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A new strength model of shell structures for offshore applications

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Abstract

The major design codes are changing to LRFD (Load Resistance Factor Design) replacing traditional WSD (Working Stress Design) approach for offshore structural integrity assessment. The LRFD factors are partial safety factors obtained from structural reliability analysis. The reliability analysis needs a tool to predict the structural capacity very accurately. Hence the strength analysis of structures with a higher degree of accuracy is quite important. Although the numerical methods can be used for reliability analysis, the computation cost involved is quite high. It further demands great effort and expertise for acceptable results. Hence an analytical solution with basic structural design parameters predicting structural capacity is more suitable for the reliability analysis. Rule based design codes are available for the assessment of structural capacity for the stiffened cylindrical structures under different loading conditions. This paper establishes a modified version of a strength model which was proposed earlier for ring, stringer and orthogonally stiffened cylindrical shells. The mean and COV (Coefficient of Variation) of model uncertainty factor of a large population of experimental data are used to compare the proposed strength model and other major practicing codes.

Keywords: *Stiffened cylinder, buckling, streth, reliability*

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1. Introduction

Stiffened cylinders are extensively used in buoyant semi-submersible and Tension leg type offshore platforms. The legs of these structures are designed as Stiffened cylinders because of its inherent capability to resist high axial loads and bending moments with lateral pressure loads.

The modern LRFD design approaches are based on structural reliability analysis for the determination of sensible load and resistance factors. The structural reliability analysis needs a tool to predict the structural capacity very accurately. This make the strength analysis of structures with a higher degree of accuracy is the key aspect in the reliability based design processes. Although the numerical analysis tools validated with reasonable model uncertainty factor are absolutely suitable for this purpose but the time and cost of computation become a major factor to prefer an analytical method. Hence an analytical approach in terms of basic structural design parameters to predict the structural capacity is more suitable for the reliability analysis. There are various rule based design codes available for the assessment of structural capacity of stiffened cylindrical structures under different loading conditions. DNV-RP-C202 and API BUL 2U are two of the major industry recommended codes in practice.

Author proposes a modified version of existing RCC (Rule Case Committee) formulation for the strength assessment of ring stiffened and ring-stringer stiffened cylinders (ABS, 1984). The bias for knockdown factor for both the ring and orthogonally stiffened cases are modified based on experimental results for similar structures conducted within last century. The codes and the proposed formulation are compared statistically with respect to mean and COV of a large population of screened test data.

2. Analytical strength model for stiffened cylinders

Figure 1: Elements of a typical analytical strength model of stiffened cylinder

The general philosophy followed by most of the codified rules for the ultimate strength of stiffened cylinders is nearly same. The strength evaluation of the structural element starts from the assessment of the elastic critical buckling strength of perfect cylinders.

The variation to this theoretical value is then accounted by applying appropriate shell knockdown factor so that the elastic critical buckling strength of the Imperfect cylinder (real structure) is obtained. A reduction factor is then applied considering the slenderness of the structure and material strength to achieve the ultimate strength of the stiffened cylinder.

The shell knockdown factor represents the effect of geometrical imperfections on the buckling strength of the structure. The reduction factor includes the effect of residual stresses and structural slenderness.

2.1 *Buckling of cylinders*

Basically the stiffened cylinder structure can buckle and eventually fail in two ways. Snap-through buckling occurs by a sudden reverse of the curvature locally at certain combination of axial loads and the successive bending moments and results in a total failure as there is no chance of moment redistribution. Other failure type is the classical type of bifurcation buckling. The mode which most dominates design and structural weight is variously referred to as ‘bay instability’ and ‘panel buckling; but inter-frame collapse is less ambiguous and is used here.

The approach taken is to liken the failure model to that of a flat stiffened panel wrapped up into a stiffened cylinder, as illustrated in Figure 2. The curved shell between stringers is the most important load carrying element. The analysis will follow that established for flat panels, but with stabilising effects of curvature included. As with flat panels, an effective width approach is fundamental to achieving the best accuracy.

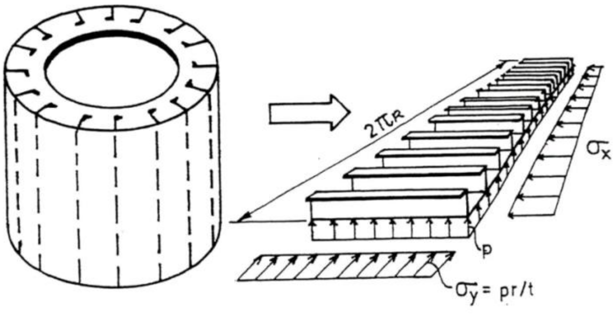

Figure 2: Stringer Stiffened Cylinder between Ring Frames

2.2 *Knockdown factors in RCC code*

The analysis revel that there is large variation exists between the experimental test results and the theoretical bucking strength prediction for both cylinder and curved shells. This deviation is predominantly a consequence of initial imperfections. The reduction from the theoretical buckling load is addressed with a term called knockdown factor denoted by ρ. So the elastic buckling strength of imperfect cylinder can be represented as,

$$\sigma_e = \rho\sigma_{cr} \tag{1}$$

where σ_{cr} is the lowest critical stress for cylinders and curved shells.

Ring stiffened cylinder

RCC proposes the knockdown factor for unstiffened and ring stiffened cylinder as,

$$\rho = B\rho_n C \tag{2}$$

where ρ_n is the structural knockdown factor and C is a length dependent coefficient.

The results show some scatter with the above factors and then introduced the parameter B which is the Bias for knock down factor to account the deviations.

$$B = \begin{cases} 1.2 & \text{for } \lambda_n \geq 1 \\ 1 + 0.2\lambda_n & \text{for } \lambda_n < 1 \end{cases} \tag{3}$$

where, $\lambda_n = \sqrt{\frac{\sigma_y}{\rho_n C \sigma_{cr}}}$; σ_y is the material yield stress

(4)

Stringer stiffened cylinder

Similar to the case of unstiffened and ring stiffened cylinders, the stringer and orthogonally stiffened cylinders also shows the effect of imperfection with a reduction in the buckling strength. As shell slenderness, which is the Batdorf width parameter (Zs) increases, the behaviour becomes more unstable and imperfection-sensitivity is greater. RCC proposes the knockdown factor for stringer and orthogonally stiffened cylinder as,

$$\rho = B\rho_n \tag{5}$$

where ρ_n is the structural knockdown factor as given below.

The scatter in the results is managed with a Bias for knock down factor B.

$$B = \begin{cases} 1.25 & \text{for } \lambda_n > 1 \\ 1 + 0.25\lambda_n & \text{for } \lambda_n \leq 1 \end{cases} \tag{6}$$

Where, $\lambda_n = \sqrt{\dfrac{\sigma_y}{\rho_n \sigma_{cr}}}$ (7)

3. New knockdown factors for elastic buckling strength

The RCC code has taken the bias for knockdown factor B straight from the aerospace industry. The loading, support, material, fabrication, environmental conditions etc. are quite different in the offshore industry. So the direct adaptation may not fully acceptable for the design purposes as the empirical factors need suitable modifications. The strength performance under different loading conditions could be addressed differently for offshore design purposes. The author proposes modified bias for knockdown factors (Pretheesh Paul C, 2011) considering various loading conditions particularly applicable for the offshore industry. The coefficients are obtained using a least square fit to match the predictions close to the experimental values.

Ring stiffened cylinder

The results for the ring stiffened panels are separated and the predicted results with the RCC formulation is compared with the experimental results. While fitting the curve with the predictions, the bias shows more sensitivity with the type of loading. The least square fitting process has been performed for the sets of results with different loading conditions and the bias for knockdown factor for ring stiffened cylinder is expressed as,

$$B = \begin{cases} D_1 & \text{for } \lambda_n < 1 \\ 1 + (D_1 - 1)\lambda_n & \text{for } \lambda_n \geq 1 \end{cases} \tag{8}$$

$$D_1 = \begin{cases} 1.40 \text{ - for Axial loading} \\ 1.20 \text{ - for Radial loading} \\ 1.30 \text{ - for Combined loading} \end{cases} \tag{9}$$

The scatter of the results has brought down significantly with the above Bias factor which is illustrated latter in the next section.

Stringer stiffened cylinder

Similar to the previous analysis the bias for knockdown factor for stringer or orthogonally stiffened cylinder is expressed as,

$$B = \begin{cases} D_2 & \text{for } \lambda_n > 1 \\ 1 + (D_2 - 1)\lambda_n & \text{for } \lambda_n \le 1 \end{cases} \tag{10}$$

$$D_2 = \begin{cases} 1.60 \text{ - for Axial loading} \\ 1.25 \text{ - for Radial loading} \\ 2.10 \text{ - for Combined loading} \end{cases} \tag{11}$$

Again, the scatter of the results has found to reduce significantly with the above Bias factor which is illustrated in a following section. The coefficients can be further modified subjected to the availability of suitable test results.

4. Statistical comparison of test data

	Ring Stiffened			Stringer Stiffened		
Reference	Axial	Radial	Combined	Axial	Radial	Combined
Dwight, J.B. (1982)	3	-	-	-	-	-
White, J.B. and Dwight, J.B. (1977)	7	-	-	-	-	-
White, J.B. and Dwight, J.B. (1978)	9	-	23	-	-	-
Sridharan, S. and Walker, A.C. (1980)	4	-	-	-	-	-
Walker, A.C. and Davies, P. (1977)	8	-	-	-	-	-
Agelidis, N.A., Harding, J.E. and Dowling, P.J. (1982)	26	-	-	-	-	-
Dowling, P.J. and Harding, J.E. (1982)	-	35	-	-	-	-
Weller, T., Singer, J. and Batterman, S.C. (1974)	-	14	-	-	-	-
Becker, H. and Gerard, G. (1962)	-	-	7	-	-	-
Das, P.K., Faulkner, D. and Guedes da Silva (1991)						
ABS/Conoco	-	-	-	14	8	22
CBI	-	-	-	1	1	4
Imperial college	-	-	-	6	-	-
Glasgow	-	-	-	3	-	-
DNV	-	-	-	4	-	-
Seleim, S. S. and Roorda J. (1986)	-	10	-	-	-	-
Ralph, E.E. (1963)	-	14	-	-	-	-
Walker, A.C. and McCall, S. (1987, 1988)	-	1	3	-	2	-
Birch, R.S. and Norman Jones (1990)	-	-	-	11	-	-
Ross, C. T. F. and Johns, T. (1998)	-	3	-	-	-	-
Ross, C. T. F. and Sadler, J.R. (2000)	-	9	-	-	-	-
Total	57	86	33	39	11	26

Table 1: Source for test data

The experimental test results are collected from a wide literature survey over the last century (Pretheesh Paul C, 2011). It is observed that majority of the experimental works on stiffened cylinders are being undertaken during 1960’s to 1980’s and there is not much experimental works available recently as the researches are comfortable with the numerical results with the increased capabilities and accuracy. This work incorporates data from various experimental programs undertaken across the world for stiffened cylinders as illustrated in Table 1.

In the simplest way, a good analytical strength model should predict the strength of the structure accurately under the imposed loading and support conditions. As mentioned earlier, because of the assumptions and approximations considered in the analytical relations along with the unaccounted factors, there always remain a certain percentage of error in the structural strength prediction. So a strength model can be rated based on the deviation from the experimental results. The best way to quantify this uncertainty is with the modelling parameter. This modelling parameter is also known as the model uncertainty factor Xm.

Model uncertainty factor,

$$X_m = \frac{\text{Experimental Value}}{\text{Predicted Value}} \tag{12}$$

5. Analysis results

The data collected are carefully arranged and tabulated with all the necessary inputs for the code based design. The data is then pushed through the analytical relations of DNV, API, RCC and the Recommended Models for stiffened cylinders. The strength predicted by each of the models is then compared with the experimental results to evaluate the model uncertainty factor Xm which is the ratio of experimental value to the theoretical prediction for each set of data. The mean and COV of the model uncertainty factor Xm is then evaluated for each case. The predicted and experimental strength (ϕ-Predicted and ϕ-Test) which are normalised with respect to yield stress are then plotted to show the closeness of experiment with prediction and the scatter in each case. For combined loading cases, the model uncertainty is plotted against L/R ratio as it is not straight forward to represent the strength for a combined loading case.

5.1 *Ring stiffened cylinders*

Ring stiffened cylinders under axial compression

The Ring stiffened cylinders are basically checked against the local shell buckling which is the dominant failure mode in this type of structures.

Table 2 Illustrate the statistical results of model uncertainty factor Xm for DNV, API, RCC and the Proposed strength model. The values indicate that the Proposed model has better statistical parameters compared to other strength models for the axial strength of ring stiffened cylinders. There is a 10% variation in the mean value and nearly 0.5% reduction in the spread of the results.

	DNV	API	RCC	Proposed Model
Mean	1.28	1.15	1.10	1.00
COV	17.94%	11.84%	11.04%	9.62%
Population	40			

Table 2: Statistical comparison of Xm for Ring Stiffened Cylinder under Axial Loading

Figure 3 and Figure 4 show the comparison of predicted and experimental data for the different strength models. The strength prediction of the Proposed model is more accurate compared to the other approaches in terms of its statistical measures. Figure 4 shows the spread of the results about its mean line having a low bias to the unity with less COV.

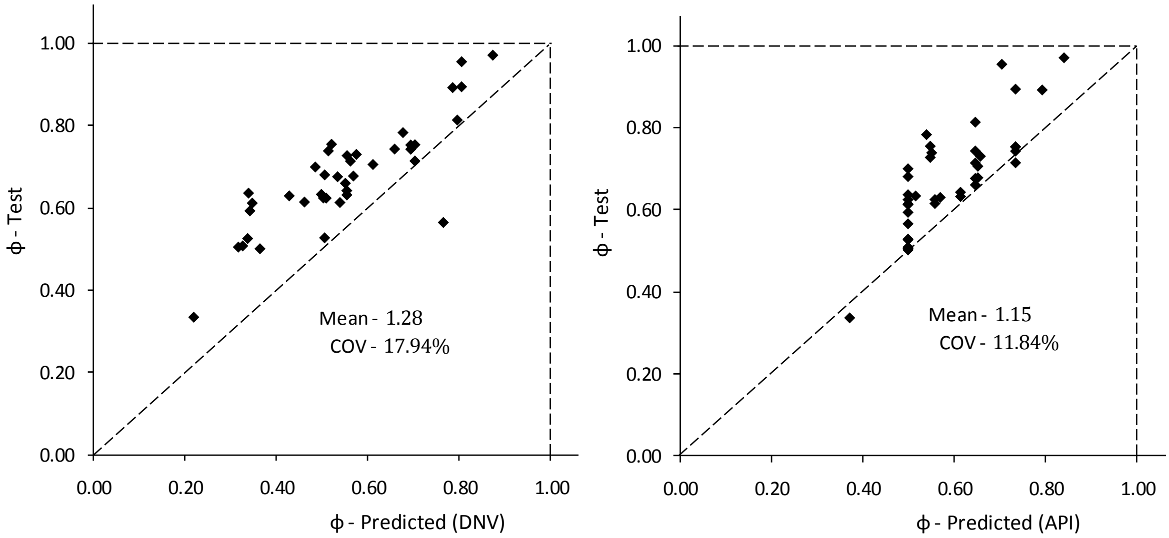

Figure 3: DNV and API prediction for Ring Stiffened Cylinders under Axial Compression

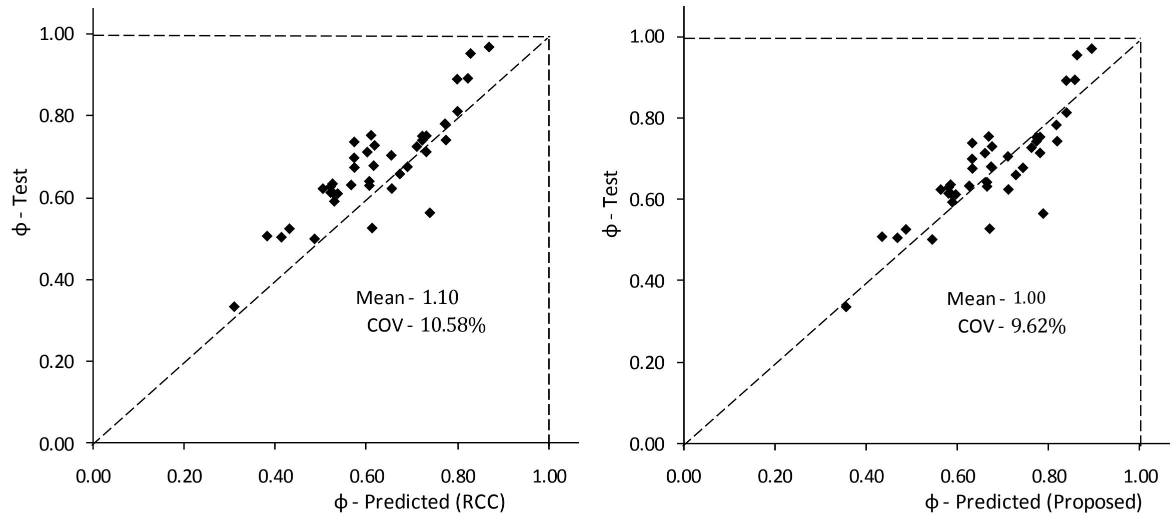

Figure 4: RCC and Proposed prediction for Ring Stiffened Cylinders under Axial Compression

Ring stiffened cylinders under radial compression

Table 3 shows the statistical analysis results for DNV, API, RCC and the Proposed strength model. It shows the comparison of predicted and experimental data for different approaches. The average and spread of the population shows better central tendency compared to the other approaches.

	DNV	API	RCC	Proposed Model
Mean	0.98	1.35	1.03	1.00
COV	19.43%	19.09%	21.19%	17.67%
Population	65			

Table 3: Statistical comparison of Xm for Ring Stiffened Cylinder under Radial Loading

Ring stiffened cylinders under combined axial and radial compression

Table 4 shows the statistical results of the ring stiffened cylinders under combined axial compression and Radial pressure for a population of 27 data for DNV, API, RCC and the Proposed strength model. The API model shows the lowest bias. The proposed strength model shows less scatter compared to all the other strength models.

	DNV	API	RCC	Proposed Model
Mean	1.46	1.07	1.14	1.17
COV	19.49%	21.71%	18.34%	16.41%
Population	27			

Table 4: Statistical comparison of Xm for Ring Stiffened Cylinder under Combined Loading

5.2 Stringer or Orthogonally Stiffened Cylinders

Stringer/orthogonally stiffened cylinders under axial compression

Table 5 shows the statistical results of the ring-stringer stiffened cylinders under Axial compression for a population of 30 for DNV, API, RCC and the Proposed strength model.

	DNV	API	RCC	Proposed Model
Mean	1.02	1.07	1.05	1.01
COV	21.57%	14.67%	14.01%	14.17%
Population	30			

Table 5: Statistical comparison of Xm for Ring-Stringer Stiffened Cylinder under Axial Loading

Figure 5 and Figure 6 show the comparison of predicted and experimental data for the different approaches. The Proposed model predicts the strength almost similar to that of the API and RCC model and which is better compared to API and DNV models.

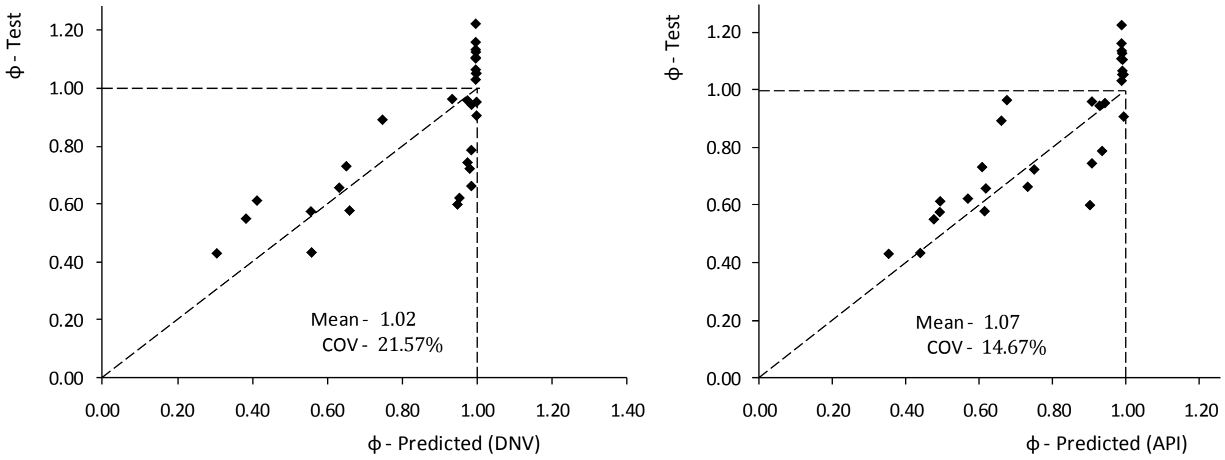

Figure 5: DNV and API prediction for Ring-Stringer Stiffened Cylinders under Axial Compression

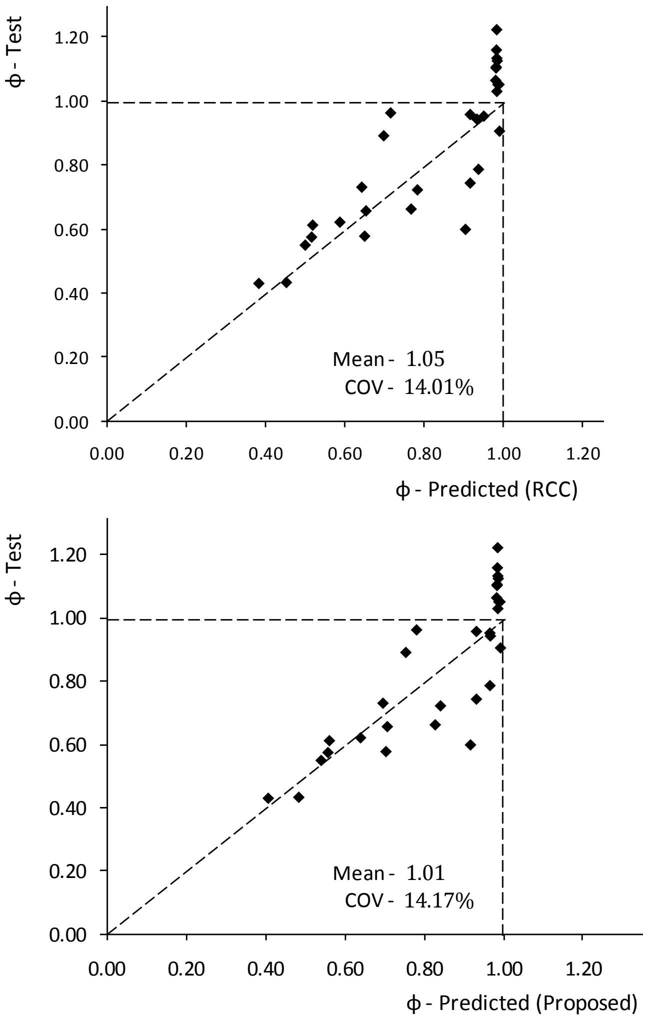

Figure 6: RCC and Proposed prediction for Ring-Stringer Stiffened Cylinders under Axial Compression

Stringer/orthogonally stiffened cylinders under radial compression

Table 6 shows the statistical results of the ring-stringer stiffened cylinders under radial pressure for a population of 9 for DNV, API, RCC and the Proposed strength model. The recommended approach is same as that of RCC and it is quite similar to the API formulation. The Proposed model appears better compared to DNV and API codes in terms of mean and spread of the model uncertainty factor.

	DNV	API	RCC	Proposed Model
Mean	1.33	1.12	1.06	1.06
COV	47.38%	21.54%	18.38%	18.38%
Population	9			

Table 6: Statistical comparison of Xm for Ring-Stringer Stiffened Cylinder under Radial Pressure

Stringer/orthogonally stiffened cylinders under combined axial and radial compression

Table 7 shows the statistical results of the ring and stringer stiffened cylinders under combined axial compression and radial pressure for a population of 25 for DNV, API, RCC and the Proposed strength model.

	DNV	API	RCC	Proposed Model
Mean	1.84	1.33	1.34	1.18
COV	43.82%	22.19%	21.02%	19.87%
Population	25			

Table 7: Comparison of Xm for Ring-Stringer Stiffened Cylinder under Combined Loading

6. Conclusions

The analyses with the experimental results illustrate the fact that the Proposed model which is a modified RCC Model, predicts the structural capacity more accurately in most cases compared to API and DNV codes. The statistical parameters of the analysis show that the Proposed model is more stable in predicting the strength of the stiffened cylinders compared to the DNV and API codes. The experimental data available for the radial pressure load cases for ring-stringer stiffened cylinders are very less and it is required to do further investigation to acquire more data. The design equations and the model uncertainty factors presented in this study are suitable for reliability analysis, sensitivity analysis and evaluating the partial safety factors for similar structures.

References

ABS, (1984). *Model Code for Structural Design of Tension Leg Platforms*, Conoco/ABS TLP Rule Case Committee (RCC)

Agelidis, N.A., Harding, J.E. and Dowling, P.J. (1982). Buckling tests on stringer stiffened cylinder models subject to load combinations, *Det Norske Veritas Report* 282-0298

API Bulletin 2U, (1997). *Bulletin on Stability Design of Cylindrical Shells, 1st ed.,* ANSI/API/Bull 2U-1992.

Das, P.K., Faulkner, D. & Zimmer R.A., (1992). *Selection of Robust Strength Models for Efficient Design of Ring and Stringer Stiffened Cylinders Under Combined Loads,* Proceedings of OMAE-92, Calgary, p.12.

Det Norske Veritas. (2002). *Buckling Strength of Shells*, Recommended Practice RP-C202.

Dowling, P.J. and Harding, J.E. (1982). *Experimental behaviour of ring and stringer stiffened shells, Buckling of shells in offshore structures,* Ed. J.E. Harding, et al., London: Granada, 73-107

Dwight, J.B. (1982). *Imperfection levels in large stiffened tubulars, Buckling of shells in offshore structures,* Ed. J.E. Harding, et al., London: Granada, 393-412

Faulkner D, Guedes Soares C. & Warwick DM., (1988). Modelling requirements for structural design and assessment. *Integrity of Offshore Structures-3, IOS-87,* Elsevier Applied Science.

Faulkner, D., Chen, Y.N. and de Oliveira, J. G. (1983). *Limit State Design Criteria for Stiffened Cylinders of Offshore Structures,* ASME 4th Congress of Pressure Vessels and Piping Technology, Portland, Oregon, Paper 83-PVP-8.

Hutchinson, J.W. and Amazigo, J.C. (1967). Imperfection sensitivity of eccentrically stiffened cylindrical shells, *American Institute of Aeronautics and Astronautics, Vol. 5,* 392-401

Morandi, A.C., Das, P.K. and Faulkner, D. (1995). *Ring Frame Design in Orthogonally Stiffened Cylindrical Structures,* paper OTC 7801, Offshore Technology Conference, Houston.

Pretheesh, Paul, C., (2011). *Strength and reliability of stiffened shells for offshore applications,* PhD thesis, Department of naval architecture and marine engineering, University of Glasgow and Strathclyde, Glasgow, UK.

Ralph, E. Ekstrom, (1963). Buckling of cylindrical shells under combined torsion and hydrostatic pressure, *Journal of Experimental Mechanics, 3,* 192-197

Ross, C. T. F. and Johns, T. (1998). Plastic Axisymmetric Collapse of Thin-Walled Circular Cylinders and Cones Under Uniform External Pressure, *Thin-Walled Structures*, *30,* 35–54

Ross, C. T. F. and Sadler, J.R. (2000). Inelastic shell instability of thin-walled circular cylinders under external hydrostatic pressure, *Ocean Engineering, 27,* 765–774

Seleim, S. S. and Roorda J. (1986). Buckling Behaviour of Ring-Stiffened Cylinders; Experimental Study, *Thin-Walled Structures, 4*, 203-222

Walker, A.C. & Davies, P. (1977). *The collapse of stiffened cylinders, international conference on steel plated structures,* Paper 33, Ed. P.J.Dowling, et al., London: Crosby Lockwood Staples.

Walker, A.C. and McCall, S. (1987). Strength of damage ring and orthogonally stiffened shells—part I-:Plain ring stiffened shells, *Thin Walled Structures, 5,* 425-453

Walker, A.C. and McCall, S. (1988). Strength of damaged ring and orthogonally stiffened shells—Part II: T-ring and orthogonally stiffened shells, *Thin Walled Structures, 6,* 19-50

Weller, T., Singer, J. and Batterman, S.C. (1974). *Influence of eccentricity of loading on buckling of stringer stiffened cylindrical shells,* Thin shell structures: Theory, experiment and design, Ed. Y.C. Fung and E.E. Sechler, New Jersey: Prentice Hall, 305-324

White, J.B. and Dwight, J.B. (1977). *Residual stresses and geometrical imperfections in stiffened tubulars,* Cambridge University, Dept of Engg, Report CUED/C-Struct/TR.64.

White, J.B. and Dwight, J.B. (1978). *Residual stresses in large stiffened tubulars,* Cambridge University, Dept of Engg, Report CUED/C-Struct/TR.67.

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Prof. Purnendu Das, BE, ME, PhD, C.Eng, C.MarEng, FRINA, FIStructE, FIMarEST has been the Director of 'ASRANet Ltd' (an ISO 9001-2008 certified spin out company of the Universities of Glasgow and Strathclyde) from its inception in February 2006. He recently retired as Professor of Marine Structures in the Department of Naval Architecture & Marine Engineering at the University of Strathclyde, UK. Past EU projects were MARSTRUCT (a network of excellence on Marine Structure) and SHIPDISMANTL (a cost effective and environmentally friendly dismantling of ship structures). Past industrial projects included work from the UK Health and Safety Executive (HSE), MoD UK, Subsea-7 UK, Shell, Woodgroup and US Navies etc. He was the principal investigator of many EPSRC projects. Before joining the University of Glasgow in 1991 he worked with British Maritime Technology as Principal Structural Engineer (1984-91). He is the author of more than 250 publications, including contract reports and more than 60 journal papers and is a member of the editorial boards of the 'Journal of Marine Structures', 'Journal of Ship & Offshore Structures', 'Journal of Engineering under Uncertainty: Hazards, Assessment and Mitigation' and 'Journal of Ocean and Climate System' amongst others. His areas of research include limit state design and analysis & reliability analysis of ship & offshore structures.

Professor Das has wide ranging industrial and academic contacts and has advised and supervised 20 PhD students, to his credit. Details of visits and collaborations include his various sabbatical study periods spent at University of California, Berkeley, USA (July – September 1996), at Lloyd's Register of Shipping (August 1997), Kockums Ltd (July 1998) and spent some time at Instituto Superior Técnico (IST), Lisbon (July 2000). He has been running various successful CPD courses which are attracting many people from different industries. These courses are on 'Fatigue & Fracture Analysis', 'Ships at Sea', 'Advanced Analysis and Design of Offshore Structures', 'Offshore Floating System Design', 'Structural Response under Fire and Blast Loading' and 'Design of Pipelines and Risers' amongst others. He was a member of ISSC (International Ship and Offshore Structure Congress) for the periods of 1991-97 and 2003-2006. He was a member of the OMAE (Offshore Mechanics and Arctic Engineering) Organising Committee on 'Safety and Reliability'. He has organised six ASRANet International Conferences in 2002 (Glasgow), 2004 (Barcelona), 2006 (Glasgow), 2008 (Athens), 2010 (Edinburgh) and 2012 (London) where a large number of participants from various countries attended. The theme of the conference is the *integration of risk, advanced structural analysis and structural reliability analysis* as applicable to various engineering structures.

He has been invited by many organisations abroad to deliver lectures on 'A state of the art on Strength & Reliability Analysis of Ship Structures', and they include; Institut Francais de Machanique Avancee (IFMA) France, Politechnike Wroclawske, Wroclaw, Poland, Klockner Institute of Technology, Czech Tech. University, Prague, China Ship & Scientific Research Centre (CSSRC), Wuxi, China, Pusan National University, Korea, University of Galati/Naval Academy, Romania, Dept. of Ocean Engineering, India Institute of Technology, Chennai, India, Dept. of Naval Architecture & Ship Technology, University of Gdansk, Poland. He was a visiting professor at Universiti Teknologi Malaysia (UTM) in Sept, 2010, April, 2011 and April, 2012. In January, 2011 he was the visiting professor at CUSAT (Cochin University of Science and Technology in the department of Ship Technology, India).