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Crucial issues for deep water rigid jumper design

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ABSTRACT

Subsea Rigid Jumpers (SRJ) are used in Ultra Deep Water (UDW) projects to connect well heads, manifolds and riser bases with Intra-field and Export Pipeline End Terminations. Short and flexible pipe sections are assembled in a variety of spatial configurations to accommodate fabrication and installation tolerances (design for installation) and to withstand the end loads and displacements caused by flow/temperature and pressure fluctuations, as well as riser base oscillations (design for operation).

Two main criticalities are recognised in Subsea Rigid Jumper design: the bending strength and deformation capacity of induction bends during installation and operation; and the fatigue resistance under the cyclic loads from flow fluctuations and dynamic response to environmental loads.

The scope of this paper is twofold: 1) to present the FE model developed to quantify the strength and deformation capacity of induction bends subject to typical deep water installation and operational loads; 2) to describe how the Vortex Induced Vibrations phenomenon in complex 3D Subsea Rigid Jumpers can be treated to assess the fatigue damage at potential stress intensification. Both issues are pertinent to Subsea Rigid Jumper design, at the moment partially covered by specific project/company guidelines.

1. Introduction

Offshore field development is presently targeting water depths of 3000 m and more, located in open ocean or in proximity to continental slopes, in severe environmental load conditions. The development of a subsea field in abyssal planes is particularly challenging, due to site remoteness and the harshness of environmental conditions. Among the main challenges deriving from deep water scenarios we can include flow conditions and assurance over time, material and linepipe technology against high external pressure and potential sour environment, high capacity laying equipment, control and monitoring from early installation to end of service, and the integrity management of difficult to access infrastructures. In this context, Subsea Rigid Jumpers (SRJs) are critical components of subsea development. They are short pipe sections assembled in a variety of spatial configurations, such as M-, inverted U-, V- and Z-shape, to meet the continuity and flexibility needs of complex subsea flowline layout (Nair et al., 2010a, 2010b, 2011 and 2013). SRJs provide a connection between well heads, manifolds or riser base and flow line end termination (FLET or PLET). Manifolds and riser bases are designed to allow for easy connection with jumpers to FLETs, controlled from surface vessels assisted by Remotely Operated Vehicles (ROV). The presence of 90° induction bends at vertexes of the pipe assembly enhances the overall system flexibility (see Fig. 1).

In the last decade, many satisfactory SRJ installation and operation experiences can be observed in different worldwide offshore districts (Casola et al., 2010; Versavel and Burke, 2011). SRJs can resist significant static loads due to installation tolerances from fabrication and metrology, self-weight, internal and external pressures, thermal expansion, pipeline walking, seismic loads etc., as well as loads due to the interaction with the connected structures. The geometric configuration and loading conditions make the design of such systems particularly challenging. The design of SRJs is at all times driven by the flexibility of the assembly, and the elements of piping can be quite slender (length over diameter exceeding 100). The mid-span bending of the longest elements (i.e. small diameters and heavy pipes) may necessitate use of intermediate buoyancy elements to relieve the applied moments. The dynamic response of Subsea Rigid Jumpers is significantly susceptible to Vortex Induced Vibrations caused by the near bottom currents, as well as to vibrations caused by the high internal flow rate coupled with slugging or activated by seismic events.

In terms of structural performance, the above flexibility accounts for the propensity to dynamic response in the frequency range of the dynamic loads already mentioned. For a given nominal pipe diameter and wall thickness, the strength of induction bends is quite different from that of a straight pipeline, due to the geometrical and material

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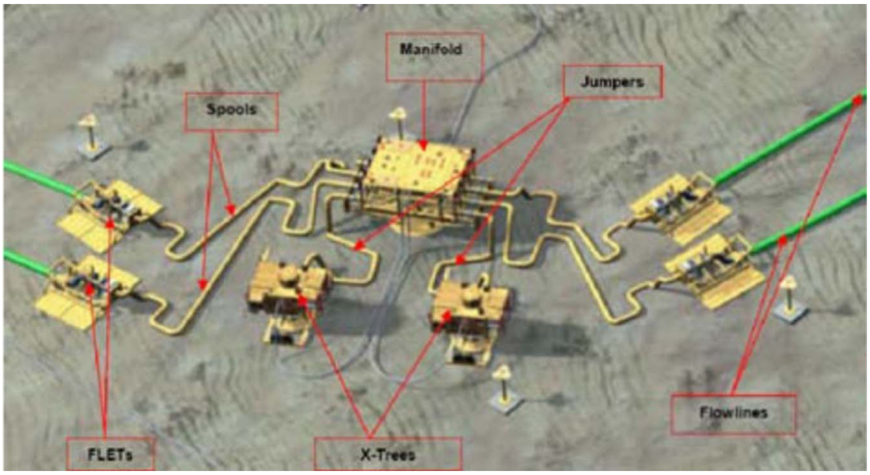

Fig. 1. Typical deep-water tie in system, taken from Casola et al. (2010).

features induced by the manufacturing process. This is unfortunately crucial for the collapse strength against external pressure. Jumper design is not fully covered by existing international standards: the guidelines currently provided only cover the induction bends for traditional applications (on land piping, stress based design etc.) but no mention is made of deep water conditions. Furthermore, flexibility driven design may give rise to an excessive propensity of the SRJs to dynamic excitation, leading to fatigue related issues. In this perspective, SRJ design should look to 3D geometry that at best protects the induction bends from localisation of significant and frequent stress cycles.

This paper discusses the challenge of deep water Subsea Rigid Jumpers and presents, through recent design applications, the FEM (Finite Element Modelling) approach used for assessing the strength of induction bends. Although still lacking in dedicated experimental reference tests, the approach relies on improved confidence in the outcome of finite element models, which can be performed with proven competence and awareness of work from onshore piping technology. As for dynamic and fatigue resistance of bends, on the other hand, the comparative application of VIV modelling on an SRJ assembly shows that the issue is far from being closed. Significant differences from the application of different predictive models are found. CFD (Computational Fluid Dynamics) can help and experimental tests can provide a sound basis. Physical understanding based on relevant hydro-elastic parameters is, however, of major concern.

2. Deepwater Subsea Rigid Jumpers challenges

In deep and ultra-deep water, induction bend design is driven by collapse (for installation) and local buckling (for operation) failure modes. As a result of the manufacturing process, induction bends present geometrical and material features that considerably affect the relevant strength capacity. In particular, the bending process of the initially straight mother pipe gives rise to considerable cross sectional out-of-roundness at the curve centre (2.5% ovality or higher), as well as wall thickness variation along the curve length (intrados wall thickening and extrados wall thinning). For a given nominal pipeline diameter and wall thickness, the behaviour of a curved pipe is quite different from that of a straight one. Existing codes generally provide Allowable Stress-based Design equations (ASD criterion) that are not fully targeted at the deep water scenario, giving over-conservative prescriptions that lead to unreasonable technical solutions.

DNV OS-F101 (2013), LRFD (Load and Resistance Factor Design) guideline, does not foresee any design criteria for induction bends: indeed, no specific reference to working stress based design for bends is given. It is common practice to apply the same criteria as those applied to rectilinear pipe elements. ASME B31.8 (1995) is mainly a working stress based design code. Pipe bend resistance is based on straight pipe resistance scaled by a stress intensification factor and a flexibility factor. The flexibility factor takes into account the reduction of bending stiffness of the bend with respect to a straight pipeline with the same internal diameter and wall thickness. A strain based design is allowed, but relevant design criteria are not explicitly given (see Fig.1). DNV OS-F101 (2013) recommends that system collapse testing of bends should be performed assuming three times the actual external pressure. In deep water scenarios, this recommendation leads to high wall thickness bends, losing the flexibility requirements, which are impossible to realise with existing forming technology. Recently, DNV proposed a “design-by-analysis” methodology, where the “three times water depth criterion” can be waived (DNV RP-C208, 2013). This methodology requires FE analysis to check relevant failure modes of induction bends exposed to differential pressure, steel axial force and bending moment, for which see Bruschi et al. (2006) and ASME VIII Division 2 (2013).

In this framework, several studies have been carried out to evaluate the maximum loads and deformation of induction/hot bends, sometimes performed in projects of challenging cross-country pipelines (likely applicable to shallow waters as internal pressure dominated conditions). These studies include analytical solutions, FEM analyses and experimental tests (a review can be found in Bruschi et al., 2006). Marcal (1967) was the first to present an analytical solution for elastic-plastic behaviour of pipe bends subject to in-plane bending moment; Spence and Findlay (1973) found approximate bounds on limit moments for in-plane bending by utilising previously existing analyses in conjunction with the limit theorems of perfect plasticity. Touboul et al. (1989) had proposed both opening and closing limit moment of elbows based on the limit analysis of Spence and Findlay and on analysis of experimental tests.

FE solutions were proposed and discussed in different works: Shalaby and Younan (1998) carried out extensive finite element analyses of various bends to study the effect of internal pressure on the limit load of elbows under in-plane (closing and opening) bending moments. Chattopadhyay et al. (1999) also carried out detailed finite element analyses of various bends geometries: the effect of internal pressure on the collapse moment of bends subjected to in-plane closing and opening bending moment was studied. Robertson et al. (2005) investigated the behaviour of induction bends subject to different loading scenarios, considering a variety of ductile failure criteria. Analysis results showed that theoretical limit analysis is not conservative for all load combinations considered. Gresnigt (1995) and Karamanos et al. (2006) performed experimental tests and FEM analyses to investigate the failure mechanisms and ultimate capacity of induction bends. Full-scale tests were performed by Hilsenkopf et al.