ANNEX VII
Geotechnical Research Projects

CONTENTS

VII.1 SUMMARY OF PROJECTS

VII.1.1 INTEGRITY MANAGEMENT & RELIABILITY

VII.1.1.1 A Pilot Study for Regionally-Consistent Hazard Susceptibility Mapping of Submarine Mudslides, Offshore Gulf of Mexico

Mississippi Delta region in Gulf of Mexico (GOM) is considered a high hazard area, where the rapidly-deposited sediments can be very weak due to their unconsolidated state, rendering them vulnerable to hurricane wave-induced pressures to trigger submarine slope failures. A mudflow susceptibility mapping for Mississippi Delta in GOM in Figure VII.1 were developed based on a geomorphic-based approach to delineate mudflow failures, sediments susceptible to future slope failure, and areas of relative stability. Based on comparison with post Hurricane Ivan bathymetric data, the developed mudflow hazard accurately characterized relatively high hazard associated with mudflow channels and the areas of greatest net change as the highest hazard. The study also indicated that a mudlobe deposition zone, located downslope of the active transport zone of gullies, should be considered a high hazard area with the potential for future mud flows and mudlobe movement.

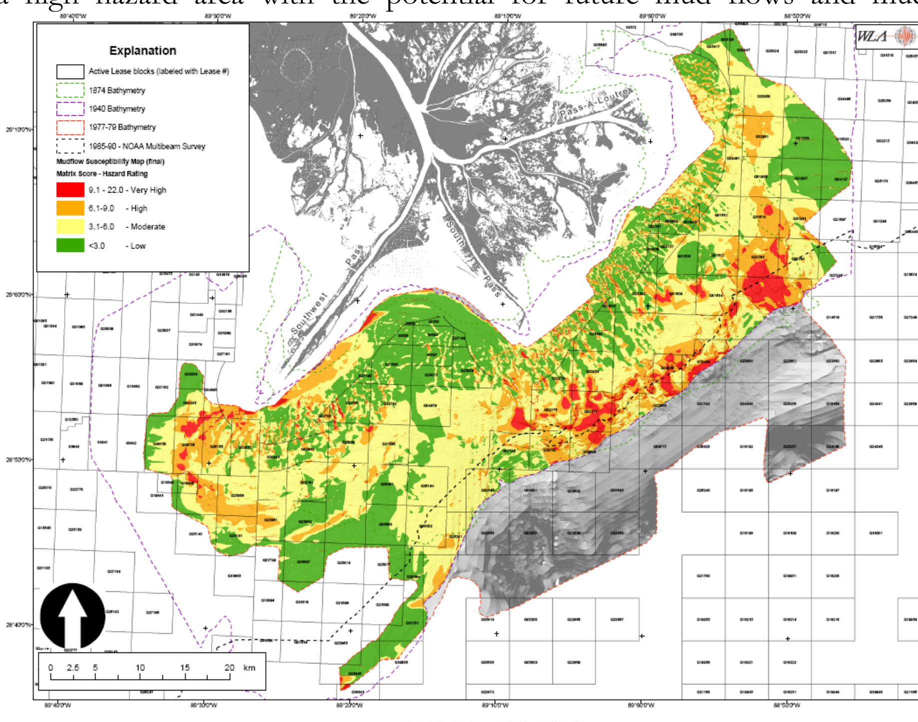

Figure VII.1: Regional mudfloor susceptibility map produced for Mississippi Delta

VII.1.1.2 Risk Assessment for Submarine Slope Stability

A numerical model was successfully developed to simulate fluid surrounding slide soil mass during hydroplaning. The kinetic pressure and shear stress applied on the soil mass by the surrounding fluid were thoroughly examined. It was verified that, in the developed numerical model, slide hydroplaning could occur when the sliding mass velocity reached a certain value to make the total uplift vertical force applied by surrounding fluid flow equal to the buoyant weight of the soil mass. The kinetic pressures and shear stresses derived from the 2-D numerical model were then simplified and incorporated into a computer program in which a block model was successfully constructed to simulate the mechanism of hydroplaning. The simulations using the block model yielded numerical results that agree well with the experimental data reported from the previous study.

VII.1.1.3 Project Offshore Deep Slope

A number of centrifuge tests were performed to investigate the mechanisms of submarine mudslides and the analyses results have demonstrated that existing simplified analytical solutions adequately predict the onset of slope instability due to the generation of excess pore pressure by the triggering events of earthquakes, wave action, gas hydrate dissociation, and rapid sedimentations. A risk-based methodology for determining the probability of failure of a slope subject to the action of trigger events was developed based on methods developed for assessing earthquake damage. The probabilistic hazard maps were produced based on the developed probabilistic approach by integrating deterministic analyses for the inertial effects of earthquake loading with the probabilistic distribution of soil conditions, slope angles and recurrence of earthquake events (See Figure VII.2on the next page).

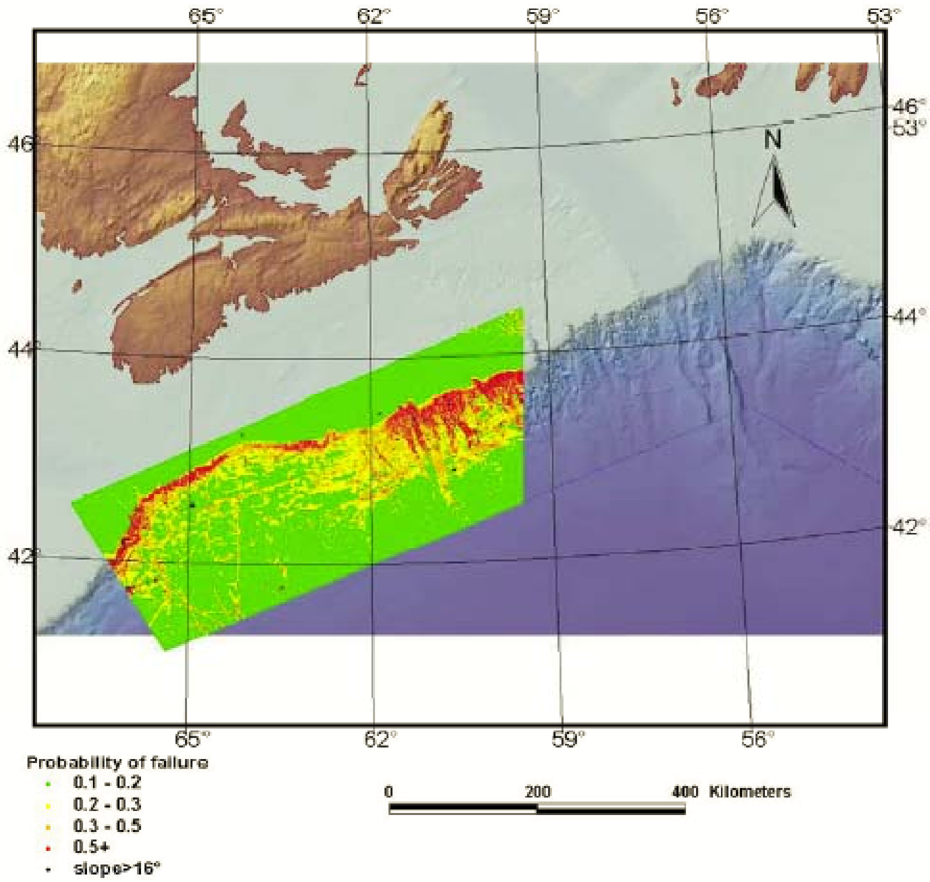

Figure VII.2:Hazard map showing probability of failure due to earthquake loading with 10% probability in 50 years

VII.1.2 VERIFICATION OF METHODOLOGY AND/OR TECHNOLOGY

VII.1.2.1 Characterizing Natural Gas Hydrates in the Deepwater Gulf of Mexico

The primary objective of this project aimed to develop the technology and data to assist in the characterization of naturally occurring gas hydrates in the deepwater GOM, which can cause the problems pertinent to drilling operation and production of oil and gas. Seismic modeling were developed to determine how seismic data should be acquired, recorded, processed and analyzed to accurately quantify and characterize the naturally occurring gas hydrate deposits. The experimental tests were conducted to determine gas hydrate kinetic and thermodynamic properties, which could be input into well bore stability model developed in this study. The expedition of field drilling, sampling and logging were performed to characterize the gas hydrates.

The recent study in Phases II and III of this project indicated that the risks associated with drilling through typical GOM hydrate occurrence in fine grained sediments was minimal. The current focus has been shifted on the characterization of hydrate occurrence in coarse grained sediments in the GOM, and such type of hydrate occurrence was considered by most geoscientists to hold a higher potential for production of methane from hydrates.

VII.1.2.2 Regional Synthesis of the Sedimentary Thermal History and Hydrocarbon Maturation in the Deepwater Gulf of Mexico

By analyzing virgin rock temperature (VRT) values interpreted from reported bottom-hole temperature (BHT) data, continuous maps of sedimentary temperature at 5 km sub-seafloor in Figure VII.3 and thermal gradient at deep sedimentary interval (2 to 7 km sub-seafloor) in Figure VII.4 were generated for Texas-Louisiana Continental Shelf, Gulf of Mexico, which may be used to estimate sediment temperature at different depths. The observation that the locations of previous H_2S occurrence fall within the high-temperature area verified the geographic correlation between hot sediment and H_2S occurrence.

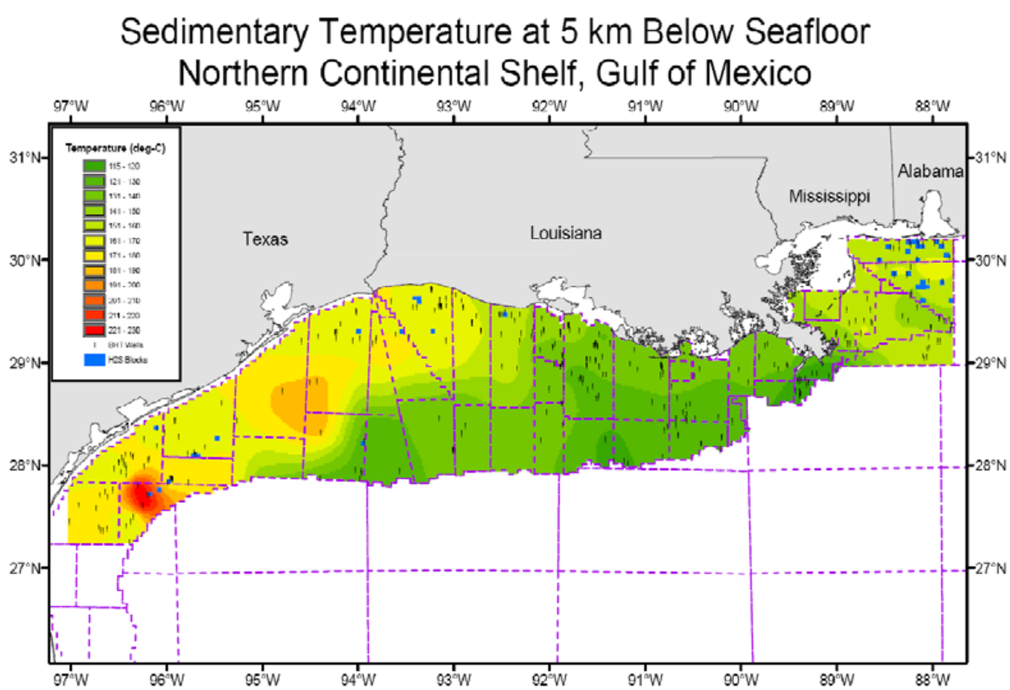

Figure VII.3:Geographically interpolated estimates of sedimentary temperature

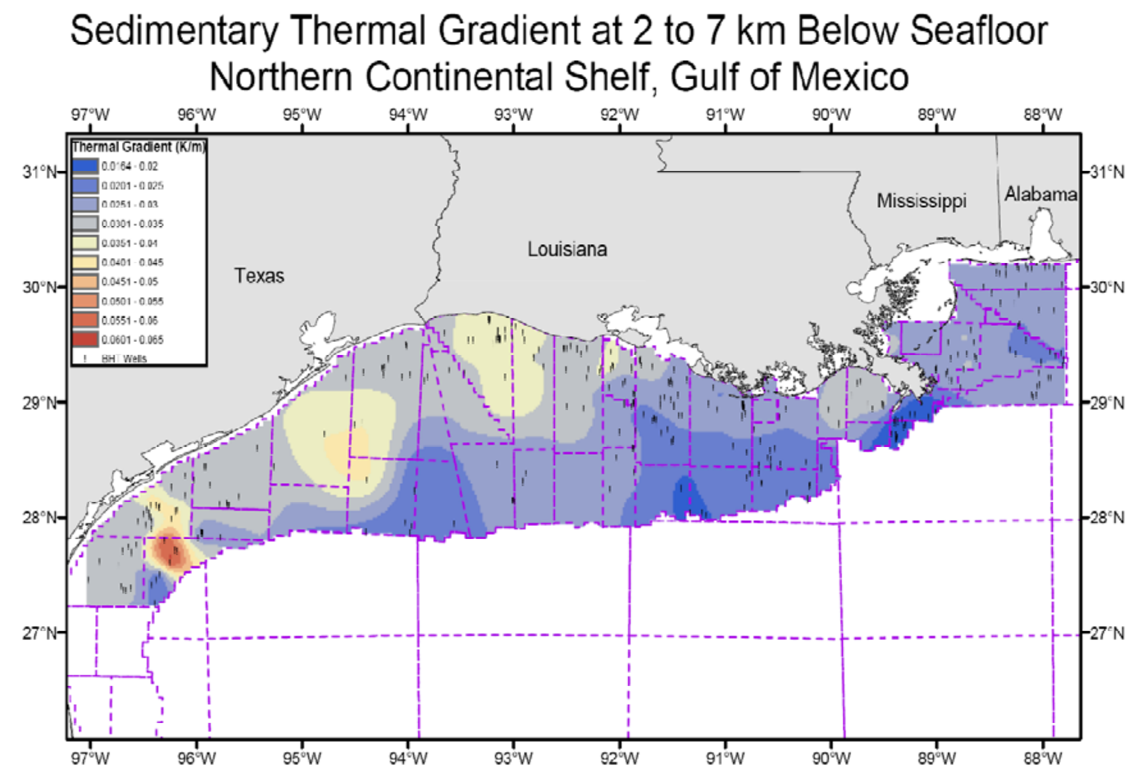

Figure VII.4:Geographically interpolated estimates of geothermal gradient

VII.2 INTEGRITY MANAGEMENT & RELIABILITY

VII.2.1 PROJECT NO. 556 - RISK ASSESSMENT FOR SUBMARINE SLOPE STABILITY: HYDROPLANING

VII.2.1.1 Introduction

VII.2.1.1.1 Background

Submarine landslides, as an important risk, impact offshore subsea structures such as pipelines. It has been reported that many slides occurred on the flat slopes (less than 10 degrees) and with significant travel distance (greater than 10 km, several even greater than 500 km). The reasons for the occurrence of such slides are only partially understood. One possible explanation for such large travel distance is that hydroplaning occurs where the slide mass moves on a thin layer of water trapping between the slide mass and ground surface. At the stage of slide hydroplaning, the total uplift vertical force applied by surrounding fluid flow is equal to the buoyant weight of the soil mass.

However, there are currently no tools to incorporate the mechanism of hydroplaning and to predict the process of a landslide from initiation to cessation of movement. The hydrodynamic forces on the slide mass and the deformation and movement of a slide mass when hydroplaning occurs are not well understood. Therefore, this project, continued from TA&R Project No. 491, was to develop a 2-D numerical model to simulate the fluid around the sliding soil mass during hydroplaning and to evaluate the forces applied on the soil mass by the surrounding fluid. The evaluation results from the numerical model was then simplified and incorporated into a developed program to simulate the movement of a slide through water.

VII.2.1.1.2 Technical Scope

This project aimed to understand better the fluid-slide mass interaction by constructing the 2-D numerical model during the hydroplaning and to develop a better representation of the hydrodynamic forces acting on a moving slide mass. The tasks for this project were to:

- Develop a numerical model to simulate the behavior of slide hydroplaning;
- Understand the kinetic pressure and shear stress exerted by the fluid on the sliding soil mass;

- Simplify the forces derived from the numerical model and incorporate them into a computer program of the moving slide mass to simulate the movement of a slide through water; and
- Calibrate the developed block model with the measurement from a series of laboratory-scale model tests.

VII.2.1.1.3 Study Limitations

The developed model considered the slide mass as a rigid block without deformation or possible separation of portions of the slide mass. However, there is some evidence from actual slides that these aspects of slide mass movement may also be important and can have an effect on the cessation of the mass movement. Also, the existing model uncoupled the soil and water motions, differing from the fully coupled motions that actually occurred in the fields. The developed computer program was only calibrated with the measurement from laboratory-scale model tests, and has not been compared with actual field observations.

VII.2.1.1.4 Method Used to Conduct the Research

The commercial software FLUENT 6.1 was utilized to build the 2-D numerical model of the fluid flow. C programming language is used to develop the computer program to construct a block model to incorporate the results derived from the 2-D numerical model.

VII.2.1.2 Project Conclusions

VII.2.1.2.1 Key Conclusions and Results

A 2-D numerical model has been successfully developed to simulate the fluid surrounding the slide soil mass during hydroplaning. The kinetic pressure and shear stress exerted by the surrounding fluid on the slide mass were thoroughly examined based on the analysis of numerical model. A significant "lift" effect that the surrounding fluid exerts on the slide mass has been observed from the analyses, verifying that the hydroplaning can happen when the "lift" force is greater than the buoyant weight of the slide mass. The hydrodynamic stresses derived from the 2-D numerical model were then simplified and incorporated into a computer program in which a block model was constructed to simulate the mechanism of hydroplaning. The simulations using the block model yielded numerical results that agree well with the experimental data reported from the previous study.

VII.2.1.2.2 OSER Goals

The main goal of this project aimed to develop a 2-D numerical model to investigate the kinetic pressures and shear stresses exerted by the surrounding fluid on the moving slide mass during hydroplaning. Then, a block model for subaqueous slides involving possible hydroplaning was developed by incorporating the simplified hydrodynamic stresses on the slide mass derived from the 2-D numerical model. Finally, the project was to validate the block model by comparison with the experimental results.

VII.2.1.2.3 Recommendations

The study recommended that the kinetic pressures and shear stresses exerted by the surrounding fluid on the moving slide mass, which were derived from the 2-D numerical model, could be simplified to estimate the hydrodynamic stresses on the surfaces of the block in a developed "block" model to simulate the sliding process of submarine slides. Based on a good agreement between the numerical results from the block model and the experimental data, the study also recommended that the block model could successfully simulate the mechanism of hydroplaning.

VII.2.1.3 Current State of Knowledge

Until now, almost all research pertaining to hydroplaning of slide debris was limited within the stage of the debris flow. The transitions from the failed slope to the debris flow and from the debris flow to the final cessation of the debris flow are not well understood. Such information is necessary for designers to predict the likelihood of the occurrence of slide hydroplaning and the travel distance of submarine slides. Although the study in this project tried to develop a computer program to simulate the mechanism of hydroplaning, the process of the initiation of the slope failure and the transition between the failed slope and debris flow was not included in the simulation in this computer program. In addition, the lack of validation by field observation on submarine slides makes it premature to apply the developed computer program to predict the motions of the submarine slides and whether hydroplaning occurs. There is a need to develop and verify an analytical/numerical model to successfully simulate the whole progress of debris flow including the initiation of the slope failure, the transition between the failed slope and the debris flow, the moving debris including possible hydroplaning, and the final cessation of debris flow.

VII.2.2 PROJECT NO. 550 - A PILOT STUDY FOR REGIONALLY-CONSISTENT HAZARD SUSCEPTIBILITY MAPPING OF SUBMARINE MUDSLIDES, OFFSHORE GULF OF MEXICO

VII.2.2.1 Introduction

VII.2.2.1.1 Background

Submarine mudslides, as an important risk, impact offshore subsea structures such as pipelines. Seafloor failure and mudflow overruns can be caused by large-scale wave-induced bottom pressures induced by intense hurricanes directly impacting the seafloor. Mississippi Delta in Gulf of Mexico is an active depositional delta with thick, very weak sediments that are inherently unstable and vulnerable to hurricane wave-induced failure. There is a lack of regionally consistent hazard information to delineate the relative susceptibility of the Mississippi delta to future submarine mudslides. Such information will be very helpful for sitting and design of pipelines and subsea structures.

VII.2.2.1.2 Technical Scope

This project was to develop a geomorphology-based approach to map mudflow susceptibility at the seafloor. The tasks for this project were to:

- Interpret available bathymetric datasets to delineate areas of relative sea floor stability over the past century, areas of active mudflow transport, and areas of mudlobe deposition;
- Rank relative contribution of geologic, slope, and depositional properties derived from available datasets to integrate the mudflow hazard map; and
- Calibrate mudflow susceptibility mapping with post-hurricane Ivan multibeam bathymetry data.

VII.2.2.1.3 Study Limitations

Due to the lack of a regionally consistent up-to-date bathymetric dataset, the bathymetric data and geologic mapping more than twenty-five years out of date were used to integrate the mudflow susceptibility map, and the submarine environment since the mapping published should be changed. By calibration with post-hurricane Ivan bathymetry data, the mudflow hazard susceptibility mapping did not capture some large mudflow occurred during hurricane Ivan and underestimated the hazard for areas with a mudlobe forming upslope.

VII.2.2.1.4 Method Used to Conduct the Research

The methods developed onshore for evaluating the distribution of possible landslide and liquefaction in response to earthquake were adopted to develop the sophisticated, numerical-based mapping of mudflow susceptibility in Geographic Information System (GIS).

VII.2.2.2 Project Conclusions

VII.2.2.2.1 Key Conclusions and Results

A mudflow susceptibility mapping for the Mississippi Delta in the Gulf of Mexico were developed based on a geomorphic-based approach to delineate mudflow failures, sediments susceptible to future slope failure, and areas of relative stability. Based on comparison with post Hurricane Ivan bathymetric data, the developed mudflow hazard accurately characterized relatively high hazard associated with mudflow channels and the areas of greatest net change as the highest hazard. The study indicated that the mudlobe deposition zone, located downslope of the active transport zone of gullies, should be considered a high hazard area with the potential for future mud flows and mudlobe movement.

VII.2.2.2.2 OSER Goals

The main goal of this project aimed to develop regionally consistent hazard maps that delineated the relative susceptibility of the Mississippi delta in the Gulf of Mexico to future submarine mudslides. The applicability of the designed mudflow susceptibility mapping was tested by the comparison with post-hurricane Ivan bathymetry data.

VII.2.2.2.3 Recommendations

The study recommended that the prediction based on mudflow susceptibility mapping might be refined and improved with the incorporation of available geotechnical information and mudflow modeling results. In order to quantitatively evaluate the potential locations and movements of mudflows during extreme trigging events like hurricanes, the authors also recommended that the mudflow susceptibility mapping developed in this study should be combined with the potential storm intensity, direction, and return interval.

VII.2.2.3 Current State of Knowledge

Mississippi Delta in the Gulf of Mexico is an active depositional delta that consists of thick, very weak sediments inherently unstable and vulnerable to hurricane wave-induced slope failure. The recent observations of Category 5 hurricanes (Ivan, Katrina, Rita, and Wilma) revealed that the large hurricane wave could cause the mud flows and mudslides on the seafloor near delta to damage platform foundations, subsea structures and pipelines. There has been no regionally consistent hazard map to delineate the relative susceptibility of the Mississippi Delta to future submarine mudslides. This project developed such a mudflow susceptibility mapping to identify areas vulnerable to submarine failure that may be mitigated by avoidance and/or further investigation and design.

VII.2.3 PROJECT NO. 491 - RISK ASSESSMENT FOR SUBMARINE SLOPE STABILITY: NUMERICAL MODELING OF FLOW AROUND A SLIDING SOIL MASS

VII.2.3.1 Introduction

VII.2.3.1.1 Background

Submarine landslides, as an important risk, impact offshore subsea structures such as pipelines. It has been reported that many slides occurred on the flat slopes (less than 10 degrees) and with significant travel distance (greater than 10 km, several even greater than 500 km). The reasons for the occurrence of such slides are only partially understood. One possible explanation for such large travel distance is that hydroplaning occurs where the slide mass moves on a thin layer of water trapping between the slide mass and ground surface. At the stage of slide hydroplaning, the total uplift vertical force applied by surrounding fluid flow is equal to the buoyant weight of the soil mass.

Nowadays, there are no successful tools to predict the transformation from a slope failure to hydroplaning, the mechanism of slide hydroplaning, and the cessation of the hydroplaning. This project was focused on the hydroplaning mechanism by evaluating the influence of the fluid surrounding a moving slide mass.

Although previous research works have been performed to investigate the mechanism of slide hydroplaning by employing empirical equations and assumptions to describe the force exerted by the fluid flow on the soil mass, most of the empirical equations and assumptions have not been verified. Therefore, this project was to develop a 2-D numerical model to simulate the fluid around the sliding soil mass during hydroplaning and to evaluate the forces applied on the soil mass by the surrounding fluid.

VII.2.3.1.2 Technical Scope

This project aimed to construct the 2-D numerical model to investigate the hydroplaning mechanism by examining the interaction between the fluid and moving soil mass. The tasks for this project were to:

- Develop a numerical model to simulate the behavior of slide hydroplaning;
- Understand the kinetic pressure and shear stress exerted by the fluid on the sliding soil mass; and
- Assess the influence of the gap between the slide soil mass and the ground surface and the frontal shape of the soil mass on the lift force applied by the fluid on the front of the slide soil mass.

VII.2.3.1.3 Study Limitations

The construction of the 2-D numerical model employed a series of assumptions that may be different from the actual conditions of submarine slide hydroplaning, and these assumptions are listed as follows:

- The sliding soil mass is assumed as a rigid body with a constant velocity without deformation during the travel time;
- Dissipation of the water into the sliding soils due to infiltration is negligible; and
- Three-dimensional effects on the lateral boundaries are neglected.

The effects of ground slope angle on the mechanism of slide hydroplaning were not examined. The built numerical model was not able to simulate the transition from the failed slope to the slide hydroplaning and the final ceasing of the slide hydroplaning that is important to predict the travel distance of submarine slides.

VII.2.3.1.4 Method Used to Conduct the Research

The commercial software FLUENT 6.1 was utilized to build the 2-D numerical model of the fluid flow. The laminar flow model and Reynolds-Stress model were used for the simulations.

VII.2.3.2 Project Conclusions

VII.2.3.2.1 Key Conclusions and Results

A numerical model has been successfully developed to simulate the fluid surrounding the slide soil mass during hydroplaning. In summary, the results from numerical analyses were:

- The shear stress along the bottom of the sliding soil mass is constant;
- The contribution to the vertical force from the shear stress for the sliding soil mass is negligible;
- The flow around the sliding mass was concluded to be turbulent everywhere;
- The kinetic pressure on the top of slide mass is nearly constant;
- The kinetic pressure on the bottom surface of the sliding mass decreases linearly from the upstream end to the downstream end; and
- The kinetic pressure on the surface of the front of the soil mass is not influenced by the gap between the bottom of the soil mass and the ground surface, but influenced by the shape of the front of the soil mass. With the higher ratio of depth-to-width of the front, the lift force on the soil mass increases with the increase of negative kinetic pressure;

It was verified that, in this numerical model, slide hydroplaning could occur when the sliding mass velocity reached a certain value.

VII.2.3.2.2 OSER Goals

The main goal of this project aimed to investigate the forces exerted by the surrounding fluid on the moving slide mass during hydroplaning. With the basic assumptions made, a numerical model by using FLUENT software was developed to simulate the interaction between the fluid and the slide mass. In this numerical model, the hydroplaning may occur at a certain velocity of sliding soil mass with the balance between the uplift vertical force applied by the surrounding fluid and the buoyant weight of the soil mass.

VII.2.3.2.3 Recommendations

The study recommended that the numerical analysis results and conclusions might be directly applied to experimental studies, since the geometry of the soil masses in numerical model was comparable to those used in the laboratory experiments of the submarine slide hydroplaning. The study also recommended that the general conclusions drawn from the numerical analysis about the stresses applied by surrounding fluid on the soil mass could be used for the offshore actual slide.

VII.2.3.3 Current State of Knowledge

Until now, almost all research pertaining to hydroplaning of slide debris was limited within the stage of the debris flow. The transitions from the failed slope to the debris flow and from the debris flow to the final cessation of the debris flow are not well understood. Such information is necessary for designers to predict the likelihood of the occurrence of slide hydroplaning and the travel distance of submarine slides. There has been no such analytical/numerical model to simulate the whole progress of debris flow including the initiation of the slope failure, the transition between the failed slope and the debris flow, the moving debris including possible hydroplaning, and the final cessation of debris flow.

VII.2.4 PROJECT NO. 472 - PROJECT OFFSHORE DEEP SLOPE: PHASE II

VII.2.4.1 Introduction

VII.2.4.1.1 Background

Seafloor stability is an important issue that must be taken into consideration during a design of offshore oil and gas facilities. It is a particularly important issue for sloping seabed in deepwater, where weak soil exists under potentially marginal stability conditions. The generation of excess pore pressure within the soil formation can be the dominating factor in many cases after a review of the processes involved in triggering submarine slope instability. The effects of earthquakes, wave action, gas hydrate dissociation and rapid sedimentation all contribute to changes in the pore pressure regime with the potential effect of reducing the stability of a sloping seabed. Therefore, the focus of this study was to improve methods of analyzing such effects, and begin considering the context in which these analyses can be used to predict the stability of real slopes.

VII.2.4.1.2 Technical Scope

The Phase I of this project reported in 2002 (TA&R Project No. 404) has identified and investigated existing information on the offshore slope instability, and carried out analyses to better understand the appropriate processes and mechanisms affecting stability. The Phase II of this project (present phase) was to develop an engineering analysis and risk model for the assessment of submarine slope instability to allow the forecast of instability events within a risk-based framework. This progress report (TA&R Project No. 472) presents an update on the activities performed in relation to Phase II of this project. The tasks were to:

- Undertake four centrifuge tests and interpret the test results;
- Calibrate existing slope stability analytical methods in comparison with experimental results and provide insight into the development of failure mechanism under specific seabed conditions;
- Develop a risk analysis model for determining potential of slope instability in a particular area, along with the required input parameters to allow a reliable risk model to be used; and
- Produce probabilistic hazard maps to integrate topographic, geotechnical and environmental information based on the developed risk analysis model.

VII.2.4.1.3 Study Limitations

The proposed risk analysis framework requires an input of various parameters, including maps of slope angles, dominant soil types and strength, geological activity, previous failure events, historical earthquake activity etc. Among these input parameters, it is general that there are too limited geotechnical data to establish the reasonable soil zoning and layering in three dimensions at a given study area, which can significantly affect the risk assessment.

The risk analysis method recommended in this study were primarily focused on the case of soil ground subject to earthquake loading condition; however, in reality, the deep slope failure was often induced by the superposition of multiple trigger events (such as earthquake, gas hydrate dissociation, oversteeping by erosion and minor slide, and rapid sediments). The mechanism of the superposition of multiple trigger events needs to be incorporated into the proposed risk analysis method to make the prediction of the potential of slope failure more reasonable.

VII.2.4.1.4 Method Used to Conduct the Research

Centrifuge tests were conducted to simulate a number of trigger mechanisms of offshore slope instability. Probabilistic analyses were employed to perform the risk assessment of the submarine slope failure by accounting for the uncertainties associated with the various input parameters, including geotechnical and geophysical soil conditions and triggering events.

VII.2.4.2 Project Conclusions

VII.2.4.2.1 Key Conclusions and Results

The major conclusions from this study were:

- The results of the centrifuge tests and analyses demonstrated that existing simplified analytical solutions adequately predict the onset of slope instability due to the generation of excess pore pressure by the triggering events of earthquakes, wave action, gas hydrate dissociation, and rapid sedimentations.
- A risk-based methodology for determining the probability of failure of a slope subject to the action of trigger events was developed based on methods developed for assessing earthquake damage.
- The probabilistic hazard maps were produced based on the developed probabilistic approach by integrating deterministic analyses for the inertial effects of earthquake loading with the probabilistic distribution of soil conditions, slope angles and recurrence of earthquake events.

VII.2.4.2.2 OSER Goals

The main goal of this project was to undertake a series of centrifuge tests to provide experimental comparison and calibration of existing slope stability analytical methods. Based on the slope failure mechanism verified by the centrifuge tests, a risk-based methodology for determining the probability of submarine slope failure could be developed by integrating various influence factors on triggering the slope failure, such as soil conditions, slope angles, and recurrence of triggering events.

VII.2.4.2.3 Recommendations

The study recommended that the developed risk analysis approach for earthquake loading could be extended for use with other triggering mechanisms. The study also recommended that an enhancement of the proposed methodology could be achieved by assessing the risk of slope failure induced by the superposition of multiple potential trigger events.

It was suggested by this study that more geotechnical data should be collected to establish reasonable soil zoning and layering in three dimension, and an guideline of establish an acceptable level of site specific information should be developed to allow the quantification of the uncertainties associated with the seabed topography and variability of soil type and strength parameters.

VII.2.4.3 Current State of Knowledge

A draft of final report of this project (Report No. R-05-003-158v1.0 by C-CORE (2005)) was issued in which, in addition to the conclusions drawn from this progress report, a model was developed to quantify the potential pore pressure increase due to hydrate dissociation and charts were produced to evaluate the slope instability as a function of hydrate content, water depth and depth of hydrate zone below mudline. A final report of TA&R Project No. 552 (2007) presented a similar probabilistic analysis methodology to evaluate the risks of wave-induced mudslide activity in Mississippi Delta region of Gulf of Mexico by analyzing the mudslides activities during Hurricanes Ivan and Katrina. A conference of "The 4th International Symposium on Submarine mass Movements and Their Consequences" was recently hosted in Austin, Texas on November, 2009 in which the triggering mechanisms of submarine slope failure, similar to those documented in this report were enumerated including storm wave generating high pressure on the ocean floor, ground acceleration due to earthquakes, increased loads due to construction, elevated pore pressure related to gas accumulation from dissociation of gas hydrates, and rapid sedimentations. A number of case studies on the submarine slope failure induced by different triggering mechanisms were also presented in this conference.

VII.3 VERIFICATION OF METHODOLOGY AND/OR TECHNOLOGY

VII.3.1 PROJECT NO. 461 - CHARACTERIZING NATURAL GAS HYDRATES IN THE DEEPWATER GULF OF MEXICO: APPLICATIONS FOR SAFE EXPLORATION AND PRODUCTION ACTIVITIES

VII.3.1.1 Introduction

VII.3.1.1.1 Background

Naturally occurring gas hydrates in deepwater Gulf of Mexico (GOM) are an important risk that can cause problems relating to drilling and production of oil and gas. The naturally occurring gas hydrates may also impact subsea structure and operating pipelines and affect seafloor stability and climate change. It is unclear if and how the gas hydrates act as a trapping mechanism for shallow oil or gas reservoirs. Therefore, to learn how to characterize the natural gas hydrate deposits in the deepwater GOM is necessary for the offshore energy industry to operate safely in deepwater where gas hydrates are known to exist.

VII.3.1.1.2 Technical Scope

This report was to document the activities of this project during the period into this semi-annual report. Phase I of this project was to develop technology and data to assist in the characterization of naturally occurring gas hydrates in the deepwater Gulf of Mexico and to investigate how the gas hydrates impact drilling operation and production of the oil and gas, as well as subsea structure and operating pipelines. The tasks for this project were to:

- Compile available data to build Gulf of Mexico Hydrates Database
- Develop the seismic modeling to quantify the size of the zones containing gas hydrates and the gas hydrate properties and saturation by analyzing seismic data;
- Develop gas hydrate dissociation and formation sensors for the measurement associated with the hydrate dissociation and formation;
- Perform gas hydrate kinetics and thermodynamic analyses and investigate the chemical and physical properties of gas hydrates;

- Determine the required data that geoscientists and engineers need to model sediments containing gas hydrates;
- Develop well bore stability model for boreholes that penetrate zones containing gas hydrates;
- Prepare guideline and detailed plans for drilling or coring through gas hydrates and protocols for coring, core handling and core testing for cores containing natural gas hydrates;
- Select locations that the gas hydrate data collection wells will be drilled and sampled.

Phase II of this project was to drill data collection wells to improve the technologies required to characterize gas hydrate deposits in the deepwater GOM using seismic, core and logging data and to validate the new gas hydrate sensors and well bore stability model.

VII.3.1.1.3 Study Limitations

- Since this report was a semi-annual report in which a lot of tasks in Phase I of this project were still going on, final conclusions associated with these tasks could not be drawn and detailed information and conclusions concerning various aspects of the project was not incorporated in this report.

VII.3.1.2 Project Conclusions

VII.3.1.2.1 Key Conclusions and Results

In summary, the results were:

- The data and case histories concerning operations had been compiled in the deepwater GOM, which are possibly related to the presence of gas hydrates in shallow depth;
- It was found that a combination of existing sensors that measure, temperature, resistivity, conductivity and motion could provide the information of the hydrate formation and dissociation;
- The research indicated that there was no existing software capable to model well bore stability in gas hydrate bearing sediments. However, it was promising that the existing well bore stability model with the elastic-plastic behavior of the sediment can be enhanced by the addition of incorporating the pressure-temperature behaviors of gas hydrate;

- Seismic modeling were developed to determine how seismic data should be acquired, recorded, processed and analyzed to accurately quantify and characterize the naturally occurring gas hydrate deposits;
- The experimental equipment had been assembled in Georgia Tech and preliminary tests had been conducted to determine gas hydrate kinetic and thermodynamic properties, but no conclusions can currently be made concerning the thermal effects on hydrate cores;
- The JIP had learned the data requirements by the geosciences and engineering models, the measurement techniques that could provide the best data, and the need for new and better sensors for making measurements;
- The work on developing protocols for drilling and coring through natural gas hydrates was still ongoing;
- The JIP was willing to use the existing protocols from Ocean Drilling Program and Mallik project program as much as feasible to develop the protocols on coring, handling, preserving, transporting, and testing for cores containing natural gas hydrates; and
- Two areas of Keathley Canyon 195 and Atwater Valley 14 were selected for further analysis to perform the drilling and sampling.

VII.3.1.2.2 OSER Goals

The primary objective of this project aimed to develop the technology and data to assist in the characterization of naturally occurring gas hydrates in the deepwater GOM, which can cause the problems pertinent to drilling operation and production of oil and gas. The other objectives of this project were to better understand how gas hydrates can affect seafloor stability, to collect data that can be used to study climate change, and to determine how the results of this project can be used to evaluate if and how gas hydrates act as a trapping mechanism for shallow oil and gas reservoirs.

VII.3.1.2.3 Recommendations

The study recommended the drill data collection wells in Phase II of this project to update the models, plans and protocols for characterizing the gas hydrate deposits that were being developed in Phase I of this project. It was also suggested in this study that the well bore stability model being developed in Phase I of this project need be calibrated using laboratory experiment.

VII.3.1.3 Current State of Knowledge

The natural gas hydrates are an important risk to cause problems on drilling and productions of oil and gas and need to be understood to operate safely in offshore. On the other hand, the naturally occurring gas hydrates in marine sediments are considered as a potential energy source.

The recent study in Phases II and III of this project indicated that the risks associated with drilling through typical GOM hydrate occurrence in fine grained sediments was minimal. The current focus has been shifted on the characterization of hydrate occurrence in coarse grained sediments in the GOM, and such type of hydrate occurrence was considered by most geoscientists to hold a higher potential for production of methane from hydrates. The expedition of drilling and logging in seven wells in 2009 has successfully proved the hypothesis that gas hydrate can and does occur within sand reservoirs in the GOM. The combined geologic/geophysical prospecting approach developed for the selection of expedition targets in Phases I and II has also been proven out by the high level of success in this expedition.

For developing naturally occurring gas hydrate deposits in marine sediment around Japan into an energy resource, Japan Oil, Gas and Metals National Corporation is currently on the stage of drilling the first production test well of methane hydrates in Offshore Japan.

VII.3.2 PROJECT NO. 432 - REGIONAL SYNTHESIS OF THE SEDIMENTARY THERMAL HISTORY AND HYDROCARBON MATURATION IN THE DEEPWATER GULF OF MEXICO

VII.3.2.1 Introduction

VII.3.2.1.1 Background

The hazard risks of the occurrence of hydrogen sulfide (H_2S) gas have been observed during drilling or production within deep sediments (2 to 7 km sub-seafloor) of the continental shelf of the Gulf of Mexico. The H_2S gas is generated by the thermo-chemical sulfate reduction (TSR) processes in deep reservoirs. The TSR is a series of chemical reactions partly controlled by the reservoir formation temperature. A map of the sediment temperature at depths in the Gulf of Mexico continental shelf is very important to assess the H_2S risk prior to drilling.

VII.3.2.1.2 Technical Scope

This project was to construct the deep sedimentary thermal regime in the Texas-Louisiana continental shelf, Gulf of Mexico by utilizing bottom-hole temperature (BHT) data reported for previously drilled boreholes. The tasks for this project were to:

- Compile a GIS database containing the available BHT data from previously drilled well;
- Derive virgin rock temperature (VRT) from the obtained BHT data; and
- Develop geographical estimates of sedimentary temperature and geothermal gradient by interpreting the VRT values.

VII.3.2.1.3 Study Limitations

VRT-yielding wells had to be geographically divided into 34 groups to determine the geothermal gradient collectively for each group with the assumption that lateral heterogeneity in the geology is negligible within each.

The variability of geologic history and sediment properties affects the heat transport and temperature distribution in the sedimentary column, which may result in a little deviation of sediment temperature extrapolated by linear geothermal gradient.

VII.3.2.1.4 Method Used to Conduct the Research

Both Horner plot technique and Deming and Chapman's method were utilized to interpret the VRT values from the obtained BHT data, and the results from these two types of corrections were in general agreement (5-10%). ArcGIS software was used to compile the BHT data and map-out the sediment temperature and the geothermal gradient.

VII.3.2.2 Project Conclusions

VII.3.2.2.1 Key Conclusions and Results

In summary, the results were:

- By analyzing the VRT values interpreted from the reported BHT data, continuous maps of sedimentary temperature at 5 km sub-seafloor and thermal gradient at deep sedimentary interval (2 to 7 km sub-seafloor) were generated for Texas-Louisiana

Continental Shelf, Gulf of Mexico, which may be used to estimate sediment temperature at different depths; and

- The observation that the locations of previous H_2S occurrence fall within the high-temperature area verified the geographic correlation between hot sediment and H_2S occurrence.

VII.3.2.2.2 OSER Goals

The main goal of this project aimed to construct a database of present-day temperature distribution within deep sediments (2 to 7 km sub-seafloor) of the northern continental shelf of the Gulf of Mexico, which was helpful to assess the H_2S risks prior to drilling. By collecting and analyzing the reported BHT data, continuous maps of sedimentary temperature and thermal gradient were developed, which can be used to estimate sediment temperature.

VII.3.2.2.3 Recommendations

The study recommended that the deep sediment temperature might be estimated based on the constructed continuous maps of sedimentary temperature and thermal gradient for the northern continental shelf of the Gulf of Mexico.

VII.3.2.3 Current State of Knowledge

There has been a need to construct a deep sedimentary thermal regime in the Gulf of Mexico continental shelf. This report addressed the need by collecting and analyzing the available BHT data. The study recently performed by Husson et al. [28] presented that there exists a widespread, systematic sharp thermal gradient increase between 2500 and 4000 m in Texas-Louisiana region of Gulf of Mexico. An analysis of pressure regime in Husson et al.'s study also indicated a systematic correlation between the pressure and temperature fields. It is in general agreement with the observations in this project that geologic history and sediment properties affect the heat transport and temperature distribution in the sedimentary column.

VII.4 REFERENCES

28. Husson, L., Henry, P., and Le Pichon, X. "Thermal regime of the NW shelf of the Gulf of Mexico: 1) Thermal and Pressure Fields," Bulletin de la Societe Geologique 179, 2 (2008) 129-137.