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Autor: Goode, C. Douglas

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The Safety of Composite Sub-Sea Structures

C. Douglas GOODE
Dr. Eng.
Secretary/Treasurer ASCCS
Draughton, Skipton, England

Douglas Goode, born 1930, spent 6 years as an engineer with Sir Robert McAlpine & Sons Ltd then 28 years at The University of Manchester, retiring in 1990.

Summary

This paper discusses the safety of sub-sea structures which are subjected to external water pressure comparing the use of a 'depth margin' with the standard 'load factor' approach and the advantages of composite construction for this situation..

1. Safety

There have been some significant, and costly, failures of offshore structures in the North Sea during tow-out or commissioning (Frigg, during tow-out Oct. 1974 and Sleipner 'A', Gandsfjord near Stavanger, 23 Aug. 1991[1]). Although inadequate design and/or construction defects may have played a part in the sinking of these structures it is the author's opinion that an inappropriate loading philosophy was the major cause.

Vessels subject to water pressure due to depth are currently designed by applying a load factor to the design depth pressure. The design depth should allow for the tidal range and the expected maximum wave height over the design life. The sea-water pressure is usually considered a dead load ('permanent action' in Eurocode 4 terminology) with load factors of between 1.2 and 1.4 applied to this pressure when considering the ultimate limit state. Norwegian designers use 1.2 for tempoary loads during construction (1.3 for permanent work), China uses 1.2, Australia 1.25, Eurocode 4 uses 1.35, and in the UK 1.4 is applied to dead loads. This approach gives a low safety margin for shallow depths and excessive safety (overdesign) for deep depths.

A more appropriate method would be to add a 'depth margin' to the design depth to allow for inaccurate modelling of the actions and uncertainties in the profile of the sea-bed, for sea-bed vessels, or accidental excursion into deeper water for submersibles and then multiply this by a small load factor (to allow for uncertainties in the assessment of the effects of the actions). The choice of values for these will depend on the accuracy with which the tidal range, storm surge and wave height have been assessed; the author considers an 80 m depth margin desirable when these are not well known decreasing to say 50 m when they have been well assessed. In both approaches partial safety factors would also be applied to the materials, or in the USA and Australia 'capacity reduction factors' to the equations, to obtain the 'safe' resistance of structural members to the action effects at the ultimate limit state.

Table 1 compares these two approaches to safety philosophy for various design depths from 67 m (the depth to the probable failure point on Sleipner 'A') to 2 km (recognising that oil exploration is being carried out in 2 km water depths), when 80 m is used for the 'depth margin' with a load factor of 1.10. This shows that at 67 m design depth a structure designed using the 'depth margin' approach would be designed for a pressure twice that of the 1.2 load factor and that they would give the same ultimate design pressure at 880 m depth. Comparing with a load factor of 1.4 shows the 'depth margin' approach gives safer structures until a design depth of 293 m is reached. At 1000 m the vessel would have to decend a further 400 m before reaching the ultimate pressure when the load factor of 1.4 is used; this does seem excesively safe.

Design depth (m)	pressure (N/mm^2)	'depth margin' 80 m load factor of 1.1 p_{ult} (N/mm^2)	load factor of 1.2 p_{ult} (N/mm^2)	load factor of 1.4 p_{ult} (N/mm^2)
67	0.68	1.63	0.81	0.95
100	1.01	2.00	1.21	1.41
293	2.96	**4.14**	3.55	**4.14**
500	5.05	6.44	6.06	7.07
880	8.89	**10.67**	**10.67**	12.44
1000	10.10	12.00	12.12	14.14
2000	20.20	23.11	24.24	28.28

Table 1. Depth margin and load factor approach compared at ultimate limit state pressure (p_{ult})

2. Composite Construction

Cylinders subjected to external pressure, such as occurs in sub-sea vessels, are sensitive to geometrical and material imperfections which can lead to instability failure before the material strength of the vessel is reached. The thinner the wall thickness the worse is this situation; and vessels designed for shallow depths will have thin walls. This is where composite construction (a steel-concrete-steel wall) has advantages over all steel construction[(2,3)]. The composite requires a thicker wall, which is stiffer and so not prone to instability, yet cheaper for the same strength; less steel is used as the concrete carries a proportion of the load (the proportion depending on the percentage of steel). At failure of the composite wall the steel will be at yield and the concrete, being subject to triaxial compression, exceeds its uniaxial strength. Failure of the composite cylinder invariably occurs where the wall thickness is thinnest and so it is better to base the resistance of the cylinder on an estimate of the thinnest wall thickness, calculated allowing for construction tolerances, rather than the nominal thickness shown on the drawing.

3. References

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