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# Development and sea trial of real-time offshore pipeline installation monitoring system

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A B S T R A C T

Deep-water or open sea area developments bring technology challenges to offshore pipeline installation safeties. With low oil price, offshore contractors endure considerable pressure and struggle to provide cost-effective services. To achieve safe operations with higher efficiencies, it is essential to acquire better understanding of pipeline conditions in-process, which benefits operation planning and decision making. Offshore operational window and pipeline fatigue damage significantly depends on vessel motions. Current engineering practices generally predict motions through metocean and hydrodynamics based numerical simulations. This approach is useful but naturally leads itself to prediction uncertainties, which are most likely conservatism. With deep-water and open sea application, the uncertainties may become underestimations of key parameters due to possibly insufficient metocean data and inapplicable hydrodynamic methods. Subsequently, a real-time offshore pipeline installation monitoring system has been developed to predict realistic pipeline behavior by adoption of real-time operation parameters including vessel motions. A sea-trial for the system has been conducted on a pipelay project in 2016. As an alternative treatment to pipeline installation planning and decision making, the system has been proven capable of accurate simulations and additional functions such as touch point monitoring and fatigue tracking.

## 1. Introduction

Submarine pipelines have been widely recognized as most feasible and efficient practice to transport oil and gas in large scale to both intrafield and onshore. With increasing energy demand from mainland China, the exploitations of oil and gas reservoirs have been driven to deep-water areas, usually in remote and harsh sea areas. Installations of deep-water pipelines are implemented by utilizing S-lay or J-lay techniques. S-lay has been in a dominated position since being developed in early 1980s mainly due to its high installation efficiency (Bruschi et al., 2015). In S-lay method, pipeline is supported by a stinger passing on a regular sequence of rollers, following a S-shape trajectory before landing on seabed. As illustrated in Fig. 1, upper curved part of the s-shape resting on stinger is known as overbend, followed by inflection point where pipeline curvature equal to zero. Before approaching seafloor, pipeline is reversed into a form known as sagbend. Achievement of the S-shape configuration is subject to the application of horizontal tension on the pipeline held by mounted tensioner device. Although capable of high laying efficiency, pipelines in S-lay may confront significant axial tensions, especially in deep-water applications (Yun et al., 2004; Bai and Bai, 2005). In addition, dynamic response of pipeline in deep-water S-lay becomes more significant and is regarded as one of the most important decisive factor in installation feasibility study (Bruschi et al., 2007, 2015; Gong et al., 2014).

Traditional engineering approaches to the issues stated above are mainly based on pipelay numerical simulations where parameters such as pipeline properties, top tensions, environmental conditions, vessel motions and pipe-soil interaction are considered. Extensive investigations have been carried out to enhance simulation accuracies. With adoption of advanced finite element softwares, dynamic behaviours of suspended catenary pipeline can be determined and the results are used to assess installation feasibilities (Gong et al., 2014; Xie et al., 2015; Suzuki and Jingu, 1982; Chatjigeorgiou, 2013; Vlahopoulos and Bernitsas, 1990; Hall and Healey, 1980). Pipe segments close to touch point generally induce high stress where pipe-soil interaction relationship is sophisticated. Properties can be predicted through existing design criteria (Det

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**List of notation**

| | |
|---|---|
| 2D | 2-dimensional |
| 3D | 3-dimensional |
| ADCP | Acoustic Doppler current profile |
| API | Application programming interface |
| BV | Bureau Veritas |
| CCS | China Classification Society |
| CNOOC | China National Offshore Oil Corporation |
| COOEC | China Offshore Oil Engineering Co |
| CoV | Coefficient of variation |
| DNV | Det Norske Veritas |
| DoF | Degree of freedom |
| FEA | Finite element analysis |
| GPS | Global positioning system |
| IMU | Inertial measurement unit |
| MVC | Model–view–controller |
| ROV | Remotely operated vehicle |
| SIT | System integration testing |
| TDP | Touch down point |
| WD | Water depth |

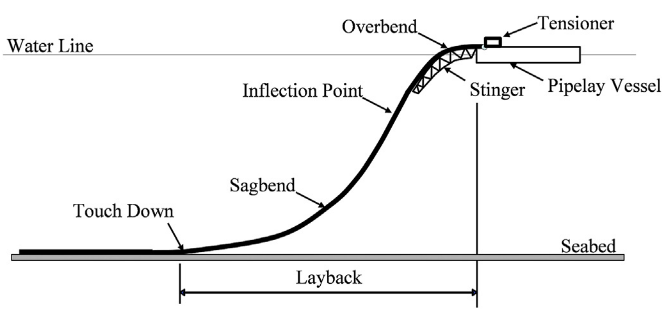


**Fig. 1.** Schematic representation of S-lay pipeline installation.

Norske Veritas, 2006; American Society of Civil Engineers, 2001). Efforts through analytical analysis (HODDER and CASSIDY, 2010), numerical modeling (Chatjigeorgiou, 2013; Murff et al., 1989; Van den Abeele and Denis, 2012) and laboratory testing (Verley and Sotberg, 1994) have been made to optimize existing methods or provide alternative solutions. With contributions by researchers and engineers, water depth records of pipeline installation have been more than 3000 m (Bruschi et al., 2015).

However, there are certain data unavailable in office design stage. For example, actual vessel motions and top tensions are not existent until operations start. Current engineering practice predicts these non-existent values and applies them in corresponding analysis, as illustrated in Fig. 2. Although predictions of these uncertain parameters by adopting either codes or other advanced computing mechanism being useful, it generally induces conservatism in practice. In addition, for projects in open sea, due to limited metocean data, predictions may not be conservative (Bruschi et al., 2015).

Therefore, a pipelay monitoring system has been developed by incorporating real-time data such as vessel motions, positioning and heading, current profile and top tension to overcome these issues, as shown in Fig. 2, where abbreviations are explained in Section 2. The system enables a better understanding of pipelay process and higher installation efficiencies, especially in severe environmental conditions. Furthermore, since capable of full-history tracking of pipeline integrity during installation, the system achieves additional functions such as accumulative fatigue calculations, touch down point monitoring etc., information of which may be beneficial for assets owners from future integrity management or contractors to reduce the usage of facilities such as Remotely Operated Vehicle (ROV).

## 2. System methodology

An on-board pipeline installation monitoring system has been developed to enhance pipelay efficiency by employing actual data rather than engineering assumptions with which are usually associated offices based installation design. This method is achieved through both hardware and software constituent parts, as illustrated in Fig. 3.

Integrated Inertial Measurement Unit (IMU), Global Positioning System (GPS) and Acoustic Doppler Current Profile (ADCP) collect key on-site data including vessel motions, positioning and current profile respectively. Real-time top tension can be acquired through onboard tensioner device. Actual measurements together with other installation parameters are imported into system database. As shown in Fig. 3, an advanced pipelay monitoring software has been developed to perform simulations by incorporating Orcaflex as model builder and analysis tool

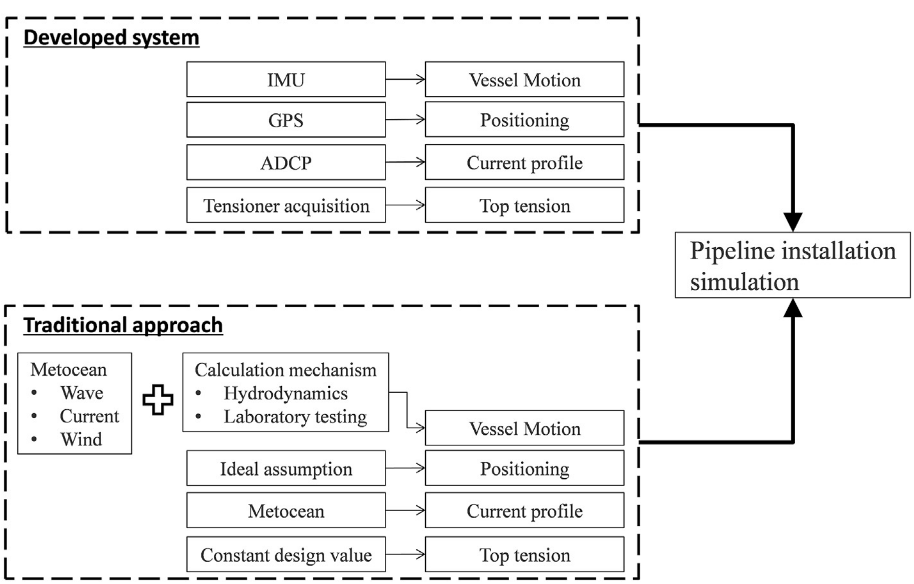


**Fig. 2.** Schematic illustration of data input methods.