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# A FIELD RESEARCH PROGRAMME TO ADDRESS ICE ENGINEERING ISSUES FOR THE NORTH CASPIAN SEA

**K. R. Croasdale[1], George Comfort[2], Greg Crocker[3], Michel Metge[4], Ron Ritch[5]**

## ABSTRACT

During the past four winters, a comprehensive "Ice Field Programme" has been conducted each year to address ice issues and gather data from which to develop design criteria.

Field activities have included stamukha profiling with thermal drills, use of an ROV to examine ice scours around stamukha, bore hole jack tests, flexural and indentation crushing tests on rafted ice, use of ground penetrating radar to survey rafted ice extents, and use of laser profilometer for ice pile up and stamukha surveys. In addition, ice interaction with structures used for exploratory and delineation drilling has been documented.

This paper describes how the "Caspian Ice Field Programme" was designed to meet the identified ice issues relating to the oil and gas offshore facilities, how it was implemented and some typical results.

## INTRODUCTION

Following a series of exploratory wells drilled with a grounded barge unit and an artificial island, the Kashagan Field has been declared commercial and offshore facilities for development are currently being designed. The Kashagan Field is in about 4.5m of water, but is over 75km from shore.

Ice covers the Kashagan Field for about four months each winter. However, the ice severity varies considerably from year to year. For example freezing degree days can vary from an annual low of about 300 °C-days to an annual high of 1600 °C-days with a mean of about

[1] K.R. Croasdale and Associates, Calgary, Canada
[2] BMT Fleet Technology, Ottawa, Canada
[3] Ballicater Consulting, Kingston, Canada
[4] Kazakhstan North Caspian Operating Company, Kazakhstan
[5] Avron Ritch Consulting, Vancouver, Canada

900°C-days. This significant annual variability presents a challenge in data collection for the determination of ice conditions for design.

Average thermal ice growth is usually less 0.5m, but in severe winters, level ice thickness up to about 0.9m can occur (Evers et. al., 2001). Rafted ice is common and creates the extreme thickness for the design of structures at about 1.4m, (although locally thicker rafting has been measured). Ice salinity is low (1-2ppt). The shallow water limits ridge keel depths but also leads to the formation of grounded ice in the form of stamukhi. A typical stamuka is shown in Figure 1, this one had a height of over 15m. Stamukhi occur at the rate of about 3 – 4 per 10km square over the Kashagan Field. If stamukhi and pressure ridges are pushed by the surrounding ice they can cause extensive sea floor ice scouring as seen from the air through the shallow water in Figure 2.

Fig.e 1 Stamuka 15 m high

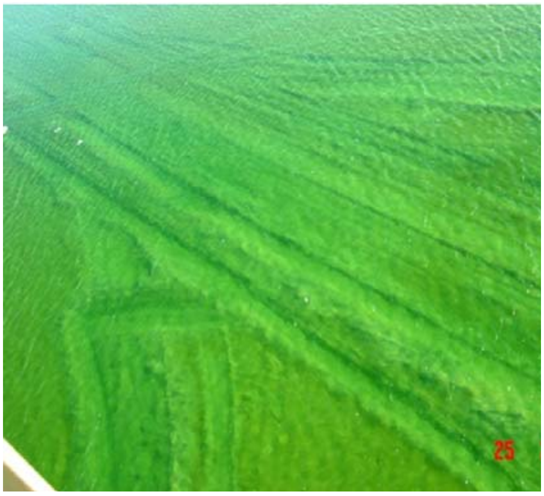


Fig. 2 Ice Scour as Seen from the Air

**OFFSHORE FACILITIES, ICE ISSUES AND ICE KNOWLEDGE NEEDED**

As with all offshore oil and gas developments key facilities and operations for the Kashagan field will consist of:

- Offshore platforms for drilling and production
- Pipelines between platforms and to shore
- Marine supply
- Escape and evacuation systems

In the Caspian Sea ice environment there are important issues relating to these facilities and operations which can be summarised as follows:

***Issue 1) Ice can hinder access to, and evacuation from, rigs and platforms***

Because of the shallow water, ice movement against wide structures (such as a drilling island or a grounded caisson) creates extensive grounded ice rubble.

Figure 3 illustrates the ice rubble field created against the first drilling island built for the Kashagan field. It was created by a westerly ice movement of about 2km when the ice was about 40cm thick on January 31, 2002. This rubble was heavily grounded (with 15m high pile ups), it extended about 100m from the island perimeter. Fortunately it was on the opposite side of the island from the quay used by the supply vessels.

The following year however, an easterly movement on February 9, 2003 created grounded rubble field of similar size on the south east side of the island. This ice event destroyed an offshore rock breakwater designed to protect the quay. Consequently the ice rubble built up at the quay, and this took several days to clear with an icebreaker (see Figure 4).

Fig. 3 Ice Rubble Against the First Drilling Island

Fig. 4 Icebreaker Clearing Rubble Next to Quay

In order to assess ice rubble build-up, determine the best location for quays and evacuation points, and specify the arrangement of protection structures, knowledge is needed on:

- Frequency and directions of ice movement
- Ice rubble extent on man-made and naturally grounded ice features
- Ice rubble extent and height as function of ice thickness and amount of ice movement.

### *Issue 2) Ice can over-ride islands, docks and platforms*

In shallow water areas such as the North Caspian, the favoured platform for oil and gas development is often the artificial island or other low free-board designs. These are susceptible to ice encroachment onto the working surfaces, as illustrated in Figure 5,

Fig. 5. Ice Rubble Built on Island

where an ice ride up occurred on the Kashagan Island in 2003. (No damage to facilities occurred because an ice encroachment margin had been included in the design).

To manage such incidents, islands need to be designed with either an appropriate free-board, ice encroachment margin or ice deflectors installed. In order to specify the design requirements for these, an understanding is needed of:

- The height and geometry of rubble piles as a function of ice thickness
- The nature of ice encroachment events (ride-over or pile up)
- The effectiveness of ice deflectors.

***Issue 3) Ice forces can cause global sliding of structures and other damage***

At the outset it was assumed that ice load methods developed for other parts of the world could be applied to the Caspian region. However it was recognised that values for ice parameters to input into these algorithms might be different. Caspian Sea ice is generally warmer than say the Beaufort Sea (where many ice load methods had been calibrated), but it also has lower salinity. In fact brine volumes of warm, low salinity, Caspian ice are almost the same as colder, higher salinity, Arctic ice.

Another unique aspect of Caspian ice is the significant occurrence of rafted ice and limited ridge keel depths because of the shallow water. This combination leads to the strong possibility that the design ice feature is rafted ice rather than a first year ridge (which is generally the controlling ice feature in most other sub-arctic ice regions).

As already mentioned, the shallow water at the Kashagan Field leads to the occurrence of grounded ice rubble in front of wide platforms. In developing ice load design criteria a range of scenarios need to be examined. These range from a gradual build up of grounded ice in front of the structure to the action of thick ice against the structure with no ice rubble present. The condition leading to the highest load on the structure is not obvious and will also depend on the structural form (sloping or vertical).

In summary, the ice load parameters on which knowledge is needed are:

- Flexural strength of both level and rafted ice
- Crushing strength of both level and rafted ice
- Extent and thickness of rafted ice
- Ice movement statistics
- Calibration of ice load methods.

***Issue 4) Grounded ice can damage pipelines and seafloor facilities***

The shallow water of the North Caspian Sea favours the development of ice scours and ice pits (under stamukha). The issue of designing pipelines for ice scours and pits has been addressed for other regions of the world such as offshore Sakhalin and Alaska. The conventional approach is to bury the pipeline well below the deepest scour or pit expected during the lifetime of the development. The margin between the deepest expected scour and the top of the pipe is a function of the expected soil strains immediately below the scouring ice feature. The analysis requires that the pipeline strains due to the imposition of the sub-scour deformations are at acceptable levels. It is usual to consider the “100 year” scour associated with a serviceability limit state for the pipeline. Then the pipeline is often checked against rupture for a lower probability level scour (in the $2 \times 10^{-3}$ to $10^{-4}$ range). Note that recent work in this field has recognised the limits to ice scour depths due to limited ice strength, and also the possibility of sustaining direct ice action when considering the rupture limit state.

In order to determine pipeline burial depths and assess pipeline integrity against ice scours and pits, the following information is required:
- Ice scour depths & frequencies
- Numbers and sizes of stamukhi.
- Ice pit depths under stamukhi.
- Soils properties along the pipeline routes.
- Strength of ice ridge and stamukhi keels.

***Issue 5) Artificially grounded ice can protect against ice forces and used as a construction platform***

In other ice regions, spray ice has been used to artificially enhance grounded ice rubble to protect structures. As well, stable nearshore ice is often used for ice roads and as a platform for pipeline installation.

Because of the high variability in annual freezing degree days in the Caspian, these methods are not assured. However as demonstrated in the winter of 2003, in an average year, spray ice can be efficiently produced if opportunities are taken of the period colder periods. Figure 6 shows how spray ice was used to increase the capability of ice barriers protecting the Sunkar drilling rig (Bastian et al).

In order to assess the ability to use ice, either for protection or as a nearshore construction platform, the following ice knowledge is needed:

Fig. 6. Spray Ice Being Built on Protection Barrier

- Seasonal variability in freezing degree days
- Correlation of spray ice production with temperature for Caspian Sea water
- Correlation of nearshore ice thickness with freezing degree days
- Stability of nearshore ice
- Investigation of methods of thickening or improving trafficability of nearshore ice.

## ICE PROGRAMME PLANNING

To acquire the ice knowledge required for Kashagan development, ice studies commenced in 1999. In developing the programme priorities and activities, the drivers have been the ice issues discussed above, which in turn are driven by the need to design and operate the offshore facilities in ice both safely and in a cost effective manner. In each year of the ice programme planning, customer groups are consulted and are asked to review the plans.

Based on the ice knowledge drivers discussed above, the key elements of the ice programme during the last several years have been:

- Ice thickness statistics (how much ice is rafted - how thick?)
- Ice strengths tests on rafted and level ice
- Stamukhi and ice rubble surveys.
- Structure monitoring - including ice barrier performance and ice rubble build up.
- Ice scour surveys including sea floor pits.
- Near-shore ice thickness and stability
- Translation of ice data into design & operating criteria for platforms, ice barriers and pipelines

In this short paper, it is not possible to describe the Caspian Ice Programme in detail, however a few selected highlights are given:

### *Ice Thickness & Rafted Ice Surveys*

Ice thickness was gathered manually using ice augers whenever there was a group of ice researchers on the ice. However, the bulk of the ice thickness statistics were gathered using ground penetrating radar deployed from a Bell 212 helicopter. The ice thicknesses predicted from the radar were checked with the manual measurements.

As an example, in the winter of 2002, the GPR surveys conducted February 19th through 22nd showed the percentage of rafted ice to vary between 4% and 31% of the observed tracks. Overall, 17% of the sea surface surveyed with the GPR contained rafted ice. The extent of extreme values of rafted ice is important. A typical plot of thickness along a survey line is shown in Figure 7.

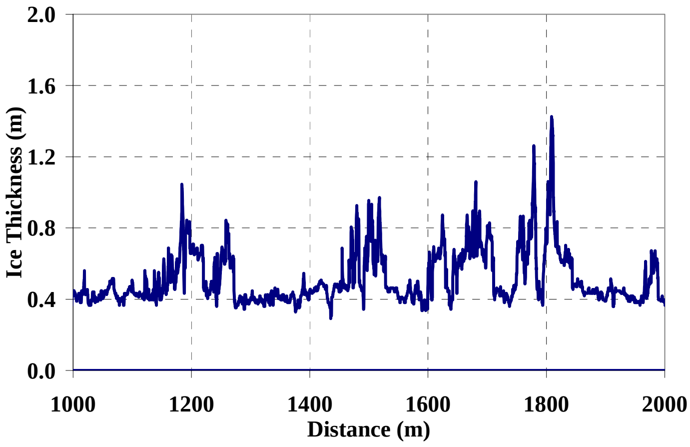

Fig. 7. Typical ice thickness along a GPR Survey Line

In general the ice thickness of level ice follows the standard dependence on freezing degree days (Evers et al, 2001). This means that in a mild winter, level ice will be limited to about 25cm, in an average year it can approach 55cm, and in an extreme year might reach 90cm or more. Rafted ice thickness varies with extent. Over areas relevant to 100m wide structures, maximum thickesses obtained to date are less than 1.4m. However, rafted ice over tens of metres has been measured to over 2m, but not fully bonded. A continued question is whether rafted ice thicknesses will be greater in severe ice years or whether there is a limit to ice thickness that can raft hence leading to a mechanical limit on rafted ice thickness (not thermal). Note however, that in cold winters the boding between rafted ice layers will penetrate into the lower layers.

***Stamukhi and Ice Rubble Surveys***

Stamukhi and ice rubble piles in front of structures have been surveyed by conducting thermal drilling and by using a laser profilometer deployed from a helicopter. The advantage of the thermal drill profiles is that they also give information on the internal structure of the ice rubble (e.g. porosity and refrozen layer). As well, thermal drilling has the ability to detect pits under stamukhi.

The laser profilometer has the advantage of speed of data gathering and can give a three dimensional image of the stamukha or ice rubble (this allows a more precise estimate of mass).

A ground party conducting thermal drilling on a stamukha is shown in the photograph in Figure 8.

A typical profile in Figure 9 shows how porosity can be estimated as the thermal drill detects voids and solid ice. This profile also shows a pit below the stamukha.

Fig. 8. Using a Thermal Drill to Measure Porosity

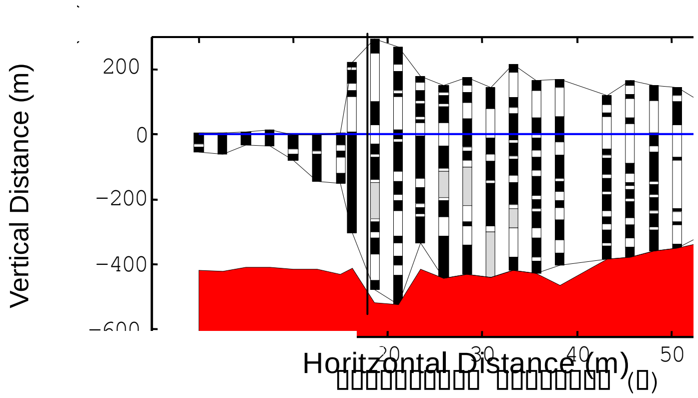


Fig. 9. Profile of Stamukha Indicating the Porosity

On-ice surveys of stamukha and ice rubble also collected data on ice thickness and block sizes. A plot of ice thickness versus maximum height of the ice rubble or stamukha has been plotted in the IAHR 2004 Barker and Croasdale paper.

In the past four years of surveys, the maximum rubble height measured on either stamukhi or in front of structures was 16m.

***Ice Scours and Pits***

In order to develop scour and pit statistics, the preferred approach is to conduct sonar surveys of the sea floor immediately after the ice leaves in the spring. These surveys can give the numbers of scours and their dimensions; of which the most critical parameter is depth.

Sonar surveys can also be conducted from the ice cover in the winter - as has been done during the Ice Programme over several years. The advantage of a winter survey is that the scours are seen prior to any erosion that may occur due to waves and currents associated with the open water season. Also during the winter, specific stamukhi can be targeted to determine the scour regime around them. Also working from the ice allows the deployment of an ROV to examine the nature of the scours before they are degraded by wave action and during the period when the water is very clear.

Figure 10 shows an image of an ice scours obtained from the ice in the winter.

As break up commences in the North Caspian Sea, it is observed that ice scours can be seen clearly from the air, as already shown in Figure 2. During 2002, it was found that counting scours from the air agreed quite well with scours obtained from the side scan sonar records (about 8 scours per kilometre over the Kashagan Field).

To date, the maximum "continuous" length of ice scour measured is about 0.7m deep. However, "local" regions within a scour have been measured to about 1.0m deep. The maximum pit depth measured below a stamukha is about 1.3m.

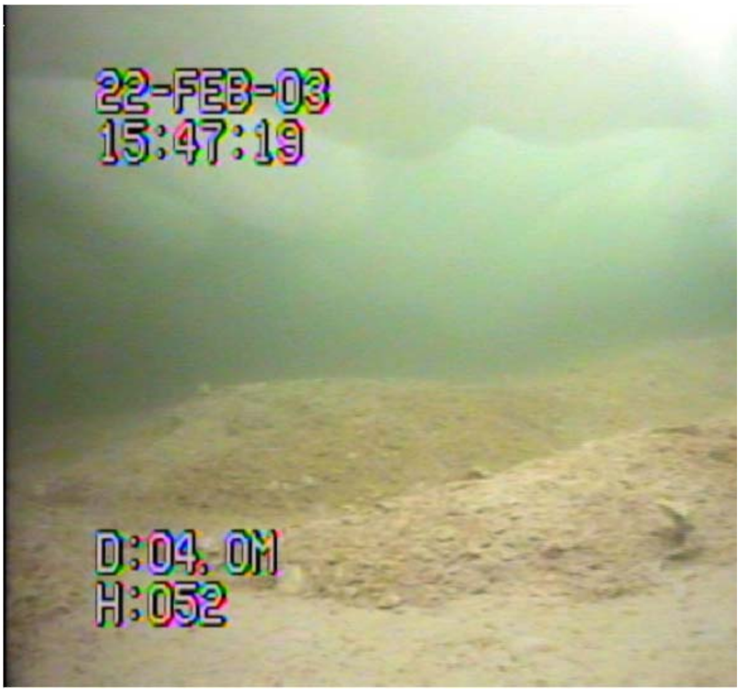


Fig. 10. Ice Scour on the Sea Floor

## ICE STRENGTH AND CALIBRATION OF ICE LOAD METHODS

A key question to be answered was whether the Caspian ice would require a change in ice load methods from those used elsewhere. This was addressed by making a number of measurements:

- Ice temperature and salinity
- In-situ borehole jack tests
- In situ flexural strength tests
- In-situ indentation crushing tests.

The measurements have been made on both level and rafted ice. Note the work on ice strength is focussed on in-situ tests. These are considered more relevant and reliable over laboratory or small scale tests on samples extracted from the ice cover.

During 2003, a series of indentation tests was performed by pushing circular indenters through the full thickness ice cover. The apparatus used is shown in Figure 11. In the test shown, the indenter is 0.5m in diameter. A typical ice pressure trace versus time is shown in Figure 12. The results confirm that for the aspect ratios tested, Caspian ice has very similar ice crushing strength to ice in other regions. As well, in these and in flexural tests and borehole jack tests, no difference in strengths between well-bonded rafted ice and level ice was detected.

Fig. 11. Indentation Apparatus

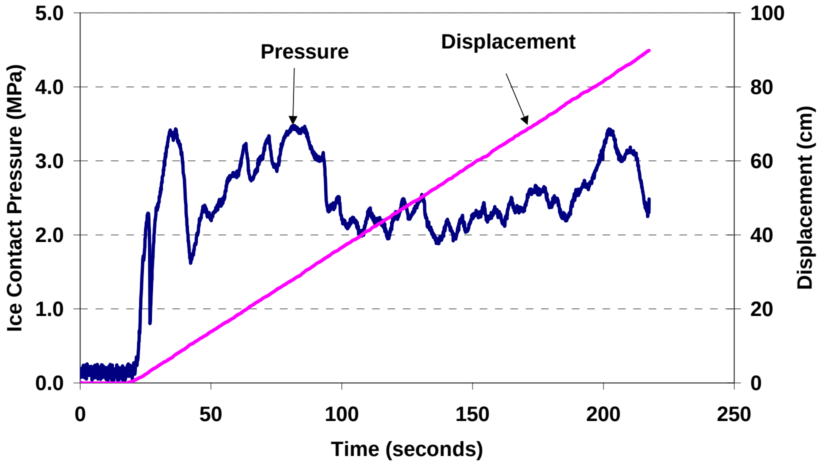


Fig. 12. Ice Pressure and Displacement Time History

## CLOSING REMARKS

This paper has described how an ice research programme has been developed and implemented for the North Caspian Sea. The priorities and elements of the research have been driven by the ice knowledge required to develop the Kashagan Oil and Gas Field safely and economically. This process of focussed planning has been described.

Despite the valuable data gathered to date, continued data gathering is considered essential because of the significant annual variability and the need to develop statistical data bases. These are needed to develop risked-based approaches to design as required by the Codes.

It should be noted that safety aspects of the ice programme each year are paramount. A detailed Health Safety and Environment (HSE) plan is developed each winter and reviewed by AgipKCO safety and aviation specialists. When ice parties are left on the ice, they report every hour by satellite phone and are picked up immediately if they fail to report or the weather is deteriorating. With every deployment the ice party has full survival gear (including a life raft) for several days on the ice. At most locations where they work, the icebreaker supply vessels could reach them within a few hours if helicopter pick up is not possible due to weather.

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