Geophysical Research Abstracts, Vol. 9, 10642, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-10642

The North Sea Fan - an integrated slope stability study

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As part of the ESF SPACOMA-EUROMARGINS programme, we performed an integrated geohazard study of the 110,000 km2 large North Sea Fan (NSF) on the NE Atlantic Margin. The study comprised geological and seismic analyses, numerical modelling of potential submarine landslides and landslide-generated tsunamis, including an evaluation of their periods and hazards.

The NSF is located at the outlet of the Norwegian Channel. The large volume of sediments it contains is mainly the consequence of glacial-interglacial cycles along of the margin characterised by periods of shelf-edge glaciations and ice streams dynamics within the Norwegian Channel and open shelf conditions during interglacials. As a result, the sediment sequence contains massive stacked glacigenic debris lobes, gravity flows and hemipelagic sediments. Whereas the distal NSF appears dominated by deposition, the proximal NSF shows evidence for both depositional and large-scale erosional processes (Nygård et al., 2005). The identification and mapping of debrites/slump deposits and scarps suggest that landslides have occurred semi-regularly over the last 0.5 Ma, involving hundreds to thousands of km3 of sediments. Considering the glacial history, slope failure is presumably facilitated by rapid loading of debris flow deposits at the mouth of ice stream and subsequent overpressure generation in underlying (glacio-)marine clays (Solheim et al., 2005).

A new theoretical and numerical model for gravity mass flows is developed, using a Non-Oscillatory Central difference scheme based on the Norem-Irgens-Schieldrop model. This stable, conservative scheme allows for the propagation of shock fronts in the flowing mass caused by terrain formations or obstructions in the flow path. An additional isotropic normal-stress viscosity is included to ensure that the lateral pressure in rapidly sheared flow does not vanish. Additionally, we performed simulations for potential slide-generated tsunamis on the NSF and their implications for the coastal lowlands. The model adopted a weakly, non-linear and dispersive Boussinesq wave model to account for tsunami generation and propagation in relatively deep water areas. The results reveal surprisingly small wave heights compared to the Storegga Slide tsunami. The low wave heights are explained by the smaller volume of sediments involved and the lower sliding velocities, though the effect of wave generation in deeper water areas should not be ignored.

The annual occurrence probability for submarine landslides may be estimated from the geological record, e.g. observed slide frequency, geological history, geophysical investigations, and radiocarbon dating of sediments; and/or analytical simulations. If the trigger for inducing a landslide is identified, the annual probability of slope instability can be established by evaluating the conditional probability of failure for different return periods of the trigger. When the triggering mechanism is not obvious, the problem is no longer straightforward. (Nadim et al., 2003) developed several ideas for quantifying the annual probability of slope instability, including (1) a Bayesian approach with Bernoulli sequence; (2) Availability problem - Markov chain; (3) Interpretation of the static failure probability as the instantaneous hazard function; (4) Interpretation of computed static failure probability in Bayesian framework.

The integration of geology, slide mechanics and dynamics, as well as tsunami modelling is necessary to obtain a better understanding of mass flows and their consequences in the offshore realm, which will improve risk assessment and probability studies.