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Reply to the Discussion submitted by W.O. McCarron of our paper entitled, "Modelling spatial variability in as-laid embedment for high pressure and high temperature (HPHT) pipeline design"

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Reply to Discussion: Modelling the spatial variability of as-laid embedment for high pressure and high temperature pipeline design, Z.J. Westgate, W. Haneberg, D.J. White (CGJ 53:1853-1865)

The authors would like to thank W.O. McCarron for his insightful discussion of the Westgate et al. (2016) paper on spatial embedment variability of subsea pipelines, and for sharing our enthusiasm for this topic. We are pleased that the paper attracted this discussion. Below are specific responses to each of the Discussers' key points.

In response to the first and second points on buckle length and averaging length, we appreciate the approximate nature of Equation 6. However, this is the standard approach to assess buckle susceptibility (based on the SAFEBUCK JIP Guideline, Atkins 2015) so provides a valid comparison with conventional practice when we introduce the relevant geotechnical variability in Westgate et al. (2016). The tendency for a buckle to initiate due to reduced lateral resistance over a length less than the critical buckle length has been demonstrated by finite element analysis using field data of as-laid embedment and calculated lateral resistance (White et al. 2014). In this analysis, for a similar pipeline to Pipe A, lateral buckles formed at locations where the embedment (and resulting lateral resistance) was reduced over a pipeline length of approximately 10 to 20 m – a much shorter length than the resulting buckle that formed. We do note, however, that such examples are specific to the pipeline properties and out-of-straightness features involved, but the analyses serve their purpose of highlighting the influence that geotechnical variability can have, and therefore the potential value of including it realistically in design.

The third point relates to the horizontal correlation length of lateral resistance, due to the variable embedment and soil properties. The Discussers queries the value adopted in the example analysis, which could represent a soil heterogeneity present in situ, or a heterogeneity created through the process of installing a pipeline on the seabed and locally remoulding the soil to different degrees.

Ultimately our overall choice for length scales of the various processes that affect embedment was driven by the field observations, which match our example case. We agree that soft clay deposits in the deep ocean, such as the Gulf of Mexico, may be more homogenous and have a longer correlation length scale than used in our example. However, we have previously published a collection of undrained strength profiles derived from offshore T-bar tests in soft clay from deep water off the coast of West Africa that provides a useful example (White et al. 2014). Within the upper 0.5 m, the COV for intact undrained strength, from this set of 12 profiles, varied in the range 0.10 to 0.42, with an average value of 0.23. Including variability due to the level of remoulding of the soil can increase the applicable COV. This supports our selected level of heterogeneity, although we recognise that the measurement error itself adds uncertainty onto the natural variability. This study gave no information on the length scale of the variability due to the wide spacing of the tests. Reviews from the broader geotechnical literature quote horizontal correlation length scales in the range 0.5 – 20 m (Lacasse & Nadim, 1996, Huber et al. 2009), so our selected values are within the range of experience. It is rare that offshore site investigations involve tests at sufficiently close spacing to identify high local heterogeneity, which is a perennial difficulty when attempting to incorporate spatial variability in geotechnical design (Nadim 2015). In our pursuit of understanding spatial variability, we have suggested that in situ tests might be performed in local pairs or be logarithmically spaced to better identify scales of horizontal variability (Bransby et al. 2015), but the value of such a strategy remains to be proven.

In summary, Westgate et al (2016) and Dr. McCarron's discussion on this paper show that spatial variability – from both geotechnical and structural effects, both natural and installation-induced – is an important topic to focus on when assessing the response of subsea pipelines. Pipeline lateral buckles are a relatively local phenomenon whereas the overall expansion and force build-up are global, and these behaviours interact. The integrity of a subsea pipeline is therefore affected both by

local actions and their global integrated average, and spatial variability controls the level to which these can differ.

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