International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 17, No. 4, December 2007, pp. 309–316

Collapse Testing on Short Linepipe for Deepwater Applications

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The collapse resistance of thick-walled UOE linepipe for deepwater applications has been studied quite extensively over the past 20 years or so, culminating in a good understanding of the influence of UOE manufacturing processes on pipe geometry and material properties. To better understand the influence of these parameters on pipe collapse resistance, a test program was initiated by Nippon Steel Corporation at C-FER Technologies. Collapse tests are normally performed on pipe samples with a length-to-diameter (L/OD) ratio of at least 8, but this program focused on pipes with an L/OD ratio of 4.1 or less. Full-scale tests were performed on these short pipes and compared to the results of companion pipes with an L/OD of at least 7.6. Integral in this program was the ability to design end closures that would minimize the influence of end restraint on pipe collapse. Thus, a rigorous finite element analysis (FEA) program was also undertaken to assist in the design of appropriate end closures for testing. This paper presents the results of all collapse tests and FEA, and shows that short pipes can be successfully tested at low L/OD ratios using correction factors to account for end restraint.

NOMENCLATURE

CE = capped end
D = mean diameter ($= \text{OD} - t$)
E = Young's Modulus (modulus of elasticity)
FEA = Finite Element Analysis
HT = heat (or thermally) treated
in = inches
L = length
m = metres
mm = millimetres
MPa = megapascals
N = number of circumferential lobes formed at collapse
n = Ramberg-Osgood strain hardening exponent
OD = outside diameter
OD_{max} = maximum outside diameter
OD_{min} = minimum outside diameter
OD_{nom} = nominal outside diameter
p = external pressure
p_{cr} = collapse pressure
p'_{cr} = corrected collapse pressure
PE = practical unrestricting
psi = pounds per square inch
t = wall thickness
UOE = pipe manufacturing process
" = inches
ε = strain
λ = $\pi D/(2L)$
μ = friction coefficient
ν = Poisson's ratio
σ = stress
σ_y = yield strength (stress at 0.5% strain)

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Received April 19, 2007; revised manuscript received by the editors July 27, 2007. The original version (prior to the final revised manuscript) was presented at the 16th International Offshore and Polar Engineering Conference (ISOPE-2006), San Francisco, May 28–June 2, 2006.
KEY WORDS: Pipe, linepipe, collapse, deepwater, FEA (finite element analysis), test, UOE (pipe manufacturing process).

INTRODUCTION

The collapse strength of thick-walled UOE linepipe depends on many factors, like OD/t ratio, ovality and material stress-strain behaviour, including yield strength and stress-strain curve shape. Many of these parameters are driven by the manufacturing process of UOE pipe, including original plate manufacture and thermo-mechanical control processes, UOE pipe fabrication techniques and post-manufacture processes, such as thermal coating or stress relief.

To better understand and quantify the influence of these parameters on pipe collapse resistance, numerous experimental programs have been undertaken over the years. These include full-scale testing of prototype linepipe for some of the largest and deepest export lines in the world (Stark and McKeehan, 1995; DeGeer et al., 2004; DeGeer et al., 2005). In collapse testing, it is important to ensure the pipe specimen is long enough to reasonably model a pipe of infinite length. The rule of thumb for performing collapse tests has been to use a length-to-diameter (L/OD) ratio of at least 7 to 8 to minimize the effects of end conditions on the collapse strength of the test pipe. However, it is recognized that for thick-walled, large-diameter pipes, the cost to manufacture test pipes can be high.

Deepwater pipelines are usually in the OD/t ratio range of 15 to 25, and are therefore quite thick and expensive to fabricate. For this reason, interest has been shown recently in the possibility of performing collapse tests on shorter pipes. Thus, a collapse test program was initiated by Nippon Steel at C-FER Technologies using pipes with an L/OD ratio of 4.1 or less. Full-scale tests were performed on these short pipes and were compared to the results of companion pipes with an L/OD of at least 7.6. Integral to this program was the ability to design end closures that would minimize the influence of end conditions on pipe collapse, allowing shorter pipes to approximate the behavior of longer pipes. A rigorous finite element analysis (FEA) program was also undertaken to assist in the design of appropriate end closures for testing. These analyses were benchmarked against the actual test results.

The program was initiated with a series of collapse tests (referred to below as Phase 1 testing), followed by an improved