ASSEM : ARRAY OF SENSORS FOR LONG TERM SEABED MONITORING OF GEOHAZARDS

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Abstract – Recent oceanographic research has demonstrated that long term time series of critical oceanographic parameters are needed to understand the various ocean systems. ASSEM is the first application of a new concept of sea bed observatory dedicated to the long term monitoring of a small area (some km^2), lying on a network of interconnected measurement nodes. It is a project enhancing some marine technologies allowing a real time monitoring of the sea bed. The main component of the system is the COmmunication and STOrage Front end, COSTOF. It is an electronic unit providing a set of sensors with the means to communicate with the external world through an underwater network, and to locally store the produced data. The evaluation of this new concept will be done through two experiments addressing two seabed problems: slope instability risks and seismic risks. During the Ormen Lange pilot experiment, sensors required for monitoring of critical failure surfaces within a slide area, particularly pore pressure sensors, will be installed in boreholes. In other respects, the interest of the ASSEM concept for monitoring a tectonically active area (tectonic movement, creeping, fluid flow) will be demonstrated by a pilot experiment in the Gulf of Corinth.

Introduction - Continental margins are the focus of increasing human activities that are moving towards deeper waters. They are witnessing the greatest technological advances in the world for deep-water development. Some of these margins are also a place where drastic phenomena like slope failures occur, hence questioning the safety of people and installations. In other respects, some water areas, surrounded by densely populated belts and associated infrastructures are located in seismic zones where the seafloor is also unstable.
In both cases, there is a need to better understand the phenomena leading to these instabilities. This understanding can be widely enabled by measuring a set of geotechnical, geodetic or chemical parameters of the sediment and seafloor. A site must be surveyed in several locations along failure lines, near a fluid expulsion zone or on a line of change of slope or a possible presence of gas hydrates. In addition, long term slow variations of the measured parameters must be detected, making necessary to have access to both spatial and temporal variability.
Understanding our ocean and the complex physical, biological, chemical and geological systems operating within it, conducts to the same requirements.
Long term seafloor observatories are already deployed, but even if they are multidisciplinary, they are mainly oriented toward seismic measurements. These measurements

require high bit rate data links. The most efficient but expensive solution is to deploy cabled seismic seafloor observatories. Nine cabled seafloor observatories exist in Japan. Three real time ones are operated by JAMSTEC on the sea floor, off-Hatsushima (8 km cable length, off-Muroto (120 km cable length and off – Kushiro – Tokachi (240 km cable) [1]. To reduce the cost of a cabled system, it is sometimes possible to re-engineer retired coaxial undersea telephone cables. The US navy has repowered SD cables to SOSUS arrays. The Hawaii-2 Observatory (H2O), sited south of the Moonless Mountains, between Marray and Molokai fracture zone, uses the Hawaii-2 Cable (HAW-2) in its part from Oahu to the observatory [2], [3].

In order to achieve low-cost long term seafloor monitoring, JAMSTEC developed and tested at sea the Mobile Seafloor Observatory [4]. The observatory consists of a multi-sensor Mother Station surrounded of four Satellite Stations at separations between 20 to 50 kilometers. Data can be retrieved by recovering the stations. Part of the sensor data in the Mother Station can be monitored through satellites by releasing pop-up buoys. The same approach is encountered in the GEOSTAR European project [5]. A low to medium capacity two-way acoustic link between the station and a surface buoy, coupled with a satellite communication system (INMARSAT) is used to control and collect a set of reduced data every day.

All these systems are too large and too expensive for long term monitoring of geohazard.

Objectives - The project ASSEM consists in developing the optimised means to measure and monitor a set of geotechnical, geodesic and chemical parameters distributed on a seabed area in order to better understand the slope instabilities phenomena, to assess and possibly anticipate the associated risks. The means are studied and realised to deploy a selection of adapted sensors on a seabed area (up to 1 km²) and transmit their data to shore for exploitation. The demonstration systems will be implemented during ten to twelve months on two sites presenting risks with high socio-economic impacts. The technological developements of the array of sensors for monitoring address the necessity in many fields to have access to both spatial and temporal variability of seabed parameters. It leads to the understanding of geohazards, their possible forecast and the specification of site monitoring equipments.

Technical description – To achieve these objectives, ASSEM brings several innovations and new methodology:

- A detailed pre site survey in order to determinate the proper sites for the selection and deployment of sensors;
- A controlled deployment of sensors and stations by ROV or submersible;
- A modular design, standard connecting and installation interface allows to configure easily the system to the site of interest, to add new sensors, and to replace components for maintenance;
- a two-way communication link between sensors and shore, built on an acoustic network;
- a local storage of all the raw data in each node with local analysis able to generate alarms;
- enhanced sensors for long term monitoring.

Sensors – Pore pressure is an important parameter for the modifications of the soil before and during geohazard event. It will be measured at several levels, in bore holes down to 200m, and in tubes of CPT probes inserted in the sediment down to 30m.

The natural occurrence and emission of gas on the sea floor (methane seeps) are increasingly recognised as an important marine process for its environmental and geohazard implications. A methane sensor from CAPSUM will be adapted for long term deployment (antifouling membrane, self calibration capability) and deeper operation.

In tectonically active areas, ground deformation sensors are claimed but under sea, geodesy is still in its infancy. Different sensors will developed and tested : a long range taut wire distancemeter (NGI), an acoustic distancemeter (IPGP) and a tiltmeter.

The measurement of temperature, salinity, turbidity, current, static and dynamic water pressure is necessary in conjunction with pore pressure, gas sensors and geodesic sensors.

COSTOF – A COmmunication and STOrage Front-end is an electronic unit providing a set of enhanced sensors with the means to communicate with the external world through an underwater network, and to locally store the produced data. Alarms can also be generated by processing these data.

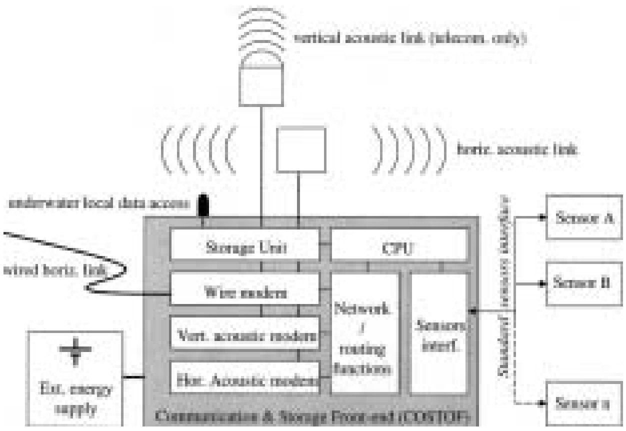

Fig. 1 – Monitoring node modular architecture

Basically, a *communication and storage front-end* will comprise:

-a communication processor,

-a memory unit for data storage,

-a *standard sensors interface* for communication with the *enhanced sensors,*

- an acoustic modem with transducers array for horizontal acoustic communication, with remote monitoring nodes (up to 2 km),

-a wire modem for communication with a neighbouring monitoring node (for instance less than 50 m away),

-a data port dedicated to connectorless communication with an ROV.

Among the various COSTOFs, one will ensure communication to shore and will receive additionally an acoustic modem and transducer or a wire modem, according to the site configuration.

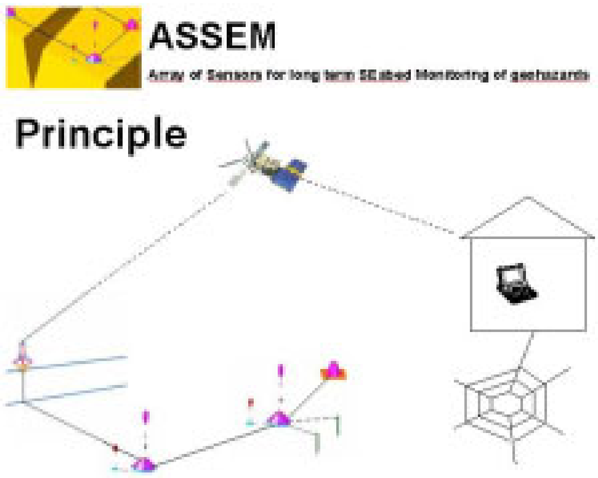

fig.2 Principle of the ASSEM observatory

The software resources enabling a monitoring node to act as a network node (routing algorithms throughout the network, network configuration management, data transmission protocol and other network layers) are implemented in every COSTOF. The data transmission management will also take into account the quantity of energy necessary to transmit data acoustically and will be adapted to the limited energy resources of a monitoring node. Alarms can be generated for example if a critical parameter, or some parameters are above a programmed threshold for a given time.

A remote integration tool will be developed and provided to all partners in charge of sensors, and to the COSTOFs manufacturer. It will consist in a bridge linking any enhanced sensor to the internet through its *standard sensors interface*. This will enable the sensor to be remotely plugged to its COSTOF (equipped with a similar bridge at the other end of Internet), both partners staying in their lab. This should greatly minimise the unavoidable tuning phase that takes place when subparts are plugged together for the first time, and provide substantial travel and time saving to the project.

This tool will be based on the adaptation of an industrial Ethernet board to the *standard sensors interface*. It will be re-usable in all systems where the *standard sensors interface* is used.

Acoustic network – The acoustic network is developed from a new version of the MATS 12 acoustic modem produced by ORCA instrumentation. This digital modem

Implemented modulations (programmable in real time)	CHIRP - Frequency Hopping - PSK 2 / PSK 4
Error correction algorithms (programmable)	VITERBI
Frequency band	10 - 14 kHz
Baud rate (programmable in real time)	20 to 2400 bit/s
Acoustic source level	185 +/- 3 dB ref microPa @ 1 m
Receive sensitivity	80 dB ref microPa
Transducer diagram	Omnidirectional or directional
Operating depth	2000 m or 6000 m
Housing material	Aluminium or bronze alloy
Dimensions (Diam x h)	14 x 70 cm
Weight in air (in water)	16 kg (8 kg)

Fig.3 – MATS12 specifications

based on micro-controller and DSP cards, is capable of data transmission under adverse channel conditions at data rates up to 2400 bits per second (bps). Main specifications of this multi-modulation modem are given fig.3.

Original network protocols, with autonomous handshaking and adaptive bit rate, adaptive modulation and adaptive routing were implemented. Patented modems perform noise analysis and impulse response measurement of the channel. Such a network offers much more reliable and much higher data rates links than are now available.

Directional transducers were developed to decrease power consumption. Fig.4 shows directivity diagrams.

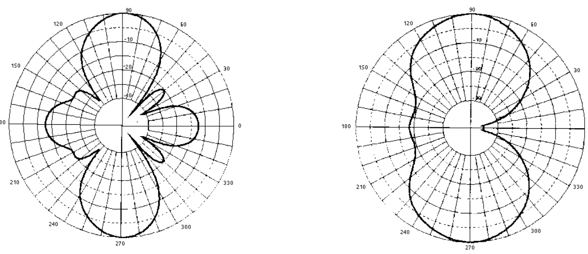

Fig.4 – Directional transducer: narrow and wide beam Electric connection allow to choose the pattern

Pilot experiments – Two complementary pilot experiments are planned. The first one will take place at a deep water site with a risk slope instability, *Ormen Lan*ge. The experiment should include hook-up of integrated pore pressure sensors installed in bore-holes and installation of standard sensor interface and communication system for data transfer to the surface. The experiment should at least include one year monitoring with remote data recovery. The main objective is to verify installation and operation of the ASSEM system in such conditions. In addition, by obtaining a validated data set of measurements on site, the importance of long-term seabed pore pressure data for slope stability assessment will be demonstrated.

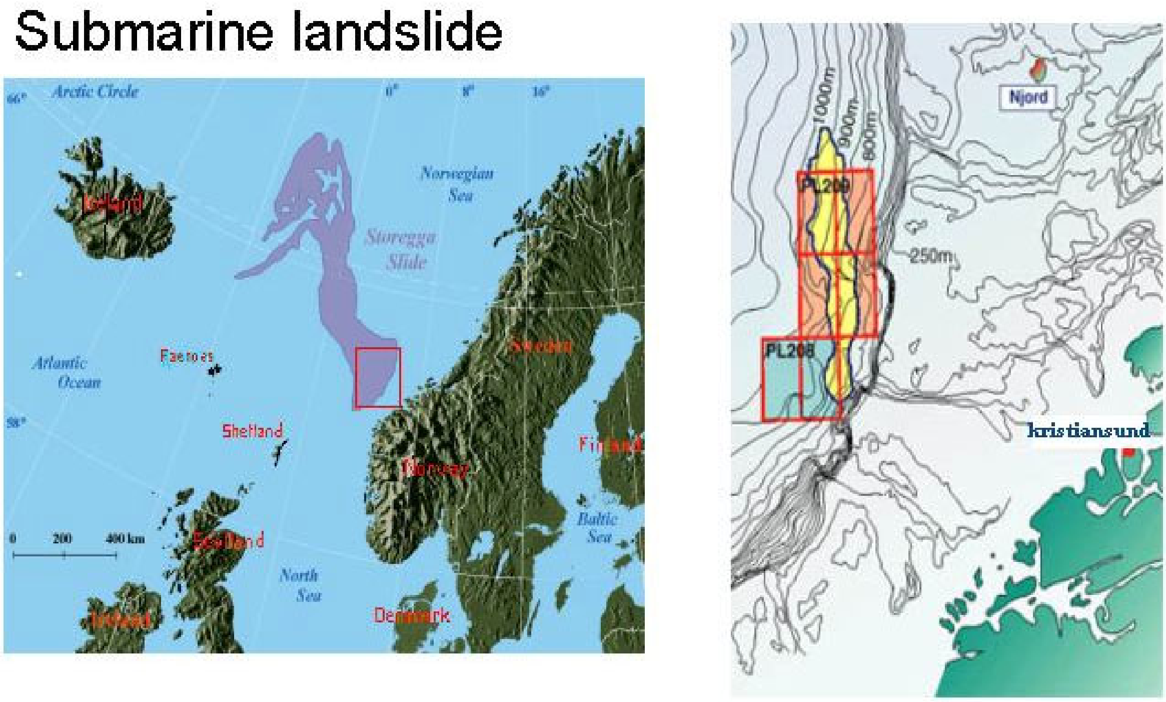

Fig.5 - *The site of Ormen Lange*

The second experiment will take place in the Gulf of Corinth. The shelf, slope and margin of the basin off the coast of a faulted area is selected for the deployment of the ASSEM array of sensors. It is the most active extensional basin in Europe, with high rates of margin uplift, basin subsidence and opening during Late Quaternary.

The selected area is located thanks to global surveys and studies made available by the partners of the project. It has suffered 7 earthquakes of Ms>6 during the last two centuries. Methane expulsion from pockmarks has been observed on the shelf of the area. Tectonic movements, creeping and fluid flow is expected to take place along the submarine marginal fault, the trace of which coincides with the base of the slope.

A detailed pre site survey will be carried out by partners NCMR and University of Patras on the shelf, slope and basin of a part of the area, in order to determine the proper sites for the deployment of the ASSEM array of sensors. Samples will be taken from the seabed sediment and laboratory analysis will be performed for the slope stability assessment of the site. Proper sites for the deployment of the array are the ones on which triggering phenomena are likely to happen and on which a variability of the measured parameters should be observed during the pilot experiment duration.

. Two sites, one on the shelf and one at the trace of the marginal fault of the basin, will be selected to deploy the monitoring nodes. Active fluid flow through pockmarks or other seeping areas will be monitored on the shelf. Pre site survey and deployment of the sensors on the shelf as well as follow-up of the results and evaluation of the node survey will be carried out by NCMR and will include of sensors will be undertaken by the University of Patras.

Pore pressure, geodesic, environmental and fluid measurements will be carried out by an array of 5-8 nodes deployed at the margin of the basin. Seismic measurement will be available from other experiments. The pre site

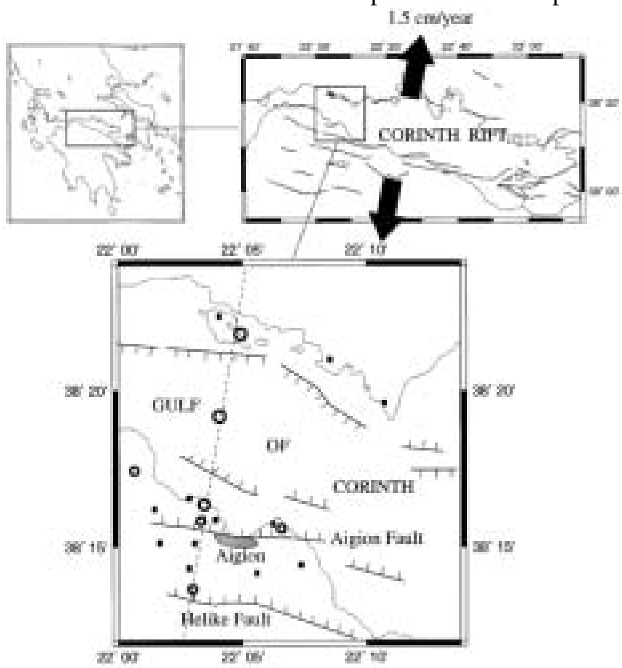

Fig. 6 – The Gulf of Corinth

exploitation of all available data as well as new high-resolution seismic survey, swath bathymetry, side scan sonar and visual observation with a manned submersible. Geodesic benchmarks will be left for future use.

Data management **–**Data collected in real time or after recovery of storage devices, will be available to end users by internet. Results from EU project EMEW for the data handling of warning systems will be applied, especially for Corinth experiment.

Conclusions– ASSEM presents a new concept of real time sea floor observatories dedicated to collect data with low sampling rate. It is also a warning system. It can be operated alone or linked to another observatory system, such as GEOSTAR. During the EU project ORION, a seismometer satellite of GEOSTAR, will be inserted in the ASSEM network of Corinth, demonstrating the compatibility between the two systems.
This concept could be applied to other long term studies in biology or environment such as dangerous wrecked ship monitoring .

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