

Hybrid towers for offshore wind energy converters

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ABSTRACT

A new kind of tower construction, calling hybrid tower, is developed for offshore wind energy converters. The tower sections consist of two steel shells which are bonded together with a core material. The core between the inner an outer steel face increases the stability of the shells. In comparison with linear buckling analyses the validity of a laminate composite shell theory was proven. With model scale tests the stability of sandwich shells was analyzed against shell buckling due to axial compression and compared to tests with steel shells. Optical measurements were used to record the geometrical imperfections and to import the imperfect geometry of such shells in FE-models. Furthermore, a comparison of critical buckling loads was carried out with numerical solutions. The test series show a significant increase in bearing capacity for sandwich cylinders, which depends on the compressive strength of the core materials. The sandwich shells with a grout as core material show a catastrophic post buckling like steel shells. In contrast to this the elastomer core supports a ductile post buckling. The failure criteria for all variants of tested sandwich shells is more a local failure due to the steel faces called face wrinkling and not a global shell buckling.

KEY WORDS: hybrid tower; wind energy; shell stability; sandwich cylinder; core material; axial loading, buckling.

NOMENCLATURE

E	Young's modulus
f_{uk}	Characteristic tensile strength
f_{yk}	Characteristic yield strength
l	Length of cylinder
M	Moment
N	Axial compression force
r	Radius
t	Nominal wall thickness
u	Deformation
ε_{el} ; ε_{pl}	Elastic strain; plastic strain
κ	Buckling reduction factor
v	Poisson's ratio in elastic range
σ	Stress

INTRODUCTION

A lot of steel constructions like substructures of offshore wind energy converters consist of cylindrical shells and tubular members. One reason for this is, that columns with a circular hollow section (CHS) have higher buckling loads compared to columns with a rectangular hollow (RHS) or a solid section (SS) for the same weight [Schmidt, 2004]. But for members with CHS the shell stability must be taken into account in the design procedure. If the stability is not sufficient different modes of shell buckling can lead to catastrophic failure of the whole steel construction. The knowledge about shell buckling increased very fast within the last decades and was included in several international standards and recommendations [EC 3 1993-1-6, 2007], [DIN 18800-4, 1990].

The intention of every engineer, planning offshore steel constructions, is to increase the bearing capacity and if possible saving weights simultaneously. With regard to axially compressed steel shells the use of high-strength steels could be one opportunity for this challenge. But the comparison in table 1 for the buckling loads of a cylindrical tower section ST S235 with steel grade S235 and a ST S460 with S460 shows that only the use of high-strength steels does not satisfy the intention.

Table 1. Comparison of buckling loads for cylindrical tower sections

Parameter	Unit	ST S235	ST S460
Young's modulus E	MPa	210000	
Length l	mm	30000	
Radius r	mm	2750	
Thickness t	mm	50	24
Yield strength f_{yk}	MPa	215	460
Ideal buckling stress $\sigma_{x,Rcr}$	MPa	1423	977
Ideal buckling load $N_{x,Rcr}$	MN	1229	407
Buckling reduction factor κ_2	-	0.87	0.59
Real buckling stress $\sigma_{x,Rk}$	MPa	187	257
Real buckling load $N_{x,Rk}$	MN	161	113