DISCUSSION

Class A prediction of Arctic caisson performance

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The Authors present the results of analyses that show considerable merit in predicting displacements and pore pressures for the sand filled caisson structure described. Their Class A predictions are of particular interest because, as the Authors note, they differ from two previously published Class A predictions of performance of this structure—one based on numerical modelling and one on physical modelling (Jefferies *et al.*, 1985). In this discussion, the Writers do not wish to review the relative merits of the various methods of prediction. It is the comparison of predicted with 'measured' behaviour, and particularly the dangers that we consider inherent to this process, that is the subject of our discussion.

For the present problem, two main input variables dominate predicted performance: the state of the sand in the caisson core, and the magnitude of the ice load. The values of each of these in the field must be known with confidence before valid comparisons between model and field performance can be made. The results presented by the Authors in their Fig. 3 illustrate the sensitivity of predictions to these parameters. For loose sand under rapid loading, ultimate failure of the structure is predicted for an ice load of less than 4000 kN/m. For dilating sand, the predicted ultimate load is in excess of 10 000 kN/m. This is in general agreement with the results presented by Jefferies *et al.* (1985), who also illustrated the sensitivity of predicted performance to small changes in sand/void ratio.

The Authors state that in situ tests indicated that the sand in the core of the Molikpaq was mildly dilatant while the sand in the berm was more strongly dilatant. The Writers have reviewed the CPT traces taken through the core and berm of the Molikpaq and have concluded that the core was probably in a very loose, contractive state, and that the berm was in a mildly dilatant state. This is also consistent with their modes of deposition—i.e. hydraulic deposition by pipeline and hopper dredge discharge, respectively.

The ice load on 12 April was caused by an ice sheet of variable thickness crushing dynamically against the structure face. Such loads are difficult to measure with accuracy, even when elaborate instrumentation is available. This is particularly the case for the Molikpaq as allowance must be made for the effects of non-uniform load distribution, dynamics and change in the properties of the caisson core as a result of pore pressure build up. It would therefore be useful if the Authors could provide the following information.

- (a) What instrumentation was used to estimate ice load on 12 April, 1986?
- (b) Where on the complex structure was it located?
- (c) How was it calibrated to measure full-scale ice loads, which might lead to dynamic effects in the structure?
- (d) Was allowance made for change in properties of the sand core as a result of pore pressure build up?
- (e) What assumptions were made with respect to spatial distribution of ice load and is instrumentation calibration sensitive to these assumptions?

In the absence of adequate answers to the above, the reported load must be questioned because it is much higher than can be inferred from precedents. In addition, as noted by the Authors, the structure was subjected to many hundred cycles of loading, as opposed to the single cycle modelled.

In summary, there are reasons to question both sand state and ice load in the field. Performance is known to be sensitive to each. In the Writers' opinion, while these uncertainties remain, it is not appropriate to compare prediction with performance. Such comparisons could lead to erroneous inferences, not only about the validity of any particular method of analysis but also about the state of hydraulic sand fills and the magnitude of ice loads that should be considered in design.

This discussion is not intended as a criticism of the prediction techniques described by the Authors. On the contrary, if, as the Writers

Fig. 29. Layout of instrumentation: (a) plan; (b) elevation, section AA

believe, the ice load on 12 April 1986 were much lower than has been reported, while the sand core were in a contractive state, it may be that the Authors' prediction for the loose sand case represents field behaviour well.

Authors' reply

Sladen and Hewitt's principal contention is that the sands in the core and berm were in a looser state than derived by Gulf and, indeed, that the core was in a very loose, contractive state. On the basis of the results presented in the

Paper, e.g. Fig. 3 or Fig. 19, had this indeed been the case, the ultimate load sustainable by the caisson could have been less than 4000 kN/m and, under those circumstances, deformations at this level of load would have been uncontrolled (contrast the horizontal load-displacement curve for loose sand in Fig. 3 with the rising curve for so-called dilating sand).

Based on the model of the structure-soil interaction problem described in the Paper, the quoted ice load is consistent with the sand in the core possessing a degree of dilatancy so that, under cyclic loading, a stable state of 'cyclic

mobility' existed in part of the core. This does, of course, allow for errors in the measurement of load and in the characterization of the sand, but not gross ones. Had the core material been much looser, it would have been liquefiable and, under cyclic loading, extreme deformations would have occurred. But as reported in the Paper, actual displacements were modest.

As to the Discussers' contention that the quoted ice loads are too high, reference can be made to the work of Sanderson (1988). He postulates a scenario not too dissimilar from that encountered by the Molikpaq in which estimates of maximum ice load by 17 international experts range from 60 to 1400 MN, a factor of 23. The issue of the precise ice load magnitude can only be resolved from measured data, and rational interpretation thereof.

The Discussers request detailed information about the instrumentation installed on the structure and, in so doing, raise larger issues concerned with back-analysis of the April 12 event, which were not directly the subject of the Authors' contribution. The instrumentation of the

Molikpaq, and the issues of calibration, are discussed by Jefferies and Wright (1988). Figs 29 and 30 illustrate the instrumentation and its location on the structure. To answer the Discussers' first two questions specifically, there were 28 'MEDOF' ice load panels, 254 strain gauges, 10 extensometers and 29 accelerometers installed on the structure as shown, supplemented by water level gauges, total pressure cells, piezometers, inclinometers, temperature sensors and video cameras.

The interpretation of the 12 April 1986 event, and the lessons to be learned from it, are very important issues and erroneous inferences are to be avoided. The Authors can contribute to this debate on the bases of rational modelling of the event, before it happened, and the interpretation of the observed behaviour in terms of the model. In the aftermath of 12 April, Gulf's response was to set up a joint industry project to analyse and interpret the data. This has been joined by five major oil companies and one major steel fabrication company, and remains open to other companies. In addition, the Discussers will be well

Fig. 30. Strain gauge locations on bulkhead

aware of a joint Canadian/US (NRC/NSF) exercise in which six teams, three from each country, back-calculated the 12 April event, reporting their findings in August 1988. Gulf have therefore adopted a very open attitude to dissemination of results, for which the academic community at least can be grateful. Incidentally, this welcome trend of early release of data of full-scale performance of structures has also been exemplified by Woodside Petroleum in Australia (Smith, Hicks, Kay & Cuckson, 1988).

The Authors, in common with many groups in industry and in the universities, have carried out back-analyses to supplement the work described in the Paper. For example, pressuremeter test data have been analysed using the Monot model, and the alternating loading model Alternat has been implemented to deal with cyclic effects. However, the Authors have avoided any references in the original Paper to these extensive post-event calculations which they have done.

Participants in the joint NRC/NSF workshop exercise are bound by a two-year confidentiality agreement, while participants in the joint industry

project are bound by a ten-year confidentiality agreement. However, it is the Authors' understanding that results will be published in the open professional literature far sooner than that.

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