# OTC 19459

# Evaluation of Landslide Impact on Deepwater Submarine Pipelines

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This paper was prepared for presentation at the 2008 Offshore Technology Conference held in Houston, Texas, U.S.A., 5–8 May 2008.



## Abstract

The push of the petroleum industry into greater water depths has lead to a tangible increase in project geohazards. Some of the most significant hazards on the continental shelf and slope are submarine landslides. Deepwater pipelines are at greater risk from landslide impact than other subsea structures. This is due to two factors: the length of installed pipeline increases exposure to landslide hazard, and the structural resistance of pipelines is small compared to landslide forces.

This paper examines the behavior of surface laid submarine pipelines under shallow landslide impact based on the results of parametric studies performed for BP. A simple closed form solution is developed, modeling the pipe as an elastic cable, the landslide as a distributed load and the soil as a rigid-plastic resistance. The model is calibrated against finite element analysis. Design charts showing the maximum landslide pressure which the pipe can resist are presented. This approach can be used as a simple screening tool to assess pipeline vulnerability during routing in typical deep-water soil conditions and to develop hazard mitigation strategies in such settings. A case study is presented for a small (2-3 m thick) landslide impacting flowlines and an export line.

The conclusions of the study are: 1) when a landslide displaces a pipeline it causes the pipe to stretch with resulting tension forces. Ultimately failure is due to tension effects, either as a full bore rupture of the pipe or by disconnecting at the pipeline end termination (PLET) or riser; 2) the landslide induced tension is resisted by axial soil forces along the pipe. As the pipeline is strong in tension and soil resistance is low, these forces are transferred long distances. If the landslide occurs near the PLET, the soil resistance will not be sufficient to fully resist the in-line tension and the end of the anchor will drag unless restrained. In this case the landslide forces will act against the PLET or riser. This is important as the PLET is not generally designed to resist significant tension or accommodate large displacements; 3) geometry of the pipeline is important. If there are horizontal curves they will be “pulled in”, making the pipeline more compliant and slide resistant. For a specific example of a 2-m thick, 400-m wide landslide impacting a 24 inch diameter pipe, it is shown that slide displacements of up to about 500 m can be resisted with limited pull in. A considerable amount of additional slack is required, however, to mitigate greater landslide runouts. The results of these analytical preliminary studies suggest that landslides risks may be reduced by laying pipes with curves in landslide-prone areas.

## Introduction

The push of the petroleum industry into ever greater water depths has lead to a tangible increase in project geohazards. Some of the most significant hazards on the continental shelf and slope are submarine landslides. Deepwater pipelines are at greater risk from landslide impact than other subsea structures. This is due to two factors: 1) the length of installed pipeline increases exposure to landslide hazard, and 2) the structural resistance of pipelines is small compared to landslide forces.

There is limited reporting of geohazard damage for deepwater pipelines in the technical literature. The majority of published data pertains to hurricane damage in shallow water in the Gulf of Mexico. In reviews of damage for hurricanes Andrew, Lili, Ivan, Katrina and Rita there were more than 1300 reported cases of damage (DNV, 2007). The main types of damage are rupture of risers and piping, although cases of full-bore rupture have also been reported (DNV, 2006).

A number of researchers have examined pipelines subject to landslide impact. Swanson and Jones (1982) developed an elastic cable model for submarine pipelines under landslide impact, and implemented the solution in a dedicated computer program. As part of a general review of geotechnical issues for offshore pipelines Bea and Aurora (1982) examined the stability of pipelines to mudflows. These authors considered the loading of a flexibly supported cable. Summers and Nyman (1985) applied the theorem of stationary total potential to assess the equilibrium condition of a pipeline with mudslide forces.