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Moving on from ISO 19906: what ought to follow ?

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ABSTRACT

The ISO 19906 "Petroleum and natural gas industries – Arctic offshore structures" standard has been published. It represents an immense effort by many dedicated people, and can be seen as a consensus of opinion in the first decade of this century. However, it is necessarily an imperfect product of imperfect human beings, and it has inconsistencies and gaps, like most consensuses. In part they reflect the difficulties and disagreements of a still immature subject.

This paper examines how to move on. It considers how to make a future code both more user-friendly and more authoritative, and how to reflect continuing gaps in knowledge. The answers to those questions reflect the unexamined conventions of code-writing.

INTRODUCTION

ISO standard 19906 'Petroleum and natural gas industries-Arctic and offshore structures' has been completed after years of hard work. It is a valuable and powerful document, and everyone in the industry will find it useful. It is not premature to consider how to move on. It needs to be made clear at the outset that to say this is not to impugn the dedication and commitment of the many people who took part in drafting the code. On the contrary, the standard clearly represents a consensus, and for the moment perhaps the best consensus that can be found.

Codes generally are considered first, and some of the unexamined conventions of codes.

CODES

The idea of standards is far from new. A month before writing this, the author saw a substantial suspension bridge over a river in Bhutan in the Himalayas, built in about 1450 by a legendary bridge-builder from Tibet, and supported by chains made of iron links about 250 mm long. Like the masons who built the great structures of ancient Rome and medieval Europe, Thangtong Gyalpo was not working without historical references. His ideas about mechanics were more basic and less clearly formulated than ours, but he had rules that had been handed down: he would have known, for example, that if an arch is too thin, it will collapse under load, and he would have had some such rule as 'do not make the thickness of an arch thinner than one-tenth the span'. Many of those rules were jealously protected secrets held by guilds of masons. Much later, in the nineteenth century, there was an explosive development of infrastructure. Many failures accompanied it. After a bridge disaster in Ohio that killed eighty people, the American

Society of Civil Engineers said that ‘the design…violated every canon of our standard practice’, but that of course raises the difficult questions of what standard practice is, who is entitled to decide what it is, how it ought to be written down and kept up to date, and how it ought to be communicated.

Code-writing is an imperfect process for getting to grips with those questions. A code is statement of minimum requirements for the protection of the community. It is not – and is not intended to be – a complete guide to good design. A design might satisfy a code, and at the same time it might be a thoroughly bad design, wasteful, ugly, difficult to construct, difficult to maintain, and so on.

A code necessarily and properly represents a consensus. Science and engineering make progress by shaky and irregular steps, in which some researchers are in the lead (but sometimes take wrong turnings), others follow a little later, and others trail far behind. The process is uneven, and it cannot wait until everyone is in perfect agreement: recall the time it took to agree on whether the Earth is flat or round, on the kinetic theory of gases, on evolution, on the theory of relativity, on continental drift, and on climate change. A code cannot and should not reflect the opinions of the leaders at the forefront of research, and it cannot wait for every last person to agree. It has to lie somewhere in the middle, and hopefully it represents an informed and educated opinion with some broad level of agreement.

Who is entitled to take part in the process of code development is itself a tricky question. Code panels are frequently self-selected, and the selection process is not free of personal likes and dislikes. Often the loudest voices carry the most weight. This is a subject that needs further research: it might usefully parallel some of the illuminating (and troubling) research on juries. The famous statement of Otto von Bismarck:

> “If you respect the law or like eating sausage, you haven’t watched either being made”

applies forcefully to codes.

A code is a product of human beings, and like any human product it contains mistakes and inconsistencies. A separate article (Palmer, 2007) lists some conspicuous and nontrivial mistakes in another code, in one instance a formula that contained a factor of 1000 that ought not to have been there. That was just one example out of many.

Another subject that needs more research attention is the reality of how engineers interact with codes. The habit of using codes leads engineers unwittingly to expect more of codes than they were ever intended to bear. The Millennium Bridge opened in London in 2000, and had to be closed a few days later, because of severe sway oscillations created by positive feedback and synchronisation between the footsteps of the people walking on the bridge. A pitiful whimper was heard: “But it’s not in the code!”, despite the fact that the phenomenon had been observed before.

Linked to that is the complication that the people who use codes are a lot different from the people who write codes. The code writers are ‘experts’ of some sort, and hopefully they are knowledgeable enough to understand some of the subtleties and limitations of what is written. A user is probably not an expert, and he may be a young engineer experienced in some different area who has just been assigned to the subject of the code. He cannot reasonably be blamed if he grasps at the code like a shipwrecked sailor who has found a lifejacket. If he worries about it at all, he will console himself with the thought that if he follows the code, and if something subsequently does wrong, he can claim that he followed what he had thought was the ‘good practice’ embodied in the code.

REVISION OF ISO19906

All the problems described above are at their most severe when the subject of the code is a primitive and immature subject, in which there is an absence of consensus about fundamentals and a lack of practical experience. Arctic engineering and ice engineering fall into that category.

Much of ISO19906 consists of reminders about aspects of the problem that need to be examined. Some examples selected at random follow:

> (section 5.3.1) “The structure and all its subsystems shall be operated in an environmentally sound manner. Conditions that can influence the functional and operational requirements shall be identified. Appropriate procedures for matters concerning health, safety and the environment shall be established and maintained…”
>
> (section 6.1.1) “The owner shall be responsible for selecting appropriate physical environmental design parameters and operating conditions. The owner shall take regulatory requirements into account, where they exist…”
>
> (section 10.3.4.1.5) Islands located near a river mouth or a region found to have large current velocities shall be designed with consideration given to the actions generated by the local currents”

Nobody could object to these reminders, but they do not say much and are not quantitative in any way.

The informative section is intended to guide the user, but in reality it offers hardly any guidance. Occasionally the text suddenly becomes much more specific. In section 8.5.2, for instance:

> “Wave-induced velocity of ice features
>
> “The incident wave and current determine the velocities of ice features impacting a structure and shall be considered. Methods to estimate the velocities depend on the ratio of the wavelength of the incident wave to the dimensions of the ice and the structure.
> “Pieces of ice with maximum dimension less the 1/15 th of the incident wavelength can be conservatively assumed to follow the water particle velocity…”

Imagine then a bergy bit, idealised as a floating 6 m cube of 900 kg/m^3 ice, and take the incident wave as 6 m in height, 90 m wavelength, 8 s period. The Airy wave orbital velocity $\pi H/T$ is 2.4 m/s, and the impact kinetic energy is 540 kJ (corresponding to 195 tonnes free-falling 0.3 m).

Such a heavy impact would do substantial damage. That is not necessarily to say that the calculation is unfounded, but no reference is given: it may be suspected that the calculation is traditional, and that it has been handed down without ever being re-examined.

It is instructive to see how ISO19906 deals with the controversial subject of ice forces. Global ice actions related to crushing are examined in section A.8.2.4.2. The forces on vertical structures are calculated in section A.8.2.4.3. The global ice action normal to a surface is given by equation A.8-20

$$F_G = p_G w h \qquad (1)$$

where p_G is an ice pressure averaged over the nominal contact area, w is the contact width and h is the ice thickness. The ice pressure is given in A.8-21

$$p_G = C_R \left(\frac{h}{h_1}\right)^n \left(\frac{w}{h}\right)^m \qquad (2)$$

where

C_R is an ice strength coefficient, in MPa

h is the thickness of the ice sheet, in m

h_1 is a reference thickness, taken as 1 m

w is the projected width of the structure, in m

m is an empirical coefficient, given as -0.16

n is another empirical coefficient, given as $-0.5+h/5$ if $h<1$ m and as -0.3 if $h\geq 1$ m

Equation A.8-21 (2) might be more clearly written

$$p_G = C_R (wh)^{n/2} \left(\frac{w}{h}\right)^{m-n/2} \qquad (3)$$

The equation (2) acknowledges that there is a size effect, so that if the aspect ratio w/h remains the same, the ice pressure falls as the contact area wh increases. The size effect has of course been known about for many years (Sanderson, 1988, Palmer and Sanderson, 1991). It has been much disputed: on the one hand, some people deny the reality of the effect, and on the other hand, others remark that it would only be surprising if there were no effect. It was perhaps prudent of the writers of the ISO19906 code not to attempt to discuss the explanation, but explanations do exist.

The coefficient C_R is given as 2.8 MPa from data from Cook Inlet, the Beaufort Sea, the Baltic Sea and the Bohai Sea, but as 1.8 MPa from data from the Baltic. Remarkably, the effects of temperature, ice velocity and salinity are absent, though there is a brief discussion of velocity effects and some references are given. Further on C_R is given as 2.4 MPa for sub-Arctic regions. Yet another approach is offered, where C_R is taken as the strength parameter for a reference area multiplied by the ratio between strength indices, which

> "…could involve a variety of compressive strength measures, including borehole jack measurements, uniaxial or multiaxial strength measurements, continuous indentation experiments, and relationships between temperature, brine volume and compressive strength.."

This cannot be seen as satisfactory. The bemused user has to choose between 2.8, 2.4, 1.8, or 1.8 or 2.4 multiplied by a strength index ratio. Various ideas are put forward, and the user is given almost no guidance. Surprisingly, C_R is smaller for the Baltic, in spite of the fact that ice in the northern Baltic has a low salinity and comparatively high temperatures, factors that are generally thought to increase ice forces. Another and different formula A.8-24 is given for global ice pressures from ship ramming tests, and now all the coefficients are given as broad probability distributions.

The confusions and conflicts in the code reflect the absence of agreement. The code writers could have said:

> 'Actually there's no agreement about this: this is the best we can do, but you are on your own'

which is true, does not reflect badly on anyone, and is a candid description of the state of knowledge.

Sloping structures are treated differently. There is a good qualitative discussion, and then two entirely different quantitative models. One is three-dimensional and based on the theory of plasticity, though plasticity is known to be a poor description of the behaviour of ice under almost all field conditions. The other is based on two-dimensional elastic bending. The user of the code is given no guidance about which of the models to choose. The size effect that was recognised for vertical structures has somehow disappeared. Again, all this lack of agreement reflects a lack of knowledge.

Local ice actions are treated differently again, and once more there are alternatives. In A.8-63 the full-thickness ice pressure is given as

$$\begin{aligned} p_F &= 2.35h^{-0.5} \quad \text{for } h>0.35 \\ p_F &= 4 \quad \text{for } h<0.35 \end{aligned} \tag{4}$$

where h is the ice thickness in m and p_F is in MPa, but a page later the local pressure due to a massive ice feature is given as

$$\begin{aligned} p_L &= 7.4A^{-0.7} \quad \text{for } A<10 \text{ m}^2 \\ p_L &= 1.48 \quad \text{for } A>10 \text{ m}^2 \end{aligned} \tag{5}$$

where A is the local design area in m^2 defined in Figure A.8-17. Obviously the formulas are totally different. Local ice action is in fact one of the better-documented parts of the subject, and there are a lot of good data and at least a little understanding of the reasons for the strong area and thickness effects.

Another thought-provoking section is A.8.2.4.7 Limit-energy global ice actions, which is concerned with iceberg impact. The formulation is based on a paper by Fuglem et al. (1999). That paper includes a careful discussion of the background and the difficulties of this complex subject, and includes warnings, for example

> "Ice failure is a complex process that includes spalling of large impact ice pieces, micro-cracking, damage processes, recrystallization, pressure melting and extrusion. Current understanding of the processes involved has not advanced far enough to develop a comprehensive failure model, so a simpler approach is used. The nominal pressure and global impact force during an impact are modelled using the following empirical relationships:..."

and later

> "It is important to give some qualitative comments regarding the above data sets. Data from which complete underwater profiles can be recreated are limited to the relatively small set of Dobrocky data. It is possible that these data are not completely representative, as shape depends on factors such as iceberg size, number of groundings, how often icebergs roll and calve, ice temperature profiles, and the history of wave and current conditions. Possible measurement and analysis errors in the original Dobrocky profiles should be noted as well.."

In ISO19906, on the other hand, those careful qualifications and warnings have been thrown away. Instead, several of the formulas from the original paper have been cut-and-pasted over, with trivial changes of notation and with almost no discussion. The unintended effect is to create a spurious air of confidence that a reference back to the original does not justify.

Many more examples could be adduced, but it is not the objective of this paper to point out all the limitations and inconsistencies of the code. The code writers seem often to have responded to disagreement by refusing to make a choice, so that two or more alternatives are put forward, without any indication of how the user is to respond.

CERTAINTY AND UNCERTAINTY

Much of the difficulty arises from the pretended omniscience of the code, so that every statement is made to appear to be definitive. One does not need to read far between the lines to see that this is unjustified, as the examples above suggest. If a code gives two or three different formulas for a calculation of the same quantity, and if it cannot bring itself to make a choice between them, the subject must be uncertain. In the case of the formulas for ice forces discussed above, that is obviously true, as is perfectly well known to everyone who works on ice forces.

The level of uncertainty varies hugely. At one extreme there are formulations that are supported by solid field data, from well-documented measurements by serious researchers in a variety of contexts and environmental conditions, and preferably (but not necessarily) backed up by some scientific understanding. They can be relied on with some confidence. At the other extreme there are shakily speculative formulations, derived from special conditions, not validated against any data, and supported by theory that is plainly invalid. Almost every engineer active in the field will acknowledge this divergence, and privately he will make some assessment of reliability and take it into account when he applies the code.

It might be better to be more open about the difficulty, and to attach to each section of the code an evaluation of the confidence that could be placed in it. There might be a rating number, ranging from 5 (solid confidence, backed up by field data and science) down to 1 (speculative guesswork) and to an occasional 0 (nothing known). To do that would not diminish the usefulness of the code. On the contrary, it would make it more useful, because it would take the code user into the code writers' confidence. A secondary advantage would be that it would better identify problem areas, and would help to bring the whole subject forward.

CODES AND COOKBOOKS

Engineers are always told that a code is not a cookbook and ought not to be treated as a cookbook. However often that is said, the reality is that some engineers will continue to use codes as cookbooks. They will consider the design process to consist of working through the code step by step, and altering the design until each clause and each formula is satisfied.

We have much to learn from cookbooks. It might be better if a code were written as a cookbook. If you want to bake a cake, you can start with several years study of the chemistry and physics of complex mixtures of flour, eggs, sugar and milk. A better option is to borrow a good cookbook and do precisely what it says, taking account of the warnings it gives. Here, for example, is part of a good recipe for a cheese soufflé (Costa, 1999)

> "Melt the butter and cook the flour in it without letting it colour. Remove from the heat and gradually add the milk, warmed if you are a novice cook. Simmer gently until the sauce is smooth and thick – about 10 minutes. Remove from the heat and let the sauce cool a little.
> "Separate the egg yolks and whites very carefully. Beat the yolks until thick and pale. Add them to the sauce and beat them in well. Then stir for a few minutes over a low heat, adding the cheese and the seasonings: salt, freshly ground white pepper, just a few grains of cayenne and a very little nutmeg. Let the mixture cool to lukewarm."

The warning about separating the eggs "very carefully" is not needed by an experienced cook, but a newcomer may not know that if even a little of the eggyolk gets into the white, the fats in the yolk will make it impossible later in the recipe to whip air into the white to form a foam. Some complicated surfactant chemistry is going on, but the user does not need to know about it: he just needs to know what to do. Another good feature of the conventions of cookbook writing is that all the information required is contained within the recipe itself, even at the cost of some repetition between different recipes. In contrast to a typical code, the user is not given a crossreference to section 3.8 on page 87 for one step, to table 2.13 on page 23 for a coefficient in a formula in another step, to an incomplete digression for a third, and to a different cookbook for a fourth. The convention of writing each recipe as a straight-through complete instruction actually helps to minimise mistakes and ambiguities.

Another paper (Palmer, 2007) explores these issues, and redrafts parts of existing codes in the somewhat different style that would be required of a cookbook code, though deliberately without altering the technical content. Writing a code so that it can be used as a cookbook would be an excellent discipline for a writer, just as writing code for a computer leaves no room for vagueness and forces the writer to think clearly and precisely.

For example, Sections A.8.2.4.7 of ISO 19906 could be rephrased in a similar way as a recipe by not omitting the information presented in the cited paper. A note could be made to inform the users that the formulations in Subsections A.8.2.4.7.2 and A.8.2.4.7.3 assume that the structure is a vertical rigid wall and that the rotation of the ice feature is small such that there is only a single impact point. An illustration using ice features of simple geometry could be made to explain the eccentricities and radii of gyration, as Fuglem et. al. (1999) demonstrated. Similarly, the pressure variation coefficients C_P and D_P and the coefficients of variation in contact geometry C_A and D_A can be explained further; e.g. the range of values for D_A could be given for simple geometry. Not only does this clarify the formulation, but it also informs the users of the parameters that they need to have in order to use the formulas, just as a cookbook recipe starts with a list of ingredients. It also illuminates the meaning of the result.

This would seem a promising direction for the next 19906. There are some possible objections. A code that offered a series of recipes might increase the exposure of the code authority and the writers to legal action if something went wrong. They are accustomed to try to protect themselves by disclaimers, but that might be more difficult if there were design recipes, though doubtless the lawyers could create a formula.

Another objection is that the ambiguity and lack of precision of existing codes provide work opportunities. One distinguished consulting engineer memorably remarked to one of the authors that:

> “If codes were better written, consultants wouldn’t have anything to do.”

CONCLUSION

ISO19906 is a noble effort, and represents a consensus of opinion in the first decade of the century. It is not the final word, and it could usefully be revised to be explicit about the uncertainties that reflect an incomplete level of understanding. A bolder step is to alter the style so that the code can reliably be used as a recipe book.

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