COSTA-CANADA, A CANADIAN CONTRIBUTION TO THE STUDY OF CONTINENTAL SLOPE STABILITY : AN OVERVIEW

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ABSTRACT

This paper describes the main outline of the COSTA-Canada project (www.costa-canada.ggl.ulaval.ca) which aims at studying the stability of submarine slopes in the framework of a cooperative program with American and European partners. This 4 year project covers issues from submarine slide inventory, their signature, their triggering, mobility, extent and consequences (e.g. tsunami). All these issues will be integrated a geotechnical risk assessment approach.

RÉSUMÉ

Cet article décrit les grandes lignes du projet COSTA-Canada (www.costa-canada.ggl.ulaval.ca) qui vise l'étude de la stabilité des fonds marins. Il vient s'intégrer avec un programme équivalent en Europe. Ce projet, d'une durée de 4 ans, couvre divers aspects dont l'inventaire des glissements sous-marins, leur signature, leur déclenchement, mobilité, étendue et conséquences (e.g. tsunami). Tous ces aspects seront intégrés dans une approche géotechnique de l'évaluation du risque.

1. INTRODUCTION

Canada's continental margin and coastline is the focus of more and more attention as we see developing economic activities in various fields including natural resources (oil and gas), transportation (port development), electrical transmission, and communication (fibre optics cables, etc…). Amongst the major natural hazards threatening economic activities and population along the Canadian coastline are earthquakes, submarine landslides and tsunamis. The submarine landslides are of particular importance since they can not only generate tsunamis but also debris flows and turbidity currents that can impact human activities far away from their place of initiation (Morgenstern 1967). For example, the 1929 Grand Banks Earthquake triggered a huge submarine landslide, which generated a tsunami that killed 27 people in Newfoundland (Fig. 1). The landslide itself evolved into a major turbidity current, which broke the communication cables laying on the sea floor over a distance of more than 1000 km from its initiation! Similar landslides are a potential hazard for current oil and gas development on the deep-water continental margin off Nova Scotia and Newfoundland. Therefore, with the development of oil and gas resources farther from the coast and in the neighbourhood of the Continental Slope, economic activity is moving into areas where these phenomena have occurred and will most likely recur. The goal of this project is, consequently, the assessment of continental slope stability along the Canadian continental margin, estuaries and fjords with respect to natural processes and human activity.

As part of the European Union's Fifth Framework Program, a group of European researchers, co-ordinated by Prof. Jurgen Mienert (Norway), has been awarded project COSTA, which stands for: COntinental Slope STAbility. COSTA follows Project ENAM II, which also looked at submarine mass movements and ended in 1999.

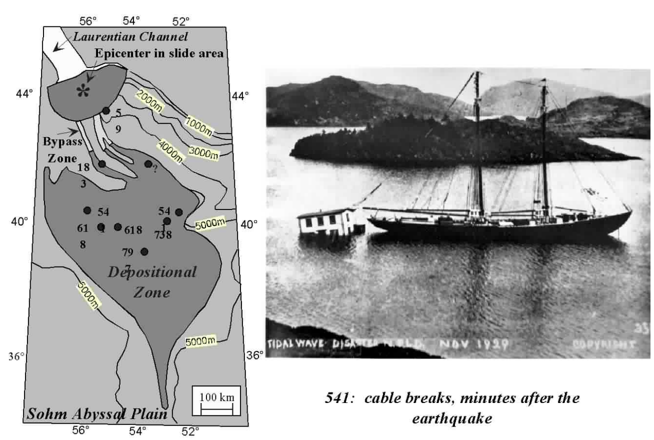

Figure 1. The Grand Banks slide, extent and consequences (tsunami generation, adapted from Piper et al. 1985, 1988; photo courtesy of A. Ruffman).

Project COSTA focuses specifically on various components of submarine landslides from the historical record to the actual risk assessment Such a multidisciplinary and concerted effort has never been undertaken before. It has moved the Canadian community into pulling its resources together in an effort to ensure Canada's participation in this major research program which is concerned with ocean and coastal issues highly relevant to the long terms development of Canada's offshore resources, transport and communication. COSTA-Europe recommended that our contribution be strongly centred around strong Canadian case histories and cutting edge technology so that all would benefit from adding and comparing the various environments which are selected (see Fig. 2).

TARGETS	RIVER-DOMINATED SETTING		GLACIAL-DOMINATED SETTING		
SHALLOW (Shelf)	Adriatic (6)	Fraser Outardes	Effingham Inlet	Saguenay Fjord	Norwegian Fjords (10)
DEEP (Slope)	NW Mediterranean (1-5)	Grand Banks Scotian Shelf	Afen (7)	Storegga (8)	Traenadjupet (9)
WATER	**WARM**	**COLD**			

Figure 2. List of European and Canadian sites selected for this project presented in terms of water depth and sedimentary environment.

The study of stability along continental margins requires the use of major resources, ships in particular, for accessing the various sites. For Europe, it has been said that the costs and requirements of studying continental slope stability along the European Margin would be prohibitive for any single nation. That would also be true for Canada and underlines the necessity to be involved in this unique opportunity.

The major partners of COSTA in Europe are the following: J. Mienert (University of Tromsoe (Norway, project co-ordinator), P. Cochonat (IFREMER-Brest, France), D. Masson (Southampton Oceanography Centre, England), F. Trincardi (Istituto di Geologia Marina, Italy), M. Canals (University of Barcelona, Spain), D. Long (British Geological Survey), H.-P. Sejrup (University of Bergen, Norway), A. Elverhoi (University of Oslo, Norway) and the Norwegian Geotechnical Institute (NGI, Oslo, Norway).

A significant aspect of this collaborative program will be to provide an excellent opportunity for Canadian students and researchers to firm their links in Canada and network with Europeans to improve their technical skills and knowledge and establish a solid co-operation.

Project COSTA is the first integrated approach into the study of submarine mass movements, from its initiation to the formation of the final deposit, and it does so by including field and laboratory investigations as well as physical and numerical modelling.

Some of the most important questions identified in COSTA project are: (1) What are the triggering mechanisms of slope failures on the continental margins ? (2) What is the variability from one site to the next? (3) Why will one region of seafloor fail while neighbouring regions remain stable? (4) What are the factors that determine where a slope failure will occur? (5) What determines the location of the slip planes? and (6) What is the role of gas hydrates in slope stability? We believe that all of these questions are relevant to the Canadian context.

Project COSTA in Europe is studying 10 sites while we plan to include 5 additional sites in Canada (Fig. 2). Altogether, this will form a unique database with a consistent representation of the different sedimentary environments where landslides have taken place and may eventually take place again.

Participating in the COSTA project will benefit the community by advancing our knowledge of:

- potentially stable or unstable continental slopes, valuable to installations and to the health and safety of offshore and coastal regions;
- the possible presence of gas hydrate and free gas zones so as to improve environmental protection during offshore activities such as cable, pipeline and drilling work;
- forces and release mechanisms of slope failures on margins, and of endangered areas, for a major contribution to sustainable development;
- predictive tools and risk assessment of continental slope activity for the next 100 -1000 years.

One of the important results that we can expect is a better recognition of the presence of trigger mechanisms that cause slope failures. We will integrate numerical and experimental modelling in order to generate a 3D approach (3D seismic + 3D geotechnical + 3D loading = 3D stability analysis) to understand the forces and the mechanical processes that control slope failures (the release mechanisms) and flow dynamics. Finally, a risk assessment is made for a problem-solving approach, because present and future plans for the installation of large structures on the seafloor and close to the shoreline urgently necessitate the estimation of continental slope stability.

2. OBJECTIVES

Our long term objectives are related to fundamental questions that persist about continental slope stability and seafloor failures: (1) why do they occur where they do, and (2) with what frequency do they occur? We are still lacking critical information concerning physical and mechanical properties of sedimentary systems prone to failure, and the distribution of gas hydrates, free gas and fluids within the upper sediment columns. The acquisition of state-of-the art geophysical and geotechnical data sets will provide us with: (1) a far greater knowledge of the structure of sediment slides and slip planes; (2) a better understanding of trigger mechanisms, *e.g.* the role of gas hydrates; (3) a better understanding of the variability of slope failures; (4) a better understanding of mechanisms and forces, allowing the formulation of models and risk assessments..

Project COSTA has identified the following **short term** objectives:

1. Assessment of historical records of slope instability, slope parameters, seismicity, and tectonic setting.
2. Understanding of seafloor failure dynamics through 3-D imaging of sediment architecture and geometry of slope failures.
3. Understanding of sediment physical, mechanical and elastic properties of slip planes and areas prone to slope sliding.
4. Determination of presence of gas hydrate and its significance for slope stability.
5. Modelling of forces and mechanical processes that control the initiation of slope instabilities (release mechanisms), flow dynamics and initiation of tsunamis.
6. Assessment of risk-fields related to slope stability.

3. SOME REVIEW

In 1980, a NATO organized a major workshop on Marine Slides and Other Mass Movements (Saxov and Nieuwenhuis 1982), the State of-the-Art Report of Prior and the recent review by Hampton et al. (1996), there is a general agreement that:

"An integrated multidisciplinary approach is essential in the investigation of the various aspects of marine slope instability, and will lead to precise description, evaluation, assessment and analysis of the processes. It should also lead to a better quantification of the important parameters, and greatly advance our understanding of different slide mechanisms and processes." (1980).

"Concentration of interdisciplinary investigations on some recent or active slides is necessary for understanding the mechanisms, geotechnical parameters and causes of failure." (1980).

"The factors leading to the initiation of failure cannot at this time (1980) be fully quantified." (1980).

"The quantification of precise cause/effect relationship is difficult owing to the problems of defining appropriate sediment strength parameters. Assessing original sea-floor geometries, and the immense scale and remoteness of the processes." (1984).

"Less is known of the timing and recurrence interval of slides in a particular region. Accurate and economical determination of in-place properties, especially beneath the seafloor, remains a problem in evaluating slope stability." (1996).

The only comprehensive inventory of submarine landslides, at a regional scale, has been carried out by the USGS (Schwab et al. 1993) for the Exclusive Economic Zone of the United States. This compilation mostly reports on morphological features (using GLORIA) and some ground control using high resolution seismic with very limited number of bore-holes. Still it has demonstrated that the more we can adequately map the sea floor, the more we discover its complexity and diversity of features, mass movement in particular (Hughes-Clarke et al. 1996, Locat et al. 1999). We can now appreciate the diversity of failure mechanism in the marine world: seismic, sediment loading, erosion, glacial loading (Mulder and Moran 1995) and gas hydrates (Kayen and Lee 1991).

For a recent update on submarine mass movements and their consequences, the reader is referred to Locat and Lee (2001).

4. PROJECT PLANING

The COSTA-Canada project (www.costa-canada.ggl.ulaval.ca) will be carried out over a 4 year period until late 2004. We will make sure that Canadian participation is fully integrated into COSTA-Europe for the benefit of all, including participation in field surveys, workshops and common laboratory and analytical studies.

4.1 Selected sites

COSTA-Europe has identified specific locations where the field work will be carried out: the Adriatic Sea (e.g. Po Delta), the Northwest Mediterranean Sea (Gulf of Valencia and Gulf of Lion), Norwegian fjords, and the Afen, Storegga and Traenadjupet slides in the North Sea. As may be seen, most of these sites have analogous settings in Canada (e.g. Effingham Inlet in British Columbia (and other sites around Vancouver Island), Québec and Labrador; Grand Banks, Fraser Delta, Manicouagan and Outardes deltas in Québec). Most of the European sites have already been investigated as part of projects ENAM I and ENAM II, so that the COSTA Project will be able to focus on very specific sites which will enable the optimization of the field surveys.

In Canada, we plan to integrate our current research sites, which include the Nova Scotia Margin, the Saguenay Fjord and Outardes delta (Québec), and the Fraser Delta and Effingham Inlet in British Columbia (Fig. 2).

4.2 Methodology

In COSTA project, the basic methodology applied to achieve the objectives can be summarised as follows: (1) systematic assessment of historical sediment failures, (2) high-resolution geophysical characterization of slide architecture, geometry, areas prone to failure and gas hydrates, (3) in situ geotechnical and geophysical determinations of surface and subsurface sediments in which instabilities arise, and detailed age dating (4) experimental and (5) numerical modelling of slope failure and flow dynamics

COSTA-Canada project provides us the opportunity to use our methods developed for: (1) laboratory analyses of sediment physico-chemical and geotechnical properties, (2) integration of GIS into submarine landslide risk assessment, (3) seismic triggering of submarine landslides and (4) modelling of landslide-generated tsunamis.

COSTA projet involves work at sea. In Europe, cruises in 1999-2002 will involve RV Marion Dusfresne (1999), RV Europe (2000/01), RV Suroit (2000/01), RV James Clark Ross (2000), RV Hesperides (2001), RV Hakon Mosby (2000/01), RV Jan Mayen (2000/01), RV Seisma (2000/01), RV Urania (2000/01) and RV Mareoceano (2001). In Canada, cruises funded by GSC-Atlantic are planned with the Hudson in July 2000, 2001 and 2002. COSTA-Canada itself is looking after cruises in the Saguenay Fjord in 2001 and 2003 onboard the Marth L. Black and in 2001 with the F.G. Creed for a multibeam survey of the area off Outardes River (Québec).

5. APPROACH

An important element here is that most of the sites investigated will involve some form of back analysis approach. Field and laboratory work will be needed as a support for this or for using the back analysis as part of the validation process of the various models. Following each heading are indicated the name of the person in charge of that component of the project and the co-workers.

5.1 Assessment of historical records of slope instability, slope parameters, seismicity, and tectonic setting (D. Piper, B. Long, and B. Bornhold.)

Data on historical slope failures will be gathered from the project partners, from industry, and from literature. Analysis of the data will look for correlation between parameters or clustering of parameters related to slope failure. Other aspects include ages of events, slide run-out distances, sediment architecture and type, gradient, height, width and thickness and shape of the flow. Slide types and frequency in various areas will be examined as a contribution to risk analysis. This will allow us to assess and review the present understanding of historical slide events and define gaps in knowledge on glacially dominated as well as river-dominated margins (see Fig. 2). Such a synthesis for the continental margin off eastern Canada is currently underway at GSC-Atlantic funding will be augmented to include all of Canada.

5.2 Understanding of seafloor failure dynamics through 3-D imaging of sediment architecture and geometry of slope failures (B. Hart, B. Long, D. Piper, J. Hughes-Clarke, and J. Locat)

An important component of COSTA is the acquisition of 2D and 3D seismic data. European cruises will provide Very High-Resolution (VHR) and High-Resolution (HR) seismic lines in the different sites, deploy and retrieve seafloor instruments, and recover sediment cores. In Canada, the following cruises are planned by GSCA, who will co-operate with other members of the team. Cruises include one on the H.M.C.S. Hudson during the summer 2001 to Grand Banks margin; Hudson 2001 deep-water ROPOS cruise with numerous partners (August 2001); Hudson 2002 to the Scotian or Grand Banks margin;. It is hope to have co-operative cruises with Petroleum industry on the Scotian margin to acquire multibeam bathymetry. In the Saguenay Ford, as part of the Saguenay Flood Project (Strategic project funded by NSERC and Alcan Ltd) we already have cruises planned for 2001 and 2002 with the Alcide C. Horth which can only support shallow sampling and seismic work. Outardes delta work will be completed via 4 days of multibeam survey and 10 days of small vessel surveys with SEISTEK. On the West Coast, opportunities are already available on various vessels (e.g. Revisor, Vector).

5.3 From 3D architecture to 3D properties (B. Hart, B. Long, D. Piper, and J. Locat)

We will apply 3D seismic technology to the study the architecture of submarine slope failure and to unfailed slopes (Hart 1999). Stratigraphic and structural features (e.g., slip planes) will be mapped throughout the data volumes. We will then integrate the 3-D seismic data with results of physical testing on cores, physical modelling of soil properties in order to produce 3-D volumes of sediment physical properties. This approach will be based on cutting edge technologies that are being developed and applied in the petroleum industry (e.g. Hart 1999) and will help to link this task with studies on failure and risk assessment. In Canada we will collect pseudo-3-D seismic data from the Saguenay Fjord, where landslides have been identified and mapped, and long cores will be made available. We will run closely spaced (20-40 m) seismic lines (SEISTEK) and merge those data into a 3-D volume. A small 3D seismic survey is planned to be carried out on the Scotian margin using the new GSC deep-tow streamer/sleeve gun system. These data will be combined to develop the physical properties volumes (e.g., geotechnical properties, weak zone definition, use of CATSCAN data to correlate sediment structure and density to strati-seismic data, MST and geotechnical properties. We shall adapt this methodology to at least one European site (e.g. Storegga) where 3-D seismic data will be made available.

5.4 Imaging submarine mass movements (J. Hughes-Clarke, D. Piper, B. Long, B. Hart, and J. Locat)

Imaging the sea floor is a key element to submarine mass movement studies and our knowledge of submerged mass movement is ultimately limited by our ability to resolve the surficial and subsurface morphology. Unlike basin scale processes, the spatial variance within a slide complex is very high. In order to understand these processes, we must employ instruments of sufficient matching spatial resolution. Swath bathymetric sonar data are often used by scientists who only have a minimal understanding of the system limitations. A major part of the research at the Ocean Mapping Group (OMG, University of New Brunswick) has been put towards quantifying the limits of resolution of these systems. This applies both to the topographic imaging and the potential for surficial sediment classification. New beam forming and stabilisation approaches (narrower beams and active yaw stabilisation particularly) have allowed us to improve on our capabilities. Work at UNB will involve three tasks in the light of submarine mass movements: (1) continue research into defining and improving the resolution of these ever-developing systems. This would include both theoretical modelling and the development of practical processing tools; (2) support the other Canadian geoscientists in the proper design, implementation and processing of their field programs that involve acoustic swath based systems; (3) learn from and exchange our knowledge with the European consortium.

5.5 Understanding of sediment physical and mechanical properties of areas prone to slope sliding (J. Locat, S. Leroueil, J.-M. Konrad, P. Byrne, H. Lee, and D. Piper)

A systematic characterization of the materials involved in the slides in each location. The analyses will be carried out, on at least 5 representative samples from each site in Europe and Canada. Each intact sample will go through the same analytical procedures including: Atterberg limits, textural analysis, cation exchange capacity, specific surface area, organic matter content, intact and remoulded undrained shear strength, pore size distribution and SEM analysis. The results will provide a unique reference on sample characteristics obtained with identical techniques. Most of the European sites should be investigated in the first year.

In collaboration with the European team, we will look into in situ and laboratory geotechnical characterization of the sediments. One of the major opportunities will be for the Canadian team to access the recent in situ technology developed in Europe. In situ measurements will use front-line equipment technology such as multi-component seismic (OBS, elastic properties) and pore pressure (PUPPI, excess pore pressure, shear strength) deep-sea technologies, and in situ deep-penetration geotechnical (PENFELD) (shear strength, bulk density) measurements. In addition we will be using recent technology developed in Canada to measure shear strength and pore pressure, and to extract pore water (Lancelot and Excalibur probes). Laboratory testing will look at providing geotechnical profiles. Static and cyclic triaxial, direct simple shear, and oedometer tests will be carried out on samples from Canada and co-ordinated sites from Europe to measure basic strength parameters (cohesion, friction angle and pre-consolidation pressure) and small strain shear modulus. All this information will be put together to develop basic conceptual models of shear strength profiles which could be derived from simple index properties (e.g. liquidity index, Perret et al. 1995; Locat and Lee 2001). These empirical strength profiles, taking into account processes like erosion, loading or cementation, could then be used in other slope stability models. This model will be integrated into the 3D volume model (see above).

5.6 Cyclic Behaviour (J.-M. Konrad and H. Lee)

The undrained response of saturated fine-grained soils is of utmost importance where large deposits of such materials are subjected to rapid shearing. Undrained shearing could either be due to cyclic loading induced by earthquakes or waves or due to rapid loading in areas with sedimentation rates or active slope erosion. Recent testing at UBC has shown that injection of even a very small amount of water into a sample as it is sheared can greatly reduce its strength and stiffness (below that for undrained), and this phenomenon will also be examined. Such injection effects occur where drainage is impeded such as below low permeability layers. In addition, the coupling effect of combined shearing simulating, both down slope and cross slope conditions, will be examined. This research section encompasses static, cyclic and post cyclic behaviour over a range of initial void ratios and consolidation stresses. Undisturbed samples will be tested wherever available and reference characteristics will be obtained on re-consolidated samples in order to establish a comparative data base, which will be useful for a regional slope stability approach.

5.7 Rheological behaviour of mud and muddy debris f low matrix (J. Locat and S. Leroueil)

As part of the analysis of transition from slide to flow, we will determine the rheological properties of the various sediments obtained. Using a HAAKE Rotovisco rheometer, we will investigate the rheological properties of sediments from selected sites in Europe and Canada over a range of water content (or sediment concentration). This opportunity to access European sites will substantially enlarge and test the validity of our rheological models (Bingham and Bi-linear) and is essential for planning laboratory small-scale simulation and numerical modelling (see later). This basic work will also provide simple relationships based on the liquidity index (Locat 1997) useful to estimate the yield strength and dynamic viscosity.

5.8 Determination of presence of gas hydrate and its significance for slope stability (D. Piper, B. Long, B. Hart, and J. Locat)

Most surficial failures on the Scotian and Grand Banks margin, in contrast, appear to date from 10 to 15 ka, although hypotheses have been proposed relating these failures to glacial loading (Mulder and Moran 1995), it seems more probable that they resulted from melting of gas hydrates as slope waters warmed up after retreat of glacial ice from the shelf edge (Piper et al. 1999). Melting of gas hydrates has the potential to increase pore pressure and thus destabilize the seabed. Abundant gas hydrates may be recognised as a bottom simulating reflector: such BSRs, which are known locally on the east coast continental margin. Shallow gas and pockmarks, however, are widespread in many areas where failure has occurred and suggest that dispersed gas hydrates may be present in the sediment. The question of the presence of gas hydrates can be addressed by re-analysis of industry seismic data (planned by the GSC-Atlantic), high-resolution seismic refraction experiments (planned by the GSC-Atlantic and Dalhousie University); and seabed sampling in areas with BSR (planned by the GSC-Atlantic). If gas hydrate is present, its significance will be assessed by comparing the timing of historical failures with proxy records of seabed paleotemperature.

5.9 Rheology (J. Locat, S. Leroueil and H. Lee)

Recently, we have proposed a bi-linear model (Locat 1997) to describe the rheological properties of muds. In collaboration with G. Parker at the University of Minnesota and A. Elverhoy (Oslo) we would like to develop a general flow model which could take into account bi-linear and Bingham models. The model will be based on laboratory measurements and in situ analysis of cores and will be tested on the applicable sites.

5.10 Slide initiation (J. Konrad, R. Phillips, P. Byrne, A. Popescu, and D. Piper)

There are many triggering factors for submarine slide initiation. Two factors will be addressed more specifically: (1) seismic events, that induce inertial forces and loss of shear strength due to soil liquefaction (e.g. Grand Banks, Saguenay Fjord, Fraser delta), and (2) gravity driven slides in area with high sedimentation rates with the presence of gas hydrates (e.g. Fraser delta). The mechanisms of submarine slope failure initiation will be studied by integrating the constitutive models of different soils to numerical modelling. Moreover, it is planned to calibrate the numerical models with few centrifuge tests conducted at C-Core. The results of the centrifuge and numerical modelling will match and complement that of objective 5.

Numerical modelling will be carried out using two models: FLAC and DYNAFLOW™. FLAC (Fast Lagrangian Analysis of Continua) with stress-strain models developed at UBC is currently used for modelling initiation and subsequent movements of dams, embankments and river bank slopes under earthquake loading. The program uses a finite difference explicit solution of the equation of motion and considers coupled stress flow, temperature, pore fluid gas as well as geometry changes which are so important for slope movement. The program, and UBC stress-strain models, have been verified with laboratory and centrifuge tests as well as back-analyses of field failures.

The work will involve gathering the stratigraphy, determining the range of soil parameters, consideration of seismic or wave loading, and running the program to encompass the range of variables. In this way, important insights into initiation can be obtained. For example, the effect of suppressed drainage due to lower permeability layers may cause failure to be triggered minutes or months after the event.

DYNAFLOW™, licensed by Princeton University, is a finite element analysis program for the static and transient response of linear and non-linear two- and three-dimensional systems that belongs to a new generation of finite element analysis programs. The program, along with its plasticity soil constitutive models and the parameter calibration methodology have been repeatedly verified in the past for soil liquefaction potential assessment using full-scale data and centrifuge geotechnical models. It will be used to investigate the 3-D effect in slope failure. We will develop a 3D analysis of the stability of submarine slope by integrating 3D seismic, 3D volume and incorporating it into DYNAFLOW. We will consider different types of slides such as block glides, slumps, translational slides, or convolute slides as well as mass flow deformations. The centrifuge models may be able to incorporate certain geo-hazard features

5.11 From slide to flow (J. Locat, S. Leroueil and H. Lee)

The mechanics of transition from failure to post-failure mass movements is still a major unknown. We want to approach it by looking at the transformation of the material properties at the time of failure and under various environmental conditions. Here we are interested in quantifying energy consumption at the time of failure, the environment of failure and other factors which can lead to greater mobility (e.g. hydroplaning, Mohrig et al. 1999). We will tackle the physics by carrying out laboratory flume tests on artificial mixtures of different characteristics (e.g. brittleness). These tests will be carried out in co-operation with G. Parker at the University of Minnesota. The research results, in other components of the project, will be incorporated here into an approach based on energy balance during the transition from flow to post-failure stages. This research will help define predictive criteria for flow or no-flow conditions, a major issue in risk assessment.

5.12 Flow dynamic: debris flow, turbidity current and tsunamis (B. Bornhold, R. Thomson, D. Piper and J. Locat)

The flow dynamics will couple the phases of the phenomena from initiation to the transition into a debris flow and further to the generation of both tsunami and turbidity current. This modelling will be done by expanding the approach of Jiang and Leblond (1992). This will help to better model transport processes, tsunami generation, and tsunami run-up in real coastal areas (i.e., with complex bathymetry and coastal morphology). The last is quite difficult (and has eluded researchers to date) but we are confident that it can be accomplished. We will also apply our model to selected European sites (Storegga, Nice).

5.13 Assessment of risk-fields related to slope stability (S. Leroueil, H. Lee, J. Locat, D. Piper and J,-M. Konrad).

A general framework for landslide risk assessment will be developed using the geotechnical characterisation of mass movements (Leroueil et al. 1996) the availability of diversified sites provides a unique occasion to adopt to the marine environment a systematic approach to look at mass movements at their various stages: pre-failure, failure and post-failure. This approach takes into account the nature of the material, movement stages and properties. For each aspect, it includes the controlling laws and parameters, predisposition factors, triggering and aggravating factors, revealing factors and consequences. Risk assessment (i.e., product of hazards and their consequences, (Leroueil and Locat 1998) will be carried out on selected sites in Canada (East Coast Margin, Fraser delta) and Europe in co-operation with our European partners.

The Regional prediction of liquefaction and related instability will need to bring together geotechnical analyses and geomorphological data into a GIS as a support for regional landslide hazard and risk assessment. An approach has been developed by Lee et al. (1999) for sites in California. It is currently being applied in the Saguenay Fjord (Urgeles et al. this volume). This project will provide an opportunity to further this approach by applying it to various environments, being tested and improved on selected cases in Canada and Europe.

6. IMPORTANCE OF EXCHANGES

Built in COSTA-Canada is a strong component for exchanges amongst the various researchers and graduate students. We are putting a lot of efforts to ensure that graduate students on both sides of the Atlantic can meet, exchange so as to develop their own network, an essential part of modern research.

To achieve this, we host regular yearly meeting with our European partners in Europe and Canada. We also participate to their cruises and invite them to ours. Finally, we have implemented a series of 3 months stay in European partner's laboratories for our graduate students. This way, we hope to develop strong ties with our European partners and share with them our research interests.

7. CONCLUSION

This project is quite ambitious and provides a unique opportunity to approach many issues in an integrated manner. It is expected that the cooperation with European and American partners will be very stimulating and could be maintained for some years to come. We also hope that the integration of COSTA (Europe and Canada) in a recent project, called EUROSTRATAFORM, will enhance our research network by providing even more opportunities to integrate marine geohazards with more fundamental marine research programmes.

8. ACKNOWLEDGEMENT

The Authors would like to thank the National Science and Engineering Research Council of Canada for their financial support. We would also like to thank our European partners, under the co-ordination of Jurgen Mienert (University of Tromsoe, Norway). We would also like to take this opportunity to thank all the graduate students and technicians directly or indirectly involved in COSTA-Canada; their contribution is essential to the success of the project.

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