Soil reaction stresses on gravity platform
Les contraintes de réaction des sols sous les plateformes-poids

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SYNOPSIS: The paper uses the results of two-and three-dimensional analyses of the soil reaction stresses on the foundation skirts and the base of a model gravity platform to illustrate a design calculation. Platform weight, horizontal wave load and overturning moment are applied. The stress distribution in the horizontal plane and with depth on the individual foundation skirts, the sharing of the horizontal load between skirts and platform base and the contact stresses on the platform base are presented.

The paper gives emphasis on the application of recent research results in actual design. Linear elastic behaviour of the soil and skirts is assumed. The calculations show that the horizontal load sharing between skirts and base is significant only for skirts with length to diameter ratio less than 0.5. Furthermore, for many purposes, one may limit the analyses of soil stresses on platform base and skirts to simplified plane strain and axisymmetric analyses. For the example shown, the reaction stresses produced by horizontal loading were significantly greater than those produced by both the moment and vertical loading.

1 INTRODUCTION

The first generation gravity platforms in the North Sea were installed in water depths of 70 to 150 m. They had vertical foundation skirts about 4 m long. For deepwater conditions, the new platform concepts use skirts with length up to 35 m. The purpose of these long skirts is to improve stability and reduce and control platform settlements and motions. The magnitude and distribution of the soil stresses on the skirts are important for three reasons: to ensure that a successful transfer of the lateral loads to the stronger bearing soil is possible, to enable a sound structural design of the skirts, and to optimize the resistance and dimensions of the skirts.

A number of investigators have evaluated the reaction stresses on foundation skirts using finite element analyses (Lam et al., 1987; Lacasse and D'Orazio, 1988). These analyses (especially three-dimensional analyses) are tedious and expensive. This paper outlines a relatively straightforward hand-calculation which can be done to estimate the stresses in cases where it is not practical not to do a finite element analysis.

The method shown is based on the results of finite element analyses performed by Lacasse and D'Orazio (1988). The method is illustrated by an example calculation of the reaction stresses acting on the gravity platform shown in Fig. 1. The reaction stresses produced by the horizontal, vertical and moment loads are calculated separately and can be added together to obtain the total stresses distribution, if the soil and structure behave in a linear elastic manner.

The example platform studied had nineteen separate skirt compartments with 4 m embedded skirt length and 20 m diameter (D). The submerged weight of the platform was 2000 MN and the horizontal wave loading was 510 MN. This horizontal wave loading produced an overturning moment loading of 20,400 MNm at the foundation base level. The soil had an undrained shear strength (s_u) of 150 kPa and a stiffness ratio E/s_u of 400 (where E is Young's modulus of elasticity). For this problem, the skirts were assumed to be rigid.

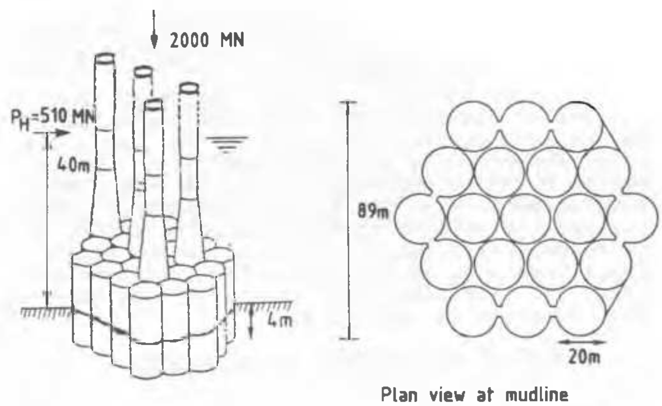

Figure 1. Sketch of platform and skirt configuration.

2 REACTION STRESSES TO HORIZONTAL LOAD

Three types of stresses resist horizontal load: 1) shear along the outer sides of the platform skirts, 2) shear along the platform base, and 3) stresses normal to the skirts.

2.1 Side shear

The side shear is computed by assuming that half of the soil strength is mobilized. The following equation can be used:

$$S_S = (R_S)(s_u)(L_S)(L) = [0.5\cdot 150\cdot 100\cdot 4] = 30 \text{ MN}$$

where S_S = Total side shear resistance
R_S = Strength mobilization factor
s_u = Undrained shear strength of soil
L_S = Total outer side length of skirts
L = Embedded length of skirts

2.2 Base shear

The finite element analyses performed by Lacasse and D'Orazio (1988) determined that the shear along the base is influenced primarily by the length to diameter ratio of the skirt compartments. This relationship is shown in Fig. 2. For the platform considered, this ratio is:

$$L/D = (4m)/(20m) = 0.2$$

For rigid skirts, $\Delta/L = 0$, where Δ is defined in Fig. 2. The base shear in that case is 7%. The total load taken as base shear is then 34 MN. This leaves 446 MN to be resisted by normal stresses acting on the skirts.

2.3 Normal stresses

The actual numerical calculations are too lengthy to be presented in this paper. Instead, a series of figures and text descriptions are used to outline the method.

In earlier analyses, it has been found that the stress distribution in the horizontal plane varies as a cosine curve, due to the nearly circular shape of the platform footprint. This cosine curve is approximated by the step function shown in Fig. 3. For the purpose of evaluating the effects of the horizontal force, it is conceptually easier to visualize the skirt compartments as rectangles rather than circles (Fig. 3). The total load resulting from the step function is also given.

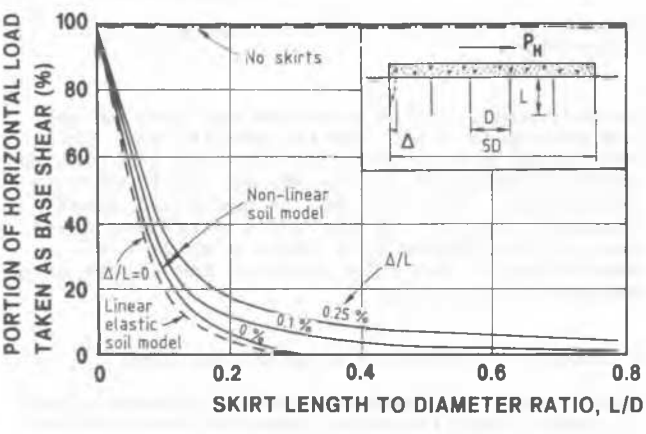

Figure 2. Shear on platform base due to horizontal load (Lacasse and D'Orazio, 1988).

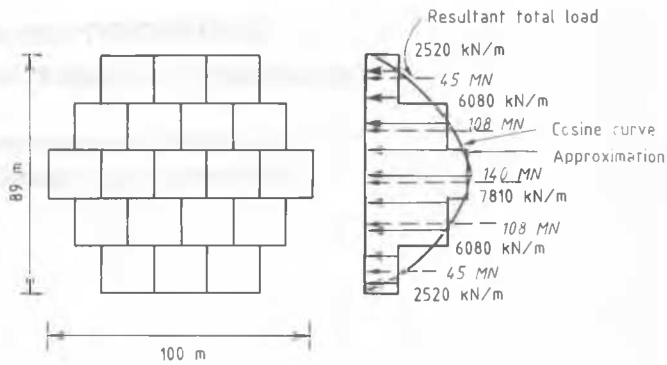

Figure 3. Step-function approximation of horizontal load.

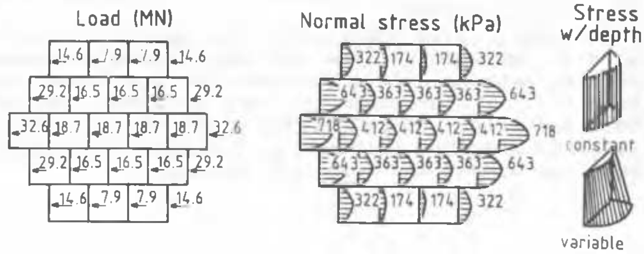

Figure 4. Load and stress distribution on each skirt due to horizontal load.

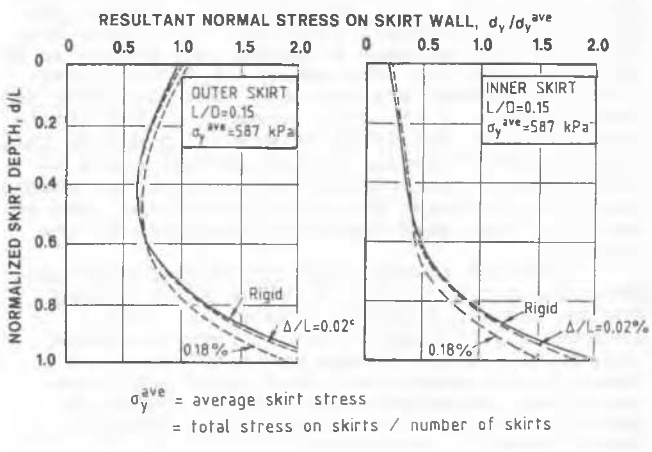

Figure 5. Stress distribution on skirts with depth due to horizontal load (Lacasse and D'Orazio, 1988).

The loads are then distributed to each skirt (Fig. 4), based on results reported by Lacasse and D'Orazio (1988). For L/D = 0.2, an outer skirt takes approximately 1.38 times the average skirt load for that section, and an inner skirt takes about 0.79 times the average skirt load for that section.

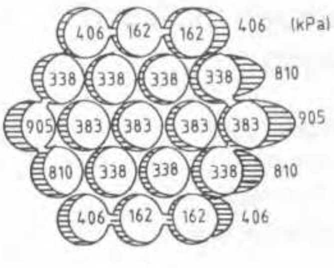

Figure 6. Stress distribution at d/L = 0.8 due to horizontal load.

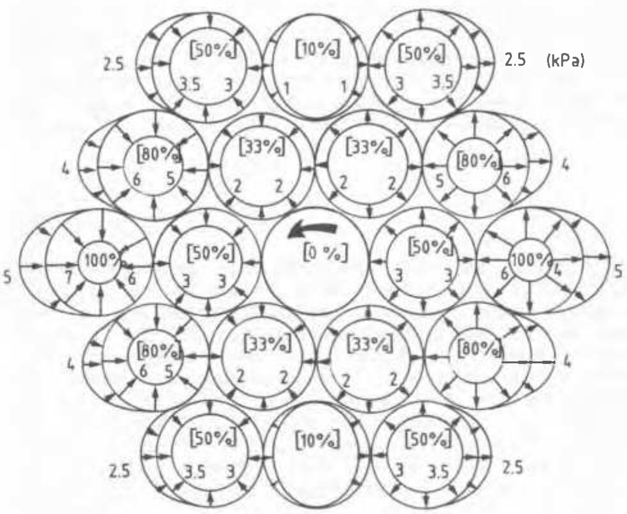

Figure 7. Stress distribution at d/L = 0.8 due to overturning moment.

Each skirt resists the loads shown in Fig. 4 by distributing them over their length and depth. This distribution takes a cosine curve shape where the area under the cosine curve is equal to the load. The shape also varies with depth, but this is difficult to compute directly so an intermediate step is shown in Fig. 4. This figure shows the stress distribution if it were assumed to be constant with depth.

In reality, the distribution looks approximately like that shown on the right side of Fig. 4. The actual numerical values of distribution with depth are obtained from Fig. 5 which was developed from finite element analyses done by Lacasse and D'Orazio (1988). This gives a complex stress distribution in three dimensions which cannot be easily shown in one figure. Instead, Fig. 6 shows the distribution at a depth of 3.2 m. A complete picture of the stress distribution can be obtained by plotting results similar to those shown in Fig. 6 for other depths.

3 REACTION STRESSES TO OVERTURNING MOMENT

The rotation caused by moment loading produces an increase in the vertical stress at the base soil contract on the leeward side of the platform, and a reduction in the vertical stresses on the windward side. This produces corresponding increases and reductions in the normal skirt stresses. These changes are related primarily to the distance from the axis of rotation. The greatest normal stresses occur on the outermost skirt compartment.

Figure 7 gives the stress distribution at d/L = 0.8. The data are based on the theoretical distributions reproduced in Fig. 8. The magnitude of σ_y^{ave} is obtained from:

$$\sigma_y^{ave} = M/(\pi \cdot 2R^3) = 20400/[\pi \cdot 2 \cdot (94.5)^3] = 3.9 \text{ kPa}$$

This is not considered to be a significant stress, but the calculations are shown as an example so the reader can determine if the stresses are significant in other cases.

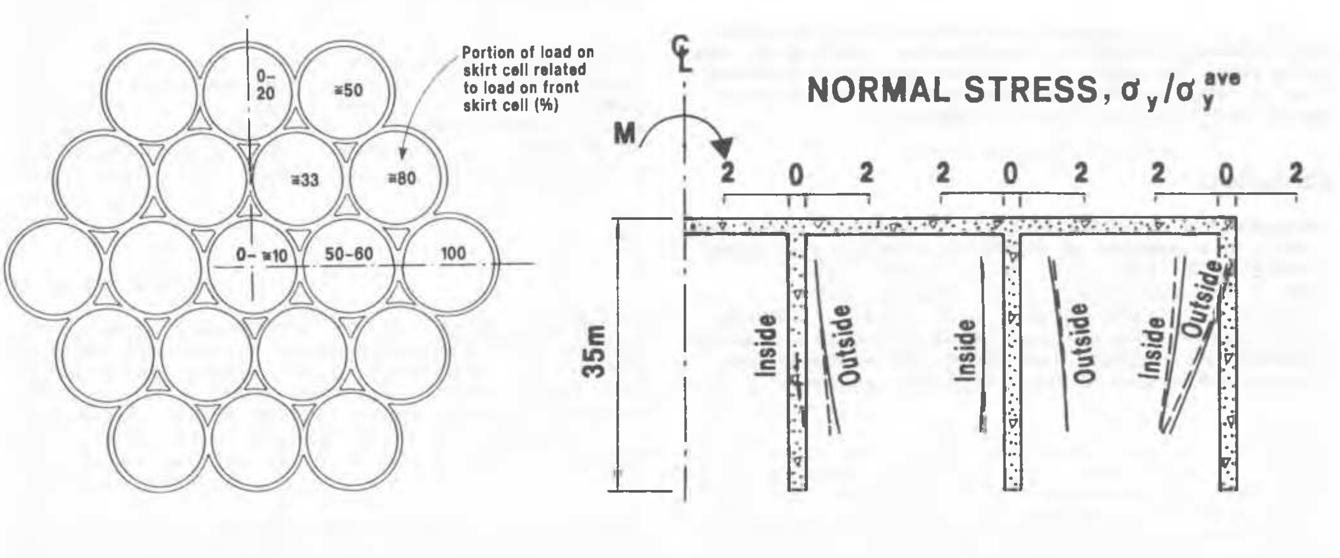

Figure 8. Theoretical stress distribution due to overturning moment (Lacasse and D'Orazio, 1988).

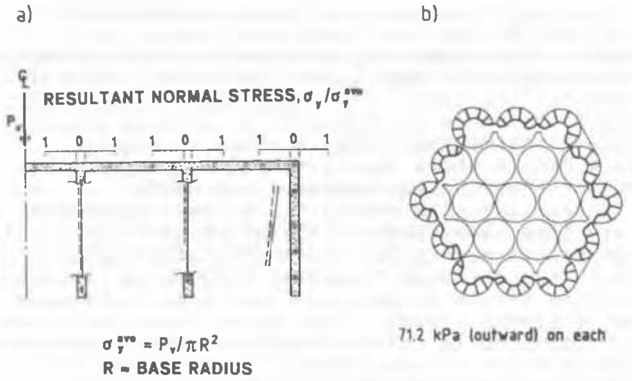

Figure 9. Stress distribution due to vertical load.

4 REACTION STRESSES TO VERTICAL LOADS

The stresses on the skirts caused by vertical loading are only significant on the outer part of the outer skirt compartments. This is because the horizontal stresses on the inner skirts cancel each other out, leaving nearly no net stresses. Figure 9a was developed by Lacasse and D'Orazio (1988) and serves as the basis for determining the stresses at d/L = 0.8 in Fig. 9b.

5 CONCLUSIONS

The stresses shown in Figs 6, 7 and 9b can be added together to determine the total stresses acting on the skirts. This cannot be done in cases where the soil is expected to behave nonlinearly.

The example calculation in the paper shows that previously done finite element analyses can be used to estimate the stresses on skirts caused by horizontal, vertical, and moment loading. For the case considered, the horizontal loading produced the greatest portion of the stresses, the vertical loading porduced substantially less stress and the moment loading produced only insignificant stresses.

REFERENCES

Lacasse, S. and D'Orazio, T.B. (1988). Soil reaction stresses on offshore gravity platforms. ASCE, JGE, Vol. 114, No.11, (Nov. 1988).

Lam, I.P., Pelletier, J.H., Murphy, B.S., Sgouros, G. and Cheang, L.C. (1987). Design for lateral skirt resistance of Arctic gravity platforms. Sixth Int. Symp. Offshore Mechanics and Arctic Engg., Houston, Texas.