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COMMITTEE V.8 RISERS AND PIPELINES

COMMITTEE MANDATE

Concern for the structural failure modes of risers and pipelines. Consideration shall be given to the dynamic response of risers under environmental conditions as well as pipe-soil interaction. Aspects related to the installation methods shall be considered. Attention is recommended for aspects related to maintenance, inspection and repair, especially in deepwater conditions.

CONTRIBUTERS

Official Discussor: Theodoro A. Netto, *Brazil*

Floor Discussers: Marcelo Igor Lourenço de Sousa, *Brazil*
Bianca de Carvalho Pinheiro, *Brazil*

Reply by Committee:

Chairman: H. Suzuki, *Japan* (Chair)
S. Chai, *Australia*
Y. Chatzigeorgiou, *Greece*
H. Howells, *UK*
G. Kuiper, *The Netherlands*
K. Kavanagh, *Ireland*
Y. M. Low, *Singapore*
C. Morooka, *Brazil*
S. Saevik, *Norway*
J. K. Seo, *Korea*
N. Sodahl, *Norway*
G. Stadie-Frohboes, *Germany*
L. Sun, *China*
J. Wu, *USA*
Y. Watanabe, *Japan* (Secretary)

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1. DISCUSSION

1.1 *Official Discussion by Theodoro A. Netto*

1.1.1 *Introduction*

I would like to express to this highly qualified Committee my appreciation of their tough work in reviewing and discussing the advances related to offshore risers and pipelines over the last ten years. The subject is vast and rather dynamic, with significant improvements in the last decade, making the task quite challenging.

It is also challenging to evaluate and discuss the work of several experts in different areas. In order to provide a better review in the topics “Dynamic Response” and “Soil-Pipe Interaction”, I counted on the expertise of Professor Celso P. Pesce (University of São Paulo) and Mr. Daniel Carneiro (Wood Group Kenny), respectively. Their help and insightful comments are greatly appreciated.

Comments, discussions and suggestions will be presented in accordance with the original report structure, using the best of my knowledge and aiming at a more complete and up-to-date report.

1.1.2 *New Design Concepts*

This chapter presents in a somewhat superficial approach some of the latest design practices of flexible risers and pipelines, including limiting scenarios.

Key issues related to current design requirements for flexible risers such as sour service and the capability to sustain more severe loads in deepwater applications are properly addressed. End fittings are also a critical component of the system and should have been more emphasized in the report. Several recent papers have presented relevant design aspects and analyses of end fittings, including material issues and its interaction with flexible tensile armour wires (e.g., Torres *et al*, 2015, Otte Filho *et al*, 2015, Fernando *et al*, 2015, Salimi *et al*, 2015, Zhu, L., Tan, Z., 2014).

The report fails to address important developments on rigid riser design, riser configurations, and related challenges for different scenarios. Some aspects are indeed mentioned later in section 3, but it is recommended to give attention here to the latest design concepts of rigid risers, which have not been included in the report.

New concepts of rigid pipelines are mentioned, with special consideration to rather interesting X-Stream and SliPIPE concepts. In my view, four important alternative concepts proposed in the recent literature have been left out: composite pipes, pipe-in-pipe, sandwich pipes, and lined or clad pipes. Over the last ten years, there has been a vast literature available on each one of these concepts. It is strongly recommended to present a thorough review of the most relevant work and the Committee’s considerations.

Novel manufacturing processes for steel pipelines and their influence on their collapse resistance should be included in the report. Larger diameter pipes (16 in and over) are cold formed from individual plates through the UOE or other similar manufacturing process, e.g. JCO and UOC, followed by heat treatment and coating. A very comprehensive description of such methods is presented by Kyriakides, S. and Corona, E. (2007). These manufacturing processes induce particular geometric imperfections and material property changes that affect the collapse resistance of the pipe (Herynk, M.D. et al, 2007, Chatzopoulou *et al*, 2015). UOE pipes are known to have lower collapse pressures than similar seamless pipes, mainly caused by the material anisotropy (Bauschinger effect) induced by the manufacturing process. This effect can be minimized by heat treatment. It has also been shown that the heat input during coating can be beneficial due to material strain aging, resulting in the partial recovery of the pipe mechanical strength (DeGeer et al, 2004, 2005).

Finally, the suitability of current design codes (e.g. **DNV-OS-F101**, 2013) for large diameter pipes with low diameter-to-thickness ratio (D/t below 16) for deepwater applications should also be assessed.

1.1.3 *Dynamic Response Investigation Review*

This chapter is organized in two sections, namely: 3.1 *Risers*; 3.2 *Free Span VIV of Pipelines*.

Firstly, it should be pointed out that section 3.1 is by far much more extensive than section 3.2, clearly revealing the discrepancy in the number of publications that may be found in the recent years concerning both subjects. In fact, *Free Span Pipelines* is reduced in the report to just one major aspect, VIV – *assessment and mitigation*, as the title and the two subtitles explicitly indicate. It might appear to the reader, from the quite summarized report on free span pipelines, that no other dynamic phenomenon, rather than VIV, should deserve special attention, regarding analysis and design. This point

should be at least emphasized and clearly justified to the reader, in the very beginning of the third chapter.

Concerning the first section, *Risers*, despite giving an extensive coverage of the subject by addressing a vast range of aspects, the text – as presented in this version – could have been structured better, regarding balance of topics, writing style and depth of analysis. The section is sub-divided into two major aspects – *wave loaded induced dynamic response* and *VIV*. Such a division, per se, could impair the depth of analysis concerning real situations, which do include both phenomena, conjunctly and synergetically. This is a point which should be at least considered by the Committee. The first sub-section – *wave loaded induced dynamic response* – is written as a monolithic text, whereas the second sub-section – *VIV* – is divided into five topics, all of them interrelated to each other.¹

In the wave induced dynamic response sub-section, key issues are addressed, as wave spectrum directionality and spreading, bi-modal sea states and their effects on consistent evaluation of the dynamic

response to extreme conditions. Slug flows are also mentioned as an important aspect that could affect the global dynamics of a riser. Long-term fatigue is covered as well, addressing important issues as proper statistical representation in irregular waves and consistent methods to select equivalent regular waves. Concomitant existence of wave loads, VIV and wake induced oscillations are mentioned as determinant to predict riser collisions.

As mentioned before, concomitant effects of motions imposed at top by the floating unit with VIV could have been explicitly addressed in this section. In fact, floating-unit motions impose geometric stiffness modulations to the risers, which may cause tuning/detuning of VIV, as well as travelling waves; see, e.g., Silveira et al (2007), Joseffson and Dalton (2010).

Analytical and asymptotic methods have not been mentioned as important design tools, guiding more extensive numerical dynamic analysis. The works by Pesce et al (2006), Chatjigeorgiou (2007, 2008, 2013, 2015), Gu et al (2013), are just a few to be mentioned, regarding analytical approaches to riser dynamics. Likewise, investigations on parametric resonances of cyclically tensioned risers have not been mentioned as regaining strength and importance; see, e.g. Yang et al (2013), Lei et al (2014), Franzini et al (2015). Additionally, nonlinear modes techniques have been recently used to construct analytical-numerical reduced order models for riser dynamics, sometimes combined with wake oscillators, representing VIV, projected onto those modal spaces; see, e.g., Mazzilli and Lenci (2014).

From the point of view of expedite tools for risers analysis and design, considering dynamic responses, a number of papers have been published in recent years, but are not mentioned in the report. Combining analytical and numerical methods, the series published by Quéau et al (2013, 2014a,b, 2015) deserve consideration. The work by Tanaka and Martins (2012), on dynamic optimization of catenary risers, including lazy-wave configurations, is worth noting as well.

An important issue is not addressed in the report: *the global buckling of catenary risers at TDP*. In this subject an elegant design criterion for buckling, considering twist, based on a geometrically nonlinear FE analysis, has been proposed by Gay Neto and Martins (2013), recovering Greenhill's formula.

In the VIV subsection, the introductory text does not reveal, at least not assertively, the multitude and vigour of studies being carried out worldwide, with interesting findings, both, from the fundamental and practical points of view. In particular, the text which follows gives a somewhat mixed description of a number of issues and approaches, going back and forth, what might cause confusion to the reader.

In item (1), *Physical phenomenon oriented scientific research*, the text starts discussing CFD techniques applied to VIV fundamentals. In the context of risers, the high slenderness of the structure makes CFD approaches rather difficult to be implemented successfully. 3D (spanwise) vortex dynamics is of great importance and, to the present, no efficient CFD based code, considering design, is available to correctly capture the VIV phenomenon. Moreover the large number of turbulence scales, which characterize intermediate to high Reynolds numbers flows, still precludes full CFD methods applicability. Research in this field has been intense, though not properly mentioned in this report.

Fundamental experimental work is addressed, including Vortex Induced Motion (VIM) of very low aspect ratio cylinders with low reduced mass. Despite the study of VIM phenomena has originated from large oscillations observed in spars and large cylindrical floating platforms, those fundamental experimental results could be applicable for riser floaters, or for hybrid riser towers, whenever a cylindrical floater of low aspect ratio is used. However, this should be mentioned explicitly.

¹ [Particularly regarding the composition of the first section, the last paragraph appears to be not directly related to wave induced loading.]

The important phenomenon of multi-modes and multi-frequencies responses in VIV of long and flexible cylinders is addressed, as well as the travelling waves phenomenon, recurrently reported in a large number of recent investigations, being those experimental or theoretical. Intermittency, mode-transition and modulation are reported as new features, when discussing the experimental work by Fu *et al* (2013), which addresses VIV of flexible cylinders driven by forced oscillations. Such phenomena have been known for a while, at least in the context of regular VIV of flexible cylinders; see for instance Vandiver *et al* (2009), Fujarra and Pesce (2000). In the context of time-frequency analysis of nonlinear and non-stationary signals, the use of a new technique in VIV (and VIM), the Hilbert-Huang Transform Method, has not been cited; see e.g., Pesce *et al* (2006), Franzini *et al* (2011), Gonçalves *et al* (2012). Another interesting related aspect that could be mentioned has been addressed by Modarres-Sadeghi *et al* (2011), through an experimental study showing the chaotic response as a generic feature of vortex-induced vibrations of flexible risers.

Despite fundamental, the dual-resonance phenomenon in VIV, at subcritical and supercritical Reynolds numbers, has not been treated in the report, being an aspect extensively investigated in Dahl *et al* (2010); see also Dahl *et al* (2007) for multi-vortex shedding phenomena.

Another essential discussion, not mentioned in the Committee report, was that by Vandiver (2012), on the proper definition of damping parameters in the context of VIV of flexible cylinders. The usual mass-damping parameter, introduced in the fifties, is shown to be “not well-suited to the organization of the response of flexible cylinders in sheared flows or for cylinders equipped with strakes or fairings”. Instead, another dimensionless damping parameter, $c^* = 2c_{\text{eff}} / \rho U^2$, is introduced and shown to be suitable for the task.

Still regarding fundamental aspects, the work by Huera-Huarte and Bearman (2009a,b), on wake structures and vortex-induced vibrations of a long flexible cylinder, is worth mentioning.

The application of analytical models based on wake-oscillators has regained practical interest and has been applied by a number of investigators; either, from the point of fundamentals, or riser dynamics. In fact, structural finite element models, coupled to distributed wake-oscillators, have been proposed and studied; see, e.g., Silveira *et al* (2007), Srinil (2011). In this context, the not so recent works by Fachinetti *et al* (2003, 2004) should deserve special attention. See also Furnes and Sorensen (2007) for an incursion on coupled wake-oscillators, considering in-line oscillations. In particular, the theoretical work by Aranha (2004) bridges mathematically the conceptual gap between the Navier Stokes equation modelling and wake oscillator approaches, demonstrating that the vortex wake dynamics obeys a Ginsburg-Landau equation. Also to be mentioned are the works by Gu *et al* (2012, 2013) on analytical approaches to riser dynamics, combining wake-oscillator models with integral transforms and averaging techniques.

Concerning an important approach to VIV prediction, the report could have cited the work by Larsen *et al* (2012) on recent developments of empirical bases.

The text describes important advances in small scale riser experiments, which do contribute to the construction of solid benchmarking bases, regarding analytical and numerical modelling of risers VIV, particularly on catenary shapes. VSIV has been also mentioned, but some recent work such that by Fernandes *et al* (2011) have been missed, as well as the pioneer one on the subject by Le Cunff *et al* (2005). It should be noticed that the work by Pereira *et al* (2013), cited in the committee report, is just a preliminary result of an extensive experimental program, carried out with small scale models of vertical and catenary risers in a towing tank, in 2012-2013. This program, when underwater optical tracking experimental techniques were innovatively used, is described in Pesce (2013). The experiments included: VIV, top motion excitations, as well their combined action. For the catenary configurations, perpendicular or aligned with the current, in-plane and out-of-plane VIV were analysed. VSIV has been also observed under top motion excitation, which was preliminarily described in Pereira *et al* (2013). In particular, the vertical riser model showed pronounced parametric resonances in various eigenmodes, driven by top end excitations; see Franzini *et al* (2015). Analysis on the huge experimental data basis is an on-going task.

Another important issue, the reconstruction of phenomenological aspects from field data, has been addressed in the report, through the work by Shi *et al* (2012). Earlier works by Mukundan (2008) and Mukundan *et al* (2009), presenting accurate VIV response reconstruction schemes from field and experimental data, could have been cited as well.

The report is comprehensive in describing recent advances in VIV suppression and mitigation. The work by Assi *et al* (2014, 2015), on VIV mitigation by ‘free-to-rotate parallel and oblique plates’, is also worth mentioning.

Finally, section 3.1 discusses some aspects of VIV fatigue assessment. A summary of advances on existing methods is given, with emphasis on empirical models applied in VIV prediction software and on full scale calibrations. The text ends by giving a brief account on the importance of VIV on flexible

risers and umbilicals, regarding fatigue assessment. Hysteretic behavior is mentioned as an important issue to be considered on the subject. A very recent paper on the subject, by Péronne *et al* (2015), could be mentioned.

1.1.4 Soil-Pipeline Interaction

Chapter 4 provides a well-structured review of key aspects of soil-pipeline interaction, contextualising the importance of this interaction in the design of pipelines. Following a brief section on characterisation of the soil beneath pipelines, it addresses a number of particular facets of the pipe-soil interaction, which are grouped into two distinct design scenarios. The proposed design scenarios present, each one, its major design concern: the management of expansion due to high temperature, high pressure operating conditions; and the on-bottom stability under hydrodynamic loading.

The field of soil-pipeline interaction has continuously evolved alongside pipeline design technology, in response to increasingly harsh design conditions. The two specific areas of pipeline design illustrated by the two proposed design scenarios are particularly sensitive to the pipe-soil interaction, having historically had major roles in fostering this evolution. This field has vastly advanced since the ISSC2000 report was published (as made clear in the report). As such, and to direct an interested new reader to complimentary reading, reference could be made to existing (and relatively recent) state of the art reviews – such as those by Cathie *et al.* (2005) and White & Cathie (2011) – and the thorough text book chapter on Pipelines and Risers Geotechnics in Randolph & Gourvenec (2011).

Section 4.2 “Soil behaviour near pipelines” provides a useful brief overview of soil characterisation for pipe-soil interaction. The report refers to White & Randolph (2007), whose work thoroughly addresses the subject. This could be complemented by White *et al.* (2015), who review the seabed characterisation practice for pipelines, in which thermo-mechanical expansion is of relevance.

One subjective statement in this section saying that “there is only limited experience with pipeline design” in calcareous sands (and arctic silts) may be questionable. While the stories told at the end of the paragraph are well known, these happened a few decades ago. Illustrating the experience built up over the recent decades with a single offshore production region, DMP (2014) shows the complex existing network of oil and gas production systems in the North West Shelf of Australia. The area is well known for its challenging calcareous soils, and has major production export pipelines operating since 1984. Whilst this type of soil continues posing design challenges, “limited experience” might not well describe the state of knowledge of local operators, design and consultancy firms and research centres.

Moving on to the first proposed design scenario, the text discusses pipeline embedment during installation, then soil resistance to pipeline lateral and axial movements. Recurrent reference to the SAFEBUCK JIP is made, which is a fair response to its relevant contribution to the current state of knowledge. While controlled lateral buckling has been successfully used for 30 years now (Ellinas *et al.* 1990), the JIP has had a key role in maturing, formalising and reporting this design philosophy. The pipe-soil interaction tests organised or collated by the JIP permitted replacing the equations previously used by the industry (including the JIP in its early days) – which had been in general developed within research programmes focusing on on-bottom stability in the late eighties and nineties – with the ones currently adopted.

Section 4.3 “Pipeline as-laid embedment and riser touchdown” title should probably be limited to its first subject. While the mechanism of dynamic penetration during pipe lay is similar to the behaviour at a riser touchdown, the duration, operational effects and consequences of the latest have not been covered. Riser fatigue at the touchdown region is largely affected by this process, and this has already been widely addressed in research (although still being an active research area). Regarding the dynamic penetration during pipe lay, the use of a fixed factor (f_{dyn}) has proven inadequate in many cases, being criticised by Carneiro (2014), for example. More modern approaches, numerically addressing the cycle-by-cycle softening of the seabed soil (e.g. Westgate 2013) should also be mentioned.

A very thorough discussion is presented in Section 4.4 “Lateral pipe-soil interaction”, well covering all the relevant aspects of this topic. Two additional references are offered, for their contributions to the understanding of the soil resistance to large, cyclic lateral pipe movement: Cardoso & Silveira (2010) and Borges Rodriguez *et al.* (2014).

Section 4.5 “Axial pipe-soil interaction” highlights very well the current state of research on this particular topic, in which the existing design approaches are being challenged while accepted alternatives are yet to emerge. Caution is suggested when stating that pipe velocity influences the response in clay soils only. Silty soils, with fines but no clay minerals, may well present a partially drained response to pipeline axial displacement. The new model suggested by Hill *et al.* (2012) and White *et al.*

(2012), well pointed by the report as being “in a descriptive stage”, has one salient aspect worth mentioning: the potential gain in resistance over cycles due to consolidation hardening. Hill & White (2015) present evidence from field observation of the in service behaviour of a pipeline, which may cause pipeline walking to cease. Such aspects of the time-dependent response, however, shall carefully address the difference in pipeline velocity and accumulated displacements along the length of a pipeline, as highlighted by Carneiro et al. (2014).

Regarding the model proposed by Randolph et al. (2012), the report’s statement “this simple model is unlikely to be applicable to more complex situations that involve buckling and axial displacement” is challenged. This reviewer sees no influence from “buckling and axial displacement” in the model performance. However, the criticism in regards to the 1-D consolidation simplification is endorsed. Aspects of the soil response that are concealed by this simplification are discussed by Carneiro et al. (2015).

While the first design scenario was very well addressed, significant recent research (e.g. Draper et al. 2015) on on-bottom stability has unfortunately been neglected by the report. The section on trenching and backfilling is relevant; however it is old-fashioned to have it as main element of this design scenario. Even though it is still recurrently used for this purpose, the state of knowledge for this particular application is well established. A much more trendy motivation for such a section would be the protection against ice gouging in the Arctic.

Following on into Section 4.7 “Pipeline stability during sediment transport and liquefaction”, it appears from the report that this issue is limited to “shallow waters offshore Australia”. While most of the recent developments on the subject has been fostered by industry projects in that particular region, much of the lessons learnt are applicable in on-bottom stability design anywhere around the world. Most of the Section is limited to reporting the conclusions of Mohr et al (2013). At the end, it advertises a particular proposed JIP, completely neglecting the vast, continuous work being undertaken over the last seven years by the StablePIPE JIP (e.g. Griffiths et al 2010).

Lastly, it is worth highlighting that, in many cases, the two proposed design scenarios may overlap. Pipelines subject to on-bottom stability concerns and/or installed on mobile seabeds can often require thermo-mechanical expansion management. As such, addressing both independently, with distinct design procedures, can be misleading and conceal significant issues. For example, the scouring and self-burial mechanism observed by Leckie et al (2015) can make the pipeline embedment during installation an irrelevant process. The resulting embedment can have significant impact in the lateral buckling design (Borges Rodriguez et al 2013), as well as other aspects of the pipeline operational behaviour (White et al 2015). Furthermore, hydrodynamic loadings can significantly affect the performance of lateral buckling design (Anderson et al 2013).

1.1.5 Failure Modes of Risers and Pipelines

This is a rather important topic that is directly related to the Committee mandate. A good review is presented. Nevertheless, I would like to suggest the Committee some additions and structural changes in order to produce a more elaborate chapter on this topic.

Failure mechanisms and failure modes of risers (rigid and flexibles) and pipelines are quite different – the Committee has done a good job by separating the categories. Again, rigid risers have been neglected – although their failure modes are similar to pipelines, failure mechanisms can be quite different.

Section 5.1 discerns the main non conformities observed in operating pipelines according to API (2007), PARLOC (2001) and Cosham and Hopkins (2004). Although it was not mentioned in the text, it is supposed that they are listed in Table 1 (reference should be provided). The following subtopics discuss main failure modes (5.1.1 and 5.1.3) and non conformities (5.1.2 and 5.1.4).

I suggest the Committee separate the list of failure modes and non conformities, review the recent literature, and discuss their possible interactions via failure mechanisms that lead to failure. Attention is recommended to the following (some have not been mentioned in the report):

- Failure modes: local buckling, collapse, propagating collapse, burst, through-cracks, blockages or flow reduction;
- Non conformities: excessive loads (thermal or mechanical), external damages (dents caused by impact of foreign objects, clashing, or during installation), corrosion, erosion (coating and pipe), material ratcheting, material fragilization, crack growth (due to cyclic or monotonic loads), scour or over embedment of buried pipes etc.

Note that the above non conformities can interact within different failure mechanisms and eventually precipitate one or more failure modes. For example, a dent or a corrosion pit can induce stress

concentration in a riser or pipeline subjected to cyclic loads (e.g. Pinheiro et al, 2014). Then, a crack can nucleate, propagate, and cause loss of containment (through-crack). Or a corrosion defect, depending on the size and operational loads, can cause material ratcheting (Lourenço and Netto, 2015) and local failure. The same corrosion defect could grow (Melchers, 2008, Mohd and Paik, 2013) causing local collapse (Netto et al, 2007, Sakikabara et al, 2009, Netto, 2010) or burst due to thickness reduction (Netto et al, 2005, Bisaggio and Netto, 2015). Depending on the ambient external pressure, local collapse can propagate dynamically, with the potential of destroying the whole line (Kyriakides and Netto, 2000) – just to mention a few. There are several relevant articles related to these topics that have been published over the last decade, some of them are referenced in the technical papers mentioned above.

A similar report structure is recommended for flexible pipe (5.2) and rigid riser sections. For instance, for flexible pipes (Netto et al, 2013):

- Failure modes: failure of the inner carcass (collapse or unlock), generalized rupture of the tensile armor wires, unlocking (or breakage) of the pressure armor, connector leakage, slippage (or breakage) of the tensile armor (riser/connector interface – end fitting), blockages or flow reduction, rupture of the polymeric internal sealing barrier;
- Non conformities: superficial damage (abrasion/wear) of external sheath, localized (hole, crack) and generalized (rupture, tear) damage of the external sheath; corrosion and localized rupture of tensile armor wires; excessive sheath deformation (torsional – twist or dilatational), excessive ovality (localized damage or dents), kinks (excessive localized curvature), excessive curvature (without kink), inadequate catenary angle at the top section of risers, blockage or leakage of the relief valve failure in the end fitting; birdcage type of instability of the armor wires; interference between pipes (crossing); annular space with the presence of corrosive agents (CO₂, H₂S and seawater), absence of floaters (in some applications), detachment and surface damage (abrasion, cracks and fissures) of the bending stiffeners.

A vast literature is available covering different aspects of failure mechanisms and modes of flexible pipes (e.g., Gay Neto and Martins, 2013, Rabelo et al, 2015, Lacerda et al, 2015). It is recommended a thorough review of papers published in the proceedings of the Int. Conf. Ocean, Offshore and Arctic Engineering (OMAE), International Offshore and Polar Engineer Conference (ISOPE), and Offshore Technology Conference (OTC), and journals such as Marine Structures, Ocean Engineering, Applied Ocean Research, and Journal of Offshore Mechanics and Arctic Engineering over the last decade.

Finally, parts of subsection 5.2.2 might fit better within section 2.1 (Latest Design Practice of Flexible Risers), and subsection 5.2.3 could be moved to section 7. As suggestion, this section could be renamed as Monitoring, Inspection and Repair.

1.1.6 Installation

This chapter provides a good discussion about installation method developments for risers and pipelines. For the sake of consistency with the whole report, I encourage the Committee to address installation issues of rigid risers and flexible risers separately. Regarding rigid risers and pipelines, some interesting developments over the last fifteen years have not been properly emphasized in the report, as follows.

Firstly, industry and academia made a significant effort in the early 2000's through several joint industry projects to assess the effect of the reeling process on the collapse resistance and fatigue performance of rigid risers. The reeling method is until nowadays the most efficient and cost-effective method of riser and pipeline installation. However, bending, unbending, and straightening processes as applied on the vessels induce the pipe to bending-curvature histories, which are well into the plastic range of the material. The pipe is straightened prior to launch, but distortions in the form of residual out-of-roundness, residual stresses, changes in material properties due to plasticity, and growing of eventual welding flaws may occur, affecting the integrity of the welded joint (Netto et al, 2008a, Castelluccio et al, 2013).

The fatigue performance of reeled risers has been studied through combined experiments and analyses. Although the reeling method affects the fracture mechanical properties of base metal, HAZ and welds, several groups proved that fatigue life requirements can be met through a proper design that considers ECA analysis for flaw acceptance criteria and fatigue analysis using simpler S-N design analyses and/or fracture mechanics approaches (Torselletti et al, 2005, Netto et al, 2008b).

DNV, TWI and Sintef (Wastberg et al, 2004) developed guidelines for reeling of pipelines. Tivelli et al (2005) studied the effect of plastic deformation pattern due to reeled pipes, after reeling and ageing. Pasqualino et al (2004) showed that the reeling process has little influence on the collapse

pressure of reeled steel pipes even when considering small bending radius (6m). These results cannot be simply extrapolated to other concepts such as composite pipes or sandwich pipes. Besides inner and outer pipe, geometric and material geometries, the collapse resistance of sandwich pipes is highly affected by the core material properties and its adhesion to the steel layers (Netto et al, 2002, Estefen et al, 2005, An et al, 2012, 2014). Bending loads as induced during reeling installation can provoke material degradation (in case of ceramic based materials, e.g., cement based composites), and debonding between layers. More recently, Paz et al (2015) have investigated the influence of reel-bending on the strength of sandwich pipes with a fiber-reinforced cementitious composite in the annulus. Preliminary results from a limited set of experiments suggest a small detrimental effect on the collapse pressure. More work shall be conducted considering different geometries and annulus materials.

In more recent applications involving sour hydrocarbon production, carbon steel pipes are often lined with a thin layer of noncorrosive material to protect against corrosion. During installation and operation, such composite pipes (known as lined or clad pipes) can experience bending or compression deformations large enough to cause the liner to buckle. Both the onset of wrinkling and the curvature at which the liner collapses are sensitive to small initial geometric imperfections in the liner (Vasilikis and Karamanos, 2012, Harrison et al, 2015). Full-scale reeling simulations have also shown that bending lined pipes in the presence of internal pressure delays liner collapse (Toguyeni and Banse, 2012, Yuan and Kyriakides, 2014).

Finally, further research shall be conducted to prove the feasibility of installing sandwich pipes and other alternative composite pipe concepts through the reel method. In some scenarios, alternative concepts are very attractive options against conventional flexible or rigid pipes. Nevertheless, these concepts must provide an overall technical and cost-effect solution to the offshore industry, ranging from design, manufacture, installation (including connectors), inspection and eventual repair techniques.

1.1.7 Inspection and Repair

In this section, the Committee presents a comprehensive review of current inspection and repair techniques for risers and pipelines. As previously suggested, subsection 5.2.3 could be moved to this section, which could be renamed as Monitoring, Inspection and Repair (MIR). This seems to be more appropriate since monitoring, inspection and repair are related topics (note that some monitoring techniques for flexible risers are already mentioned in this section).

Numerous interesting monitoring, inspection and repair techniques have been proposed over the last years. Some techniques have wide applications, while others have been developed for specific purposes. Non conformities, failure mechanisms, and failure modes observed in practice are the main drivers for these technology developments. Most of these mechanisms and related MIR techniques have been properly addressed by the Committee.

I would like to propose an additional discussion on blockages in pipelines. Many crudes contain dissolved waxes that can precipitate and deposit under the appropriate environmental conditions. Natural-gas hydrates are ice-like solids that form in gas pipelines when free water and natural gas combine at high pressure and low temperature. Inorganic scales are another source of blockages. These can build up in production equipment and pipelines, potentially restricting flow and creating other problems. There are several preventive and mitigation techniques related to each one of these phenomena. Remote or local interventions are sometimes possible (e.g. usage of chemicals, heating of the line or internal fluid, pressure increase/decrease, pigging, etc). Obviously, the best practice is to be proactive rather than reactive. In this scenario, early warning of blockage occurrence would be valuable, suggesting the usage of monitoring techniques in pipelines in which such problems are more likely to occur (e.g. Chen et al, 2007, Papadopoulou et al 2008, Silva et al, 2014).

Lastly, I encourage the Committee to tackle this topic in the broader perspective of risk based inspection, repair, and integrity management of riser and pipeline systems. Several research papers have been published over the last decade presenting formulations to estimate, through reliability analyses, the probability of failure of pipelines (e.g. Teixeira et al, 2008, Bisaggio and Netto, 2015). These predictions can be used as basis for scheduling repairs and establishing inspection intervals with more confidence.

1.1.8 Final Remarks

I suggest the Committee rearrange the last chapter in order to highlight their recommendations and areas requiring future research. A list of topics could provide readers a more explicit account of the Committee's review and assessment of the state of the art. I agree with the conclusions and recommendations presented.

The report accomplishes the objectives of the Committee's mandate by presenting a good review of the research developments over the last decade in different aspects related to offshore risers and pipelines. Despite the fine work done, in my view, there is still some room for improvements - time permitting - as emphasized throughout the text. It would be appreciated if this Committee could make comments and elaborate more on those topics.

Lastly, I would like to thank ISSC for the privilege of being able to contribute. I sincerely hope that my comments, suggestions and discussions will meet the Committee's expectations towards an updated and comprehensive report on offshore risers and pipelines, including current challenges.

1.1.9 References

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1.2 *Floor and Written Discussions*

1.2.1 *Marcelo Igor Lourenço de Sousa (Federal University of Rio de Janeiro)*

In recent years we have seen flexible pipes manufacturers doing an effort to qualify pipes used as risers for ultra-deep waters. Typical application is in pre-salt fields offshore Brazil with approx. 2200 m water depth. My question to the committee is if they found recent publication related to this subject.

Moreover, I would like to know if the option to use extra tension armor layers in the flexible pipe structure is effective to overcome fatigue issues.

1.2.2 *Bianca de Carvalho Pinheiro (Federal University of Rio de Janeiro)*

Firstly, I would like to congratulate the committee for the comprehensive report and also the official discussor for the valuable comments and high level discussion provided.

I would like to ask the chairman a question concerning repairs on pipeline dents, a subject that I think was not well addressed in the committee report/presentation. The use of composite repairs is increasing in the last years. In which extent do you believe the fatigue life of dented pipelines can be enhanced with the use of composite repairs with glass fibre and epoxy matrix laminates?

1.2.3 *Agnes Marie Horn (DNV GL)*

As discussed in the committee report, fatigue damage due to VIV needs to be assessed during design of a riser or pipeline. Currently, the fatigue evaluation has been based on constant amplitude S-N curves (ref. to BS7608 (1993) “Guidance to fatigue design and assessment of steel products” and DNVGL RP0005 (2014) “Fatigue design of offshore steel structures”). However, in the latest edition of the BS 7608 (2014), variable amplitude S-N curves have been included. Hence, by assessing the fatigue life based on variable amplitude S-N curves in BS 7608 especially for VIV loadings shows a significant reduction in fatigue capacity compared to constant amplitude curves which has been industry practice up to know. Does the Committee have any views on what typical design scenarios; stress range and high or low cycle environment, etc. should variable or constant amplitude loading curves be assessed when assessing the fatigue design of a pipeline or SCR? Are there any scenarios or reported accidents that should require a more stringent fatigue evaluation of VIV?

2. **REPLY BY COMMITTEE**

2.1 *Reply to Official Discussion*

2.1.1 *Introduction*

First of all, Committee V.8 would like to express its sincere thanks to Prof. Theodoro A. Netto as the official discussor for the detailed and extensive review. This committee also would like to sincerely thank Prof. Marcelo Igor Lourenço and Prof. Bianca de Carvalho Pinheiro and Dr. Agnes Marie Horn as floor and written discussors.

The Committee had the first meeting just after it was formed. The committee examined the committee mandate below and discussed our position for committee work. Technical area covered by the

committee is very broad and diverse although the committee mandate gives focuses. The committee needs to have selective focuses. Another additional hard condition for our committee work is that the last ISSC report concerning this filed was published in ISSC2000. The committee felt necessity that technological developments in this broad technical area since ISSC2000 should be reported from the research point of view. The committee decided literatures published from 2004 to 2013 should be reviewed. This is different from traditional reporting style of regular ISSC committee reporting. As a result, contents have to be more or less selective although the all technical fields were tried to be covered equally as much as possible. This broadness is also the case for the official discussion. The volume of discussion reaches almost half of the committee report and needed a few contributors to draw the discussion.

Committee Mandate for Committee V.8 Risers and Pipelines

Concern for the structural failure modes of risers and pipelines. Consideration shall be given to the dynamic response of risers under environmental conditions as well as pipe-soil interaction. Aspects related to the installation methods shall be considered. Attention is recommended for aspects related to maintenance, inspection and repair, especially in deepwater conditions.

Hereafter we would reply the discussion of Official Discusser following his discussion structure at first. Then the replies to floor and written discussions would be shown.

2.1.2 New Design Concept

When the failure mode of the flexible riser is discussed, the local detailed modeling and stress analysis in the end fitting is important. But most of the references pointed out by the discussor were not available at the time of writing the report. The importance of this issue has, however, been pointed out in 2.1.2 also referring to new solutions to circumvent the problem as proposed by Campello et al. 2012.

The rigid riser is an important topic, but the committee decided to place more focus on flexible risers. Although some aspects of new concept of rigid riser design are mentioned in the later section, the description is very limited. Hybrid risers as these systems utilize flexible risers were reviewed.

The committee agrees that some pipeline designed concepts were selected and reviewed. Some other concepts such as composite pipes, pipe-in-pipe, sandwich pipes, lined or clad pipes are reviewed in the later section, but strong emphasis are not placed in this section.

The committee agrees that some parts of the committee report are detailed and some are digested. Subjects treated in the report are closely and mutually related. Another more optimized report structure can be possible by reallocating some materials.

The discussor points out importance of the manufacturing process of steel pipeline and suitability of current design codes for large diameter pipes. These are important but are not within the scope of committee mandate.

2.1.3 Dynamic Response Investigation Review

Concerning the dynamic behavior of the free span of pipeline, the committee focused on VIV as pointed out. Others were placed outside the report scope. Dynamic behavior of pipeline under soil action is reported in section of pipeline-soil interaction

The committee agrees that the influence of floating unit motion on VIV is a subject which should have been addressed in the report.

In the part of riser VIV section 3.1.2, a huge amount of very important and relevant investigations are available in the literature in VIV. Due to so vast amplitude of researches regarding the VIV phenomenon, the present report was restricted to those investigations which are more focused on practical ocean engineering applications, and global dynamic behavior with emphasis on hydrodynamic interactions. In this sense, studies presented in the broadly available literature database, such as in ocean and offshore engineering conferences have been related (ASME, ISOPE, OTC, OnePetro among others) and related journals. The discussion of the report points out a very nice and valuable insight into researches on VIV more related for visualization of the phenomenon and physical description of it. They are fundamental for solution of practical VIV problems solutions in risers and pipelines, and they must be considered.

The literature for the VIV in cylinders from the scientific point of view is very much rich, and a large number of important studies have been published from the past. On the other hand, particularly in the last decade many works are motivated for the research on ocean and offshore engineering. Survey for the present report was concentrated in the literature of the last three years. And, due to the limitations imposed to its length, investigations focused on VIV studies in realistic scenarios have been chosen, including fundamental studies seeking for practical riser applications as presented in the

first subsection. Keywords in the following sections were depicted in order to detach the importance of VIV and relationship with the engineering relevance of risers.

Concerning the comment on subsection 3.2.1, in fact, researches on the VIV phenomena around pipes have been emphatically investigated by research scientists worldwide. And, there is no doubt about contributions of those studies for offshore pipeline and riser applications. The present report did not intend to exhaust researches in the field of the VIV of risers, and the section was divided into sub-topics which is believed being beneficial for the understanding and good overview for recent research works that focused on the practical engineering applications. Regardless the main purpose of the section and limitations for extension of the report, the topic as suggested by the discussion is agreed being important for the understanding of long pipeline vibrations.

2.1.4 Soil-Pipeline Interaction

For the pipeline design in calcareous sand, the discussor points out that “limited experience” might not well describe the state of knowledge. Although there are projects of pipeline operating in calcareous soils, it is proprietary to the company related to the project without any information releasing to the public. Besides, there is neither design guideline nor industry standard on the design of pipelines in calcareous soils. Due to the nature of high friction angle and easy compression of calcareous soils, the pipeline design could be different including soil investigation, pipe embedment, lateral buckling, axial walking etc.

The discussor points out that the more modern cycle-by-cycle softening of the seabed soil (e.g. Westgate 2013) should also be mentioned but the committee is unable to locate the mentioned reference. The committee would like to leave it to next committee to address the issue.

For the axial pipe-soil interaction section, importance of soil model of partially drained response to pipeline axial displacement was pointed out but the committee is unable to locate the mentioned reference.

For recent research on on-bottom stability, the mentioned reference is quite new and the committee is unable to locate the reference and also outside of literature survey period of 2004 to 2013.

The committee is unable to locate the mentioned reference of StablePIPE JIP.

Overlapping between two proposed design scenarios was pointed out by the discussor, but the committee is unable to locate the mentioned reference. The committee would like to leave it to next committee to address the issue.

2.1.5 Failure Mode of Risers and Pipeline

The major comment made by the official discussor is primarily related to 1) Report structuring, 2) Explicit classification and listing of failure modes and 3) The use of latest literature when it comes to failure mechanisms. When it comes to item 2, the committee agrees with the discussor concerning classification into pure failure modes and non-conformities. Rather than listing these, reference have been given to the API standard and the PSA reports addressing the mentioned issues. The major problem faced by the industry in recent years is, however, related to the time lag between root cause of failure and revision of the standard also with respect to new failure modes. This is pointed out in 5.2.1 and the important implication of this with regard to the need for improved qualification procedures by analysis and testing has been addressed in 5.2.2.

An extensive literature study has been carried out with respect to failure modes, however, not including the 2015 references mentioned by the discussor as they were not available at the time of writing the report. When it comes to the 2013 reference by Neto and Martins, 2013 on torsion stability we agree that this is an important issue since the critical load will have direct influence on the installation weather window and associated costs. In Neto and Martins, 2013 work the problem of torsion instability is investigated by applying a give rotation at the lower end of a catenary configuration applicable for an installation scenario and assuming elastic material properties. There is certainly more work to be done into this problem, since the critical tension/compression load also will be influenced by the non-linear moment curvature nature of flexible lines. It is also to be mentioned here that the torsion instability can result from the combination of cyclic loads and local buckling of the helix components leading to torsion imbalance. The latter has been properly addressed in sub-section 5.2.2 related to lateral buckling where torsion instability will ultimately result as part of the local instability process. There is therefore a need for global models that includes both the effects from the non-linear moment-curvature relationship and the loss of torsion balance from local buckling to reach accurate design criteria.

2.1.6 Installation

Methodologies for installation of riser systems were focused on the survey of the literature. Offshore petroleum industry has experienced a successive business growth in the last decade, facing a new scenario of field development in ultra deepwater, and as also mentioned in the discussion, with a petroleum fluid with aggressive components for risers and pipelines which forced innovations in the pipeline, material and manufacturing. The committee agrees with discusser for the importance of effect of plastic strain on strength of pipe, effect of reeling on lining and clad, and feasibility of reel lay for composite pipe. Although the importance of this aspect, this section was focused to new riser system concepts and system installation processes.

2.1.7 Inspection and Repair

The committee would, first of all, like to point out that the word “Maintenance” was included in the original draft of the section title as “Maintenance, Inspection and Repair”. Missing the word “Maintenance” is a simple editorial error which happened during the editorial works and should have been corrected in the final draft. The committee used the traditional wording of “Maintenance” rather than “Monitoring”. Concerning the comment on the flow assurance, the committee agrees it is an important subject but decided not to be included in the present committee report. Risk based approach would be effective to make inspection more systemized and rationalized. Monitoring in subsection 5.2.3 is mainly related new failure modes and should not be included in Chapter 7.

2.1.8 Final Remarks

The committee agrees that some emphases might be desirable for the final remarks and recommendations. Developments and researches are driven by challenges for deepwater in many different technical disciplines. But the subjects are quite diverse, and findings and recommendations were listed in rather simpler manner.

Finally the committee would like to express thanks again to the official discussor for the valuable comments. The discussor made many useful suggestions and some of them were actually discussed by the committee during the process of preparation of report material, but could not be included in the committee report. The committee suggests next committee would address the issue.

2.2 Reply to Floor and Written Discussion

2.2.1 Floor Discussion by Marcelo Igor Lourenço de Sousa

The committee did not review the effort made by industry to qualify flexible pipes for ultra-deep water, but the research community is investigating basic mechanical behaviour such as torsion stability, more generally non-linear moment-curvature relationship and the loss of torsion balance from local buckling which would be considered to be critical for ultra-deep water application and lead to accurate design criteria.

2.2.2 Floor discussion by Bianca de Carvalho Pinheiro

The committee members agree with discussor’s comment. Cycle fatigue becomes a main concern when a steel pipeline as well as composite pipeline is subjected to mechanical damage such as a dent defect. The committee has captured literatures concerning repairs with glass fibre and epoxy matrix laminate. However, it is very difficult to get the information during committee’s literature review. It may be included and/or considered in next ISSC 2018 committee “Subsea Technology”.

2.2.3 Floor discussion by Agnes Marie Horn

The fatigue damage under random loading is traditionally evaluated based on Miner’s law and constant amplitude S-N curves. Under this framework, appropriate safety factor is selected considering accuracy of stress analysis method. Although many improvements have been proposed so far, the methodology works satisfactorily in many areas of structural engineering. The committee did not find reports of accidents or researches which require more stringent fatigue evaluation of riser or pipeline during the review process.