induced mode, (D) stiffener collapse mode induced by tripping mode, and (T) stiffener collapse mode induced by a stiffener web buckling. In addition, the effects of the collapse characteristics on the ultimate strengths were analyzed, and the characteristics of the stiffened curved plates derived through this analysis were investigated.

(3) The defined stiffened curved plate collapse mode will be used as important information for the development of a theoretical analysis method when considering the respective deflection characteristics of the corresponding collapse characteristics. In the future, this mode can be used as a deflection equation for applying theoretical analysis and numerical methods to each collapse mode derived.

(4) Further study is needed to verify the collapse mode characteristics based on the experimental methods, and a follow-up investigation is needed to develop an equation for predicting the ultimate strength of the stiffened curved plate for each verified collapse mode.

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References

ANSYS. (2015). Introduction to Material Nonlinearities. ANSYS11.0 User’s Manual, ANSYS Inc., USA.

Cho, S.R., Park, H.Z., Kim, H.S., & Seo, J.S. (2007). Experimental and Numerical Investigations on the Ultimate Strength of Curved Stiffened Plates. Proceedings of the 10th International Symposium on Practical Design of Ships and other Floating Structures, Houston, Texas, USA, 453-60.

ISO. (2007). Ships and Marine Technology - Ship Structures, Part 1: General Requirements for Their Limit State Assessment. International Standard ISO 18072-1, International Organization for Standardization: Geneva.

Kim, J.H., Park, J.S., Lee, K.H., Kim, J.H., Kim, M.H., & Lee, J.M. (2014). Computational Analysis and Design Formula Development for the Design of Curved Plates for Ships and Offshore Structures. Structural Engineering Mechanics. 49(6), 705-726. https://doi.org/10.12989/sem.2014.49.6.705

Kwen, Y.W., Park, Y.I., Paik, J.K., & Lee, J.M. (2004). Buckling and Ultimate Strength Characteristics for Ship Curved Plate Structures. Proceedings of the Annual Autumn Meeting, SNAK, Sancheong Korea, 351-356.

Maeno, Y., Yamaguchi, H., Fujii, Y., & Yao, T. (2004). Buckling/Plastic Collapse Behaviour and Strength of Bilge Circle and Its Contribution to Ultimate Longitudinal Strength of Ship’s Hull Girder. Proceedings of International Offshore and Polar Engineering Conference, Toulon, France.

Oh, Y.C., Kim, K.T., & Ko, J.Y. (2011). Investigation for Collapse Mode of Stiffened Curved Plate with Tee Shaped Stiffeners. Journal of the Korean Society of Marine Environment & Safety. 17(3), 295-300. https://doi.org/10.7837/kosomes.2011.17.3.295

Park, H.J., Cho, S.R., Chung, J.N., & Lee, D.B. (2005). Ultimate Strength Analysis of Curved Stiffened Shell of Container Bilge Strake. Proceedings of The Annual Autumn Meeting, SNAK, Yongjin, 189-195.

Paik, J.K. (2018). Ultimate Limit State Analysis and Design of Plated Structures. Chichester, UK: John Wiley & Sons.

Park, J.S., & Seo, J.K. (2019). Development of Design Factor Predicting the Ultimate Strength for Wide Spacing in Container Curved Bilge Structures. Journal of Marine Science and Technology. 24, 526-542. https://doi.org/10.1007/s00773-018-0572-0

Park, J.S., Iijima, K., & Yao, T. (2008). Characteristics of Buckling and Ultimate Strength and Collapse Behaviour of Cylindrically Curved Plates Subjected to Axial Compression. Advanced Materials Research, 33-37, 1195-1200. https://doi.org/10.4028/www.scientific.net/AMR.33-37.1195

Seo, J.K., Song, C.H., Park, J.S., & Paik, J.K. (2016). Nonlinear Structural Behaviour and Design Formulae for Calculating the Ultimate Strength of Stiffened Curved Plates under Axial Compression. Thin-Walled Structures. 107, 1-17. https://doi.org/10.1016/j.tws.2016.05.003

Smith, C.S., Davidson, P.C., Chapman, J.C., & Dowling, P.J. (1988). Strength and Stiffness of Ship’s Plating under In-plane Compression and Tension. Royal Institution of Naval Architects Transactions, 130(1988), 227-296.
Author ORCIDs and Contributions

| Author name     | ORCID                  | Contributions |
|-----------------|------------------------|---------------|
| Park, Joo Shin  | 0000-0001-5335-8151    | ①②③          |
| Ha, Yeon Chul   | 0000-0003-3591-8471    | ④            |
| Seo, Jung Kwan  | 0000-0002-3721-2432    | ④⑤           |

① Conceived of the presented idea or developed the theory
② Carried out the experiment or collected the data
③ Performed the analytic calculations or numerical simulations
④ Wrote the manuscript
⑤ Supervised the findings of this study