Appendix

# VIBRATIONS OF THE HEIMDAL FLARE BOOM

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by

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## Heimdal background

Heimdal is a field in the Norwegian part of the North Sea and is operated by Elf Aquitaine Norge (EAN). The platform was installed during the summer 1984. A general drawing of the platform is showed on figure 1.

The main engineering contractors was Kværner Engineering with Brown & Root and Sofresid as subcontractors. Det Norske Veritas (DnV) was the verification consultant for EAN.

## The flare boom vibrations

The flare boom was designed by Brown & Root (UK) as a subcontractor to Kværner Engineering. The calculation of cross-flow vibrations was done according to the DnV design codes and the design was verified by DnV.

A study carried out by Bergen Engineering requested by NPD using another design approach showed that certain elements were critical to vortex shedding. However, based on an evaluation of the consequences of possible vortex vibration, the NPD gave concent for installation.

However, NPD required observations to be incorporated in the normal inspection program for the Heimdal structural part. These observations lead to the discovery of the vibration problems 1 November 1984. The vibrating members are shown on figure 2 and 3.

All nodes connected to critical member was NDE inspected. MPI or dye penetrant of brace to chord welds (all welds at node) was used in order to determine whether cracks developed. Two cracks were observed and later repaired. Material from one of the cracks was removed for analyse. It was later established that the crack was due to fatigue.

In order to gain further information on the dynamic characteristics of the Heimdal flare boom, a measurement programme was conducted by Veritec. This programme consisted of exciting six members of the flare boom with a rubber hammer and measuring the resulting vibrations with 1-3 transducers mounted on the member. The output signals were recorded on tape for subsequent analysis.

A spectral analysis was performed on the free vibration signals using the Fast Fourier Transform (FFT) method. This produced information relating to the natural frequencies on the flareboom members.

The damping values were calculated from the decay in the vibration amplitude with time, the signals first beeing filtered at the resonance frequencies.

This produces the following expression for damping:

$$\text{Percent of critical damping} = \frac{1/N * \ln \frac{X}{X_n} * 100}{2\pi}$$

where

$X$ is initial amplitude of vibration

$X_n$ is amplitude of vibration after N cycles

$N$ is number of cycles

A comparison between the measured and calculated frequencies for the members in the top chord was made. The calculated frequencies was selected to correspond to vibration of the specific members only.

The calculated frequencies was relatively close to the measurements. However, the measurements showed significant responses at more than one frequency. These measured frequencies did not appear to be a simple multiples of each other.

Consequently it was concluded that the multiple frequencies are not due to different vibration modes of the single members, but could be caused by interaction with surrounding members.

<u>Action taken to stop vibrations</u>

In December 1984 and January 1985 a total of 19 members of the flare boom was wound with ropes. Rope diameter was approximatly 10-12 % of diameter. One loop of the rope was covering a length of 5 times the diameter. Three ropes was used. The ropes was equally spaced around the perimeter.

After the winding small vibrations were observed in 5 of the members.

In January and February 1985 a total of 4 nodes and 2 members were braced by fitting a wire to the structure and then pretensioning the wire.

In total these methods were effective. Nevertheless small vibrations were observed, but since the observed amplitude was approximatly 10 mm, the vibrations were not considered as critical.

Different methods to stop the vibrations permanent was evaluated by DnV, Technip Geoproduction and Brown and Root. Based on these evaluations additonal wind tunnel tests was done by Laboratorie Eiffel, Paris. The shroud solution gave the best results, low drag coefficient and the best vibration prevention. This solution was recommended for the final modification. All members being critical following the final design criteria were modified.

No vibration has been reported after the modifications.

Vortex Shedding in design

The design against cross-flow vibrations was performed according to DnV (1976 and 1977) stating that cross-flow vibrations may occur where:

$$VR \geq 3.5$$

and $$KS \leq 16$$

where

$$KS = \frac{2 * m * \delta}{\rho * D^2} \quad \text{stability parameter}$$

$$VR = \frac{V}{f_1 * D} \quad \text{reduced velocity}$$

a damping ratio of 0.5 % was used according to DnV (1977).

The subsequent analysis was performed and vortex shedding was discounted. The presence of vibration due to vortex shedding indicates that use of the stability parameter KS < 16 was inadequate although it reflected the state of art at the time of analysis.

Damping

Traditionally a damping of 0.5% has been assumed for most steel structures and was recommended by DnV (1977), and used in the original design.

However, closer examination of a structural damping of 0.5% reveals that it has been derived mainly from vibrations of integral structures rather than component members. Clearly within an integral structure the effects of the node constraints form a major effect in the damping mechanism. Thus by inference one would expect that the structural damping must be a function of the slenderness ratio, (L/D) in that the more slender the member, the more it would be expected to behave as unfabricated steel, giving a structure damping coefficient significantly less than 0,5%.

In order to pursue this argument the full scale measurements reported by Veritec, and stability parameters recommended by ESDU were used to determine the structural damping versus slenderness ratio function as shown in figure 4.

Again by reason of the same arguement as stated previously the ESDU stability parameters for varying slenderness ratio can only reflect the variation of damping with the slenderness ratio, since all other terms are clearly defined and ESDU recommend a damping level of 0,5%. Full scale damping measurements reported by Veritec, show that for vibration of members rather than panels, the damping levels was in the range 0.15 - 0.2 %; where these members had slenderness ratios in the region 40 - 50.

All this information was compiled together and damping plotted as a function of slenderness ratio, the results of which clearly demonstrate that for the structural elements observed vibrating in the base of the flare boom the equivalent stability parameter for a structural damping level of 0.5 % should be 5 rather than 16.

Slenderness ratios of the order 40 - 60 have been used in the base of the Heimdal flare boom. Whereas many other structures have been designed by the use of a stability parameter with a structural damping of 0.5 % their members have lower slenderness ratios. The Heimdal flare boom has highlighted an unexpected inadequacy in the code of practice, namely the selection of structural damping.

Thus the use of a stability parameter of 16 may still be considered valid, provided that it is based on a value of structural damping corresponding to the slenderness ratio as shown in figure 5.

Calculations of those members observed vibrating revealed that all failed the revised stability parameter test except for one of the side panel members which was marginal. However, in this case it was linked to a member which was vibrating freely so that vibration could have been passed via the common node.

Using a damping of 0.15 % (NPD, 1989) will lead to a simple relationship between member diameter and all thickness of a tubular : $D/t < 23$.

### Wind velocity

DnV (1977), incicate that when a Reynolds number of greater than $5 \times 10^5$ occurs the vortex shedding pattern behaves in a wide banded random shedding manner thus inhibiting vibrations. In addition, measurements indicate that for wind speeds of greater than 20 - 25 m/s the effect of atmosphere turbulance over the sea surfaces causes a breakdown in the development of vortex shedding. Thus the wind speed range of each critical member was examined and those which fell into either of the above categories were dismissed. Bell and Shears give 20 m/s and Editions Eyrolles (1976) give 25 m/s.

## Conclusion

Based on the input from different contractors EAN concluded to use the following criteria to determine critical members needing structural modifications: ~~It is the most conservative values from each of the consultants:~~

Damping = $0.14 + 0.36 \exp(-0.0855 * L/D)$
($L/D$ = Length/Diameter)

Stability parameter Ks $\leq$ 20

Reynolds number < 350.000

Range critical speed < 23.5 m/s
(Corresponding to critical speed of 25 m/s)

Note that this damping ratio is applicable to individual structural members only.

In the NPD guidelines (1987) a damping of 0.1 % of critical was recommended. During the design of the BP-Gyda flare boom it was showed that this damping would give unreasonable dimensions of the flare boom. In 1989 the NPD has proposed to revise this number to 0.15 %.

## References:

Bergen Engineering: Heimdal Development, Control report on in-place analysis of flare boom, 11.04.1984.

Brown & Root (UK): Heimdal flare boom invenstigation, January 1985.

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DnV : Rules for submarine pipelines systems, appendix A (1976).

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EAN : Flare boom vibration HMP-1, Summary and situation report, 23.04.1985.

EAN : Flare boom vibration HMP-1. Evaluation of problem/permanent modification, 23.04.1985.

Editions Eyrolles: The effect of snow and wind on structures. Regulations NV 65-67. English version, Paris 1976.

ESDU-78006 : Across flow response due to vortex shedding (1978).
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NPD : Guidelines for determination of loads and load effects. Stipulated 02.01.1987.

NPD : Public hearing - changes of the guidelines for the determination of loads and load effects of 15.03.1989.

Technip Geoproductions : Expertice - Heimdal flare boom of January 1985.

Veritec : Flare boom vibration, Heimdal of 25.01.1985.

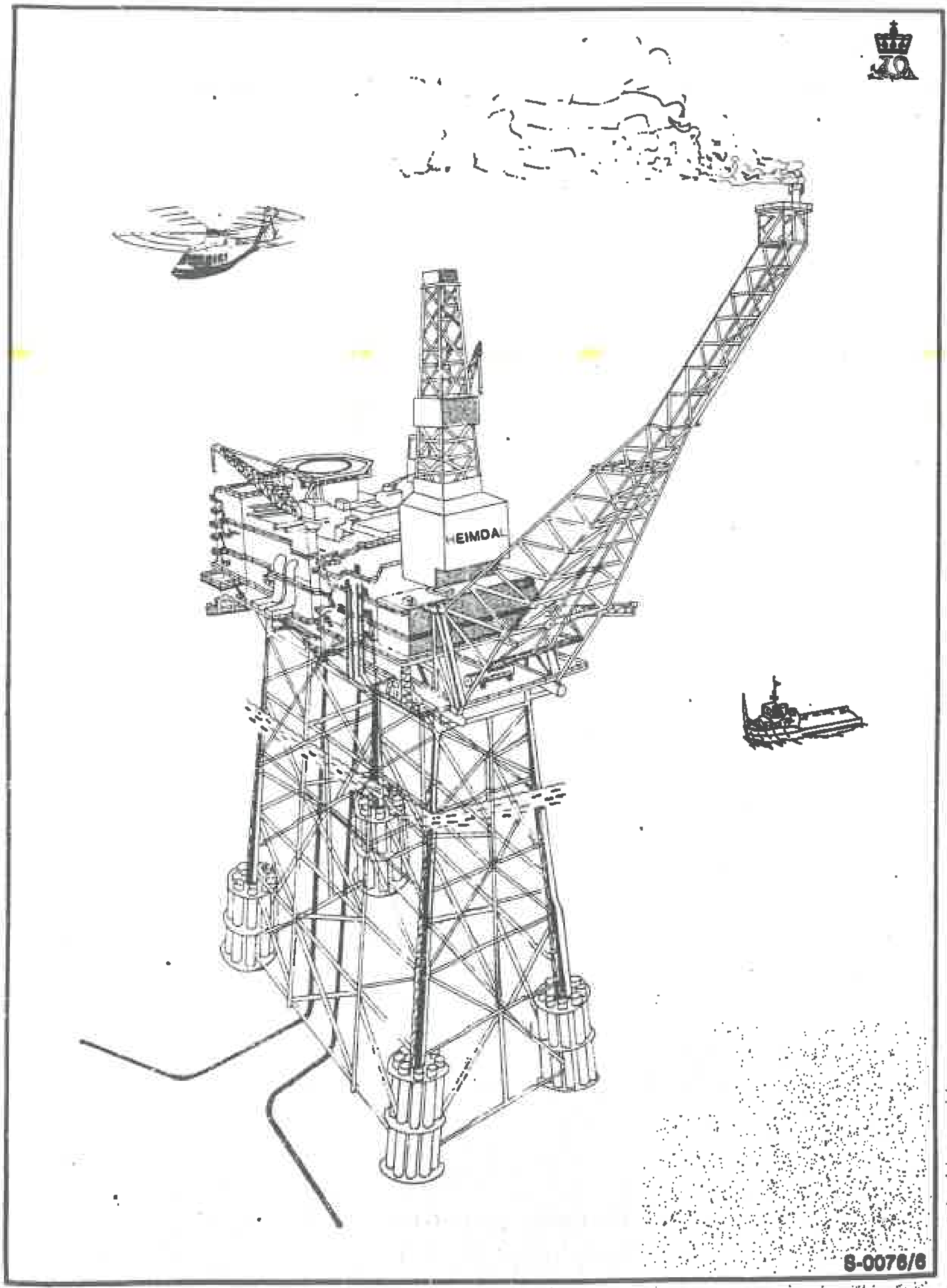

Figure 1: DRAWING OF THE HEIMDAL PLATFORM

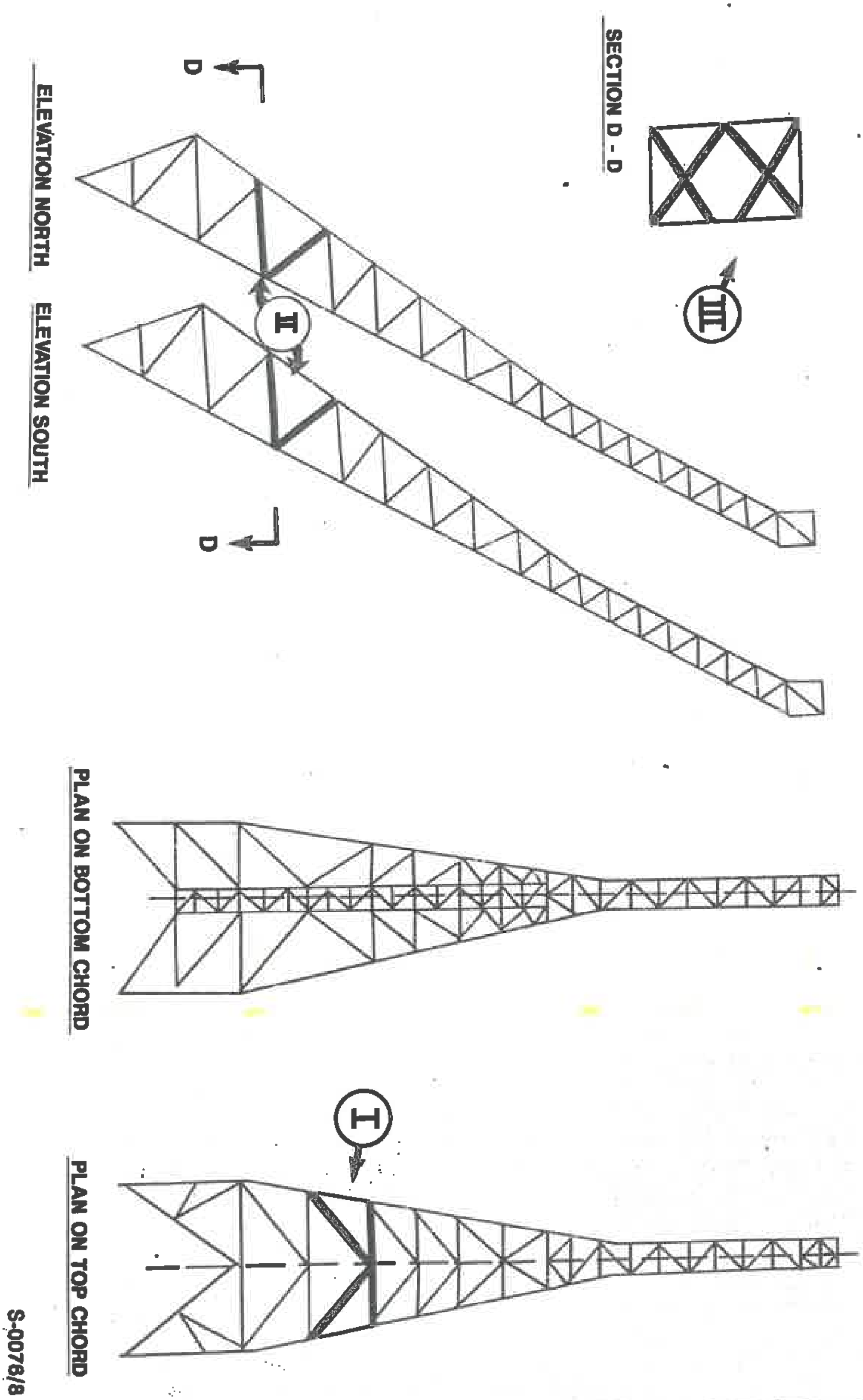

Figure 2: MEMBERS OBSERVED VIBRATING AS A FRAME

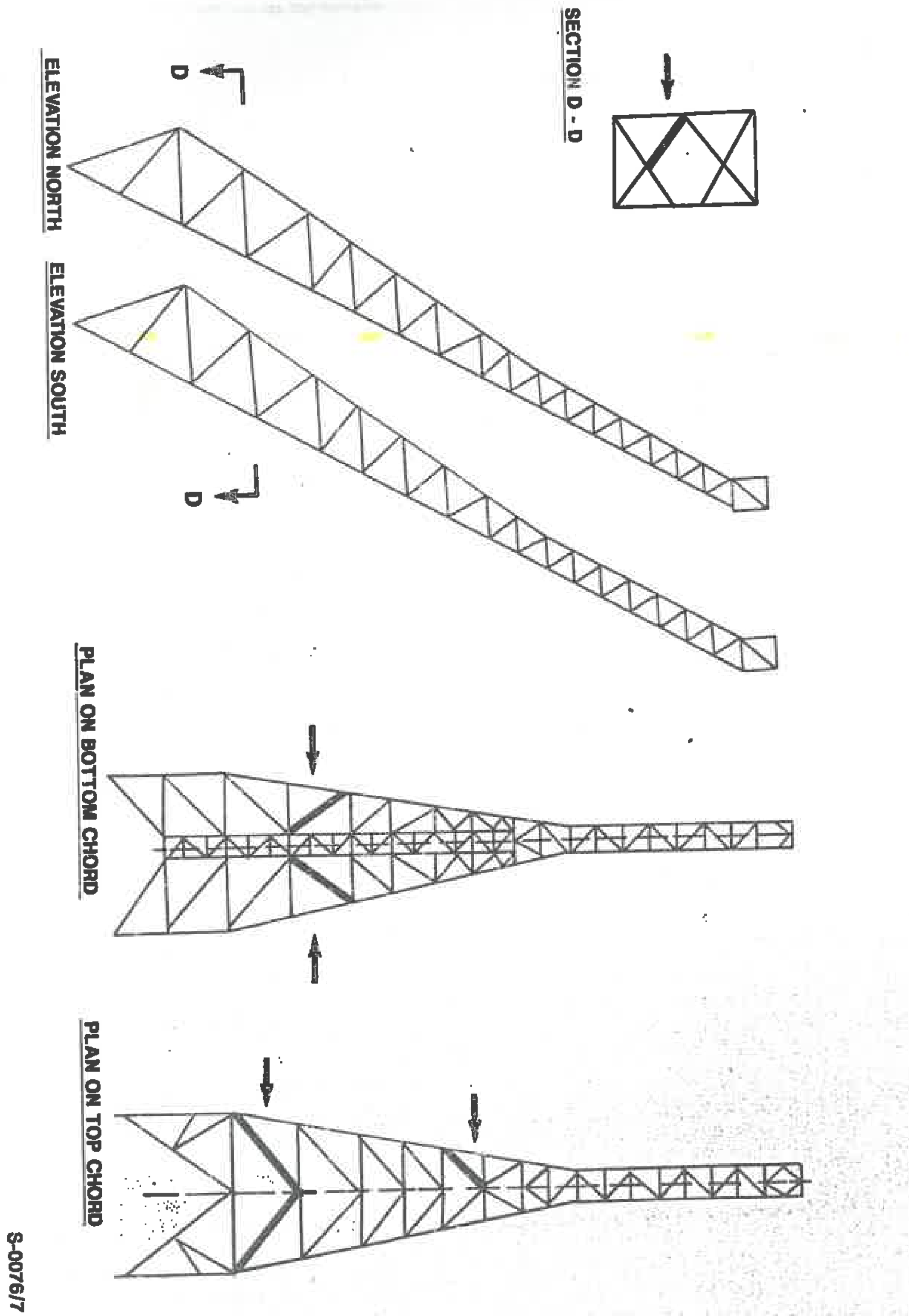

Figure 3: MEMBERS OBSERVED VIBRATING AS SINGLE MEMBERS

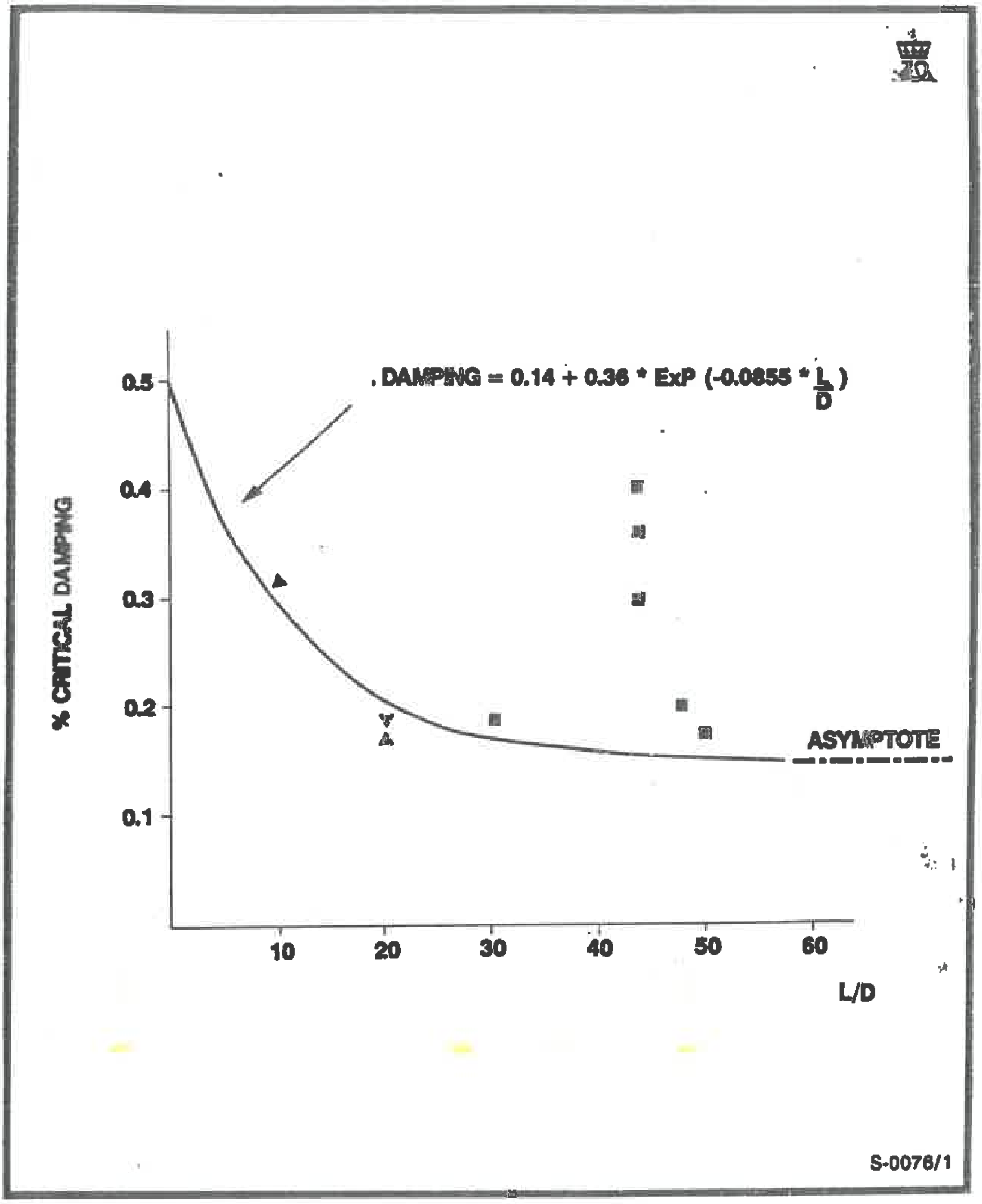

Figure 4: STRUCTURAL DAMPING IN A MEMBER AS A FUNCTION OF SLENDERNESS RATIO. TO BE USED FOR INDIVIDUAL MEMBERS ONLY (BROWN & ROOT, 1985)

▲ ESDU - 7800[illegible]6 - CANTILEVER
▼ ESDU - 7800[illegible]6 - SIMPLY SUPPORTED
■ HEIMDAL FULL SCALE MEASUREMENT

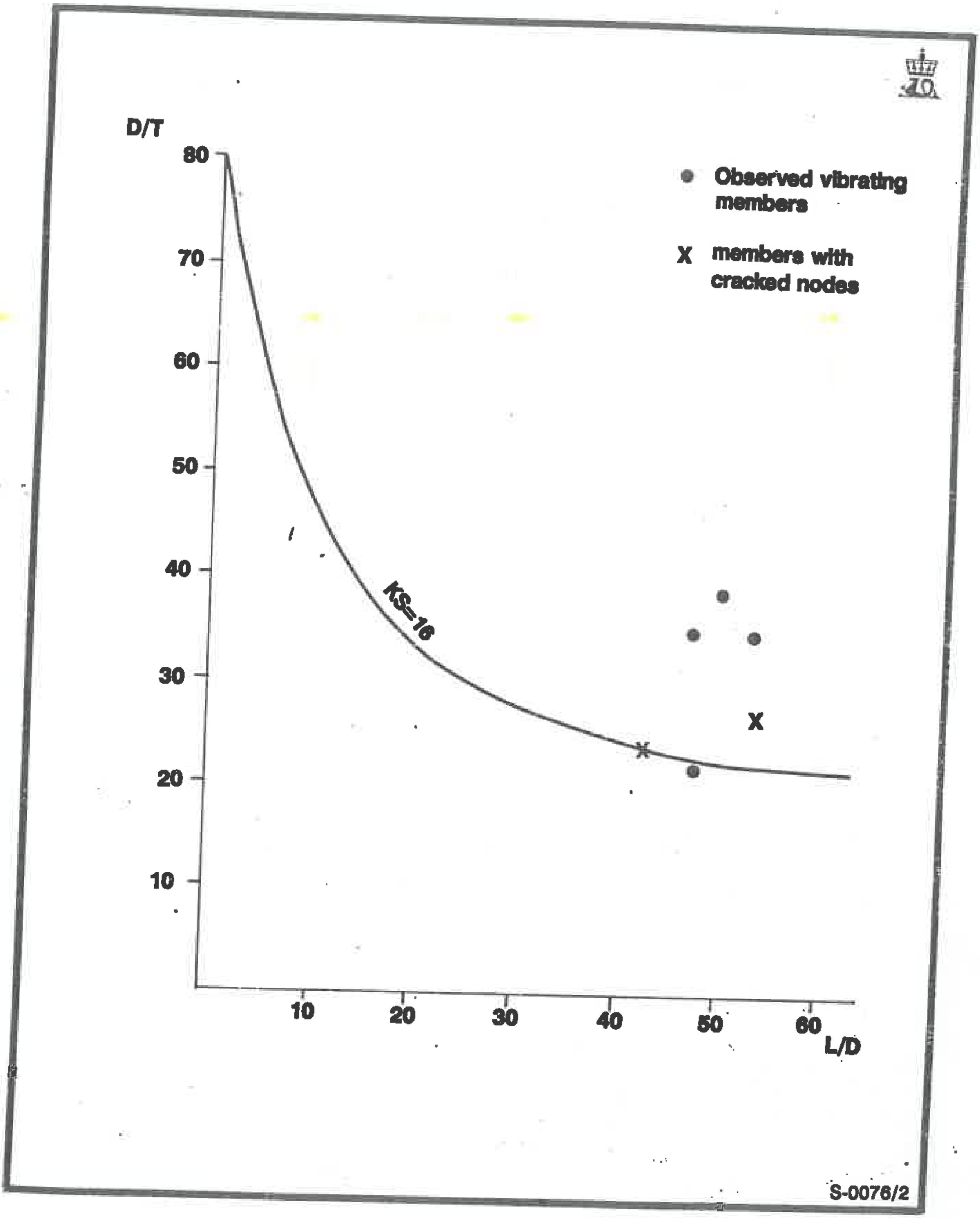

Figure 5: LIMITING D/t RATIO AGAINST SLENDERNESS RATIO TO PREVENT VORTEX SHEDDING (BROWN & ROOT, 1985)