TRONDHEIM DECEMBER 1994 - WIND INDUCED RESONANT CROSS FLOW VIBRATIONS ON NORWEGIAN OFFSHORE FLARE BOOMS

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The background of this presentation is the experienced vibrations and fatigue cracking in flare boom structures on a number of platforms on the Norwegian continental shelf. In 1978 and 1984 severe vibrations were observed in the flare booms of Statfjord A and Heimdal. Many cracks have later been found on Statfjord B and C, Gullfaks B, Vallhall PCP and Odin.

Earlier design practice has been based on the notion that if the vibration amplitudes was kept low; the induced fluctuating force would be randomly distributed over a broad band of frequencies. The means to achieve this was to require limitations of the reduced velocity value as a function of the flow regime (Reynolds number) and with additional requirements to the Scruton's number if the reduced velocity requirement could not be met. The effect of vortex shedding was considered negligible for values of Scruton's number larger than a certain value. The formula used for calculation of a maximum amplitude was sensitive to the stability parameter and thereby damping. A rather high value of damping was assumed; 0.5 % of critical.

After experiencing vibration problems, the Statoil design specification was revised in 1990 shortly followed by a change in the NPD guidelines. In search for a design procedure yielding economical and "robust" structures consistent with observed behaviour the DIN 4133 standard has been adopted with minor modifications. It is less sensitive to damping and Scruton's number is introduced with no limitations. Maximum vibration amplitudes are calculated as a function of the vibration modes in addition to the aero-elastic response and damping. A fatigue life calculation is performed based on a wind velocity probability distribution with a cut-off level for high wind velocities. The use of the DIN 4133 standard for offshore applications has though raised some questions and uncertainties.

Some design rules state that the vibrations will stop when the Scruton number exceeds a certain number. DnV(1977) and Statoil (1985) use 16 and DnV (1991) use 25. We have calculated the Scruton number on the members having vibrated using a damping value of individual members of 0.15%. Most of the problems have occurred on members with Scruton number less than 25. Even though the large vibrations on Statfjord A were on members having a Scruton number of 28 and several members with fatigue cracks on Gullfaks B having 34. From our point of view the Scruton number is not a good criteria to prevent cross flow vibrations.

A criteria based on a reduced velocity less than 4 (as in BS 8100 and Eurocode 1) should give a sufficient method to prevent cross flow vibrations. There is as far as we know no background in Norwegian experience indicating that this is not reasonable. Design practice have demonstrated that a design based on a criteria to completely avoiding cross flow vibrations might cause expensive solutions. For offshore applications the question arise of which mean wind velocity should be used for this purpose. BS 8100 use one hour mean, Eurocode 1 use 10 min mean and Statoil use 30 seconds. A reduced velocity limit of 4 using a wind velocity averaged over 10 minutes correspond to a reduced velocity of about 4.6 using a wind velocity averaged over 30 seconds, or 5 if the basis was one hour. A physical validation on the choice of measuring period is not available.

The Heimdal experience have demonstrated that wake effects might move the limits were the cross flow occur at higher reduced velocities numbers. The cross flow displacements in a wake might also increase, compared with free field behaviour. The Statoil specification for Sleipner require that wake interference should be evaluated if a member is closer than 15 diameters. How to handle wake effects in design is not specified in any design code.

Measurements of damping have been performed world wide on several welded tubular steel structures. The results have a tremendous scatter. The DIN 4133 give a damping ratio of 0.24%. In Norway a damping of 0.15% is used according to the recommendations in the NPD guidelines. The large scatter might also be one of the reasons why many members according to the calculations have a very low fatigue life, but with out any sign of cracking.

Using the design concept in DIN 4133 the predictability of the low amplitude cracking in several platforms have been good. Even though the observed vibrations at Statfjord A and Heimdal indicate vibration amplitudes significantly higher than found using DIN 4133. Values of the maximum displacements of individual members divided by the diameter of at least 0.11 have been found on Statfjord A and 0.13 on Heimdal. The DIN standard is unclear if it give maximum or RMS values. An interpretation as a maximum value is normally used. If the numbers in DIN 4133 reflects the RMS values, the maximum amplitudes of individual members at Statfjord A and Heimdal might represent some 5 standard deviations of the values presented in the DIN standard.

On Statfjord A, B and C, Vallhall PCP and Heimdal cross flow vibrations of substructures or panels have been visually observed or found as a possible reason for cracking in tubular joints. How to handle such vibrations is not covered in any design code. In their panel analysis Veritec assumed that the vortex shedding acted on one diagonal. They argue that it is not likely that the force will act in phase on several members at the same time.

CONCLUSIONS

The current design procedure in Norway for offshore applications is based on the DIN 4133 standard. It is used, however, a variety of interpretation of parameters attempting to cover offshore conditions more specifically and to establish boundaries for avoiding resonant vibration problems. The wind data should be based on a site specific long term distribution. The level of the lift force coefficient and cut-off level for high wind velocities should be calibrated versus results from model testing or full scale observations.

Alternatively a critical velocity range or a reduced velocity range for avoiding vortex induced vibrations may be given. Relevant supplementary parameters are needed, also connected with some uncertainty:

1. The reduced velocity or Strouhal's number as a function of the flow regime.
2. The wind velocity and the up-stream turbulence effect on the cut-off level for vortex induced vibrations.
3. The effect of wind direction not perpendicular to the member axis.

Vibrations in the wake of vortices from structures up-stream and vortex induced vibrations of "substructures" should be considered. Necessary robustness of the structure will further limit the T/D ratio, i.e. requirements related to local buckling and welding quality.

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