LIQUEFACTION AROUND MARINE STRUCTURES

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During the period 2001-2004 EU supported a research program on **LI**quefaction around **Ma**rine Structures (LIMAS) (http://www.skk.mek.dtu.dk/english/research/finished-proj/limas.aspx). The program was undertaken by a consortium of 10 European institutions (universities, hydraulics and geotechnical engineering laboratories and consulting companies). In this paper, this research program is described, highlighting the objectives of more than ten sub-projects under the program, focusing on different aspects of the topic. The major part of the program concerned the wave-induced liquefaction although the seismic-induced liquefaction was also studied with regard to its impact on marine structures.

LIMAS AND ITS OBJECTIVES

Liquefaction Around Marine Structures (LIMAS) was a three-year (2001-2004) research program funded by the Commission of the European Union Directorate General XII within the framework of EU Fifth Framework Program with specific program: Energy, Environment and Sustainable Development, Key Action 3 "Sustainable Marine Ecosystems". The objectives of the program were two-fold: (1) To investigate potential risks for failure of structures due to liquefaction; and (2) To prepare and disseminate practical guidelines (guidance for design and maintenance), to be developed from the present research and also taking into consideration all state-of-the-art knowledge.

MOTIVATION

In the geotechnical-engineering terminology, liquefaction stands for the state of the soil where the effective stresses between the individual grains in the bed vanish, and therefore the water-sediment mixture as a whole acts like a fluid. Liquefaction of marine soils may be induced by waves (Seed and Rahman, 1978, Sassa and Sekiguchi, 1999, Sumer and Fredsøe, 2002, Chapter 10, Sumer et al., 2006 a), or it may be induced by seismic actions (Kramer, 1996, Chapter 9). Under this condition, the soil fails, thus precipitating failure of the supported structure such as breakwaters, seawalls, pile structures, sea barriers, pipelines, and armouring systems. Some such failures have been catastrophic (e.g., Figs. 1 and 2). With the soil liquefied, buried pipelines may float to the surface of the seabed (Fig. 1); large individual blocks (like those used for scour protection) may penetrate into the seabed; sea mines may enter into the seabed and eventually disappear, etc.

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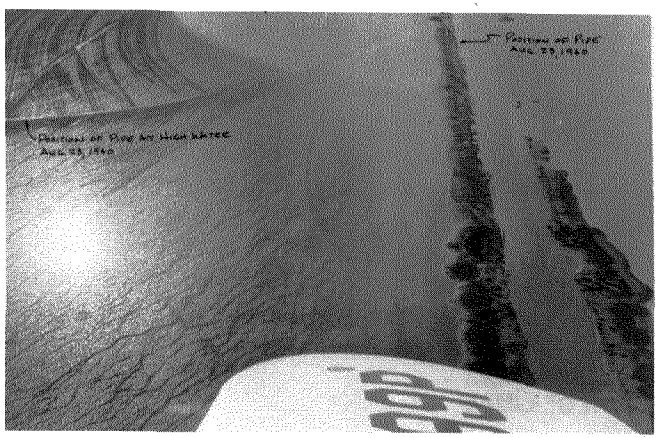

Figure 1. Aerial view of two pipelines floated to the surface on a mud flat. Taken from Damgaard (2004). Courtesy of David Osario.

Figure 2. Kocaeli (Turkey) Earthquake, 1999, Derince Port. Backfill behind the quay wall was liquefied and eventually settled. Quay wall damaged and crane damaged. The image in this figure illustrates the backfill area 3 years after the earthquake. Taken from Sumer (2004 a).

While a substantial amount of knowledge had accumulated on flow and morphological processes around marine structures in eighties and nineties, comparatively little was known about the impact of liquefaction on these structures. The topic had been very little covered in EU research which had substantially advanced the design of coastal structures, but not of their foundations with regard to soil liquefaction. This was essentially what motivated LIMAS.

The present paper will describe LIMAS, giving briefly the highlights of the program including its end products. An earlier version of this paper was presented at the 6th International Conference on Hydrodynamics in Perth, Australia, Sumer (2004 b).

ORGANIZATION OF LIMAS

LIMAS was organized in two tasks: Task 1. Liquefaction/Structure/Scour; and Task 2. Related processes and implementation.

Task 1 consisted of five workpackages (WP):

- WP1. Liquefaction around a structure due to buildup of pore pressure under waves;
- WP2. Fluid-Soil-Structure interaction in liquefaction around coastal structures
- WP3. Investigation of processes susceptible to lead to liquefaction in the bed below caisson breakwaters. Large-Scale facility experiments;
- WP4. Field study of liquefaction and scour around coastal structures; and
- WP5. Stability of slender cylindrical structures on a liquefied bed, and scour around structures in fully or partially liquefied soil.

Task 2 also consisted of five workpackages:

- WP6. Bearing capacity of sand during partially drained conditions caused by impulsive loads;
- WP7. Development of a soil sampler for investigation of real gas content in pore water;
- WP8. Impact of earthquake-induced liquefaction on marine structures;
- WP9. Formulation of guidelines for design and maintenance; and
- WP10. Mathematical modelling of pore-pressure generation due to earthquakes and the effect of the Kocaeli (Turkey) Earthquake on marine structures.

Laboratory studies (WP1, WP2, WP5, WP6, WP7, WP10), large-scale laboratory studies (WP3), theoretical and numerical methods (WP4, WP5, WP6, WP8, WP10), and field investigations (WP4, WP7, WP10) were adopted to achieve the previously mentioned objectives.

LIMAS CONSORTIUM

The research program was undertaken by a consortium consisting of ten member institutions:

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LIMAS WORKSHOPS

Progress made in the research program was reported in six-monthly workshops. The final workshop, held in Pau, France, 5-6.April, 2004, was in the form of an end-user meeting to present state-of-the-art knowledge. The presentations made in this workshop can be found at the following website:
http://www.skk.mek.dtu.dk/English/Research/Finished-proj/LIMAS/LIMASsub/Final-Workshop.aspx
The presentations include

- Physics of liquefaction phenomena around marine structures by M.B. de Groot
- Soil liquefaction around and its implications for pipelines by J.S. Damgaard
- Liquefaction underneath wave-loaded gravity structures by M.B. de Groot
- Seismic-induced liquefaction around marine structures by B. M. Sumer

- Mathematical modelling of soil liquefaction by S. Dunn
- Soil measurements regarding soil liquefaction (including the measurement of air/gas content) by R. Sandven
- Observations of momentary liquefaction caused by breaking waves around a coastal structure - Field study by M. Mory

LIMAS END PRODUCTS

Research reports, conference papers, journal papers, video recordings etc. summarizing the results of more than ten sub-projects were published during the cycle of the research program. A complete list of LIMAS publications can be found at the website http://www.skk.mek.dtu.dk/English/Research/Finished-proj/LIMAS/LIMASsub/Publication.aspx.

In addition to the previously mentioned LIMAS publications, A LIMAS Special Issue was published in ASCE Journal of Waterway, Port, Coastal and Ocean Engineering, in two volumes, Sumer (2006 and 2007), comprising sixteen papers, on the following aspects:

Physics of liquefaction processes around marine structures (de Groot et al., 2006 a), stability of pipelines on liquefied seabeds (Teh et al., 2006), critical floatation density of pipelines in soils liquefied by waves including density of liquefied soils (Sumer et al., 2006 b), liquefaction around pipelines under waves where pore pressures were measured on the surface of buried pipelines (Sumer et al., 2006 c), numerical modelling of wave-induced liquefaction around pipelines (Dunn et al., 2006), fluid-soil-structure interaction around a cyclically moving cylinder half-buried in seabed soils (Foray et al., 2006), guidelines for marine pipeline on-bottom stability (Damgaard et al., 2006), large scale experiments on pore pressure generation underneath a caisson breakwater (Kudella et al., 2006), and liquefaction processes underneath marine gravity structures subjected to wave loads (de Groot et al., 2006 b); these are the issues covered in the first volume (Sumer, 2006); and

Development of a sampler for gas-content measurements in soils (Sandven, 2007), wave-induced scour around piles in liquefaction-hardened dense soils (silt) (Sumer et al., 2007 a), a field study of momentary liquefaction around a coastal structure (Mory et al., 2007), soil reactions in saturated sand subject to impulsive loads (Hansen and Gislason, 2007), mathematical modelling for assessment of seismic-induced liquefaction of marine soils with special application to the 1999 Turkey earthquake (Sawicki and Swidzinski, 2007), seismic-induced liquefaction around marine structures (Sumer et al., 2007 b), an extensive review and guidelines, and momentary liquefaction caused by combination of waves and gas/air content in marine soils (Tørum, 2007), the topics covered in the second volume (Sumer, 2007) of the Special Issue.

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