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Autor: Warland, Terje Aas / Gudmestad, Ove T. / Hove, Knut
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Offshore Structural Concrete

Béton armé des plateformes pétrolières

Offshore Konstruktionsbeton

Terje Aas WARLAND
Civil Eng.
Statoil a.s.
Oslo, Norway

Terje Aas Warland who obtained his civil engineering degree at the Technical University of Hannover spent eight years with civil engineering firms in Germany and Norway. Since 1980 with Statoil. For three years responsible for Statoil Sleipner structural engineering group.

Ove T. GUDMESTAD
Dr. Sc.
Statoil a.s.
Oslo, Norway

Ove T. Gudmestad has a M.Sc. from Univ. of Tromsoe Norway and a Dr. Sc. degree from Univ. of Bergen. He has been with Statoil since 1975 where he has been involved in several projects related to offshore concrete structures.

Knut HOVE
Civil Eng.
Veritec
Oslo, Norway

Engineering training at Univ. of Wisc & Calif. With DnV since 1971 as head of design control of Ekofisk Tank and the first Condeeps. Head of development of DnV Rules Offshore. Major interests: deepwater structures and earthquake engineering.

SUMMARY

This report deals with design and dimensioning methods related to North Sea offshore platforms. Post-tensioning, shear and fatigue in connection with high strength concrete in particular, are assessed. Results from in-situ tests taken from slip are discussed and compared with results regarding bond behaviour of bars in slipform casted concrete.

RÉSUMÉ

Ce document traite les méthodes de dimensionnement et de conception des plateformes pétrolières de la Mer du Nord. Les modes de précontrainte, le mode de cisaillement et la fatigue relatifs au béton à haute résistance sont tout particulièrement traités. Des résultats d'essais in situ réalisés sur les structures érigées suivant la méthode du coffrage glissant sont discutés et comparés avec ceux concernant le comportement d'adhérence de barres d'armatures contenues dans des structures coffrées selon la même méthode.

ZUSAMMENFASSUNG

Dieser Artikel befasst sich mit Berechnungs- und Bemessungsverfahren für Offshore-Plattformen in der Nordsee. Insbesondere werden die Vorspannung, Schub und Dauerfestigkeit von hochfestem Beton behandelt. Es werden Ergebnisse von Baustellenversuchen zum Verbund von Bewehrungsstäben im mit Gleitverfahren hergestellten Beton diskutiert.

1. INTRODUCTION

Design of concrete structures for use in offshore petroleum production involves detailed analytical investigation of complex shell structures subject to dynamic loading from waves and also seismic action. A detailed knowledge of the dynamic response, the local distribution of forces and stresses and resistance to failure in fatigue as well as the ultimate load carrying capacity is therefore of paramount importance.In order to cover these aspects refined global finite element analyses using shell or solid element models are generally required, the results from which must be scaled to cover the structural dynamic response which is determined by use of stocastic methods.

The Sleipner A platform /4/ for 82 m water depth in the North Sea incorporates new features in concrete design and analysis. This platform with a volume of 74000 m^3 of concrete is presently being constructed in Stavanger Norway. Slipform construction is used for the cells and the shafts. The top of the shafts has a near rectangular form to suite the supports of the Modul Support Frame (MSF). This is well covered in the analyses of the structure. The near rectangular top of shafts will be slipformed through application of new slipform technology.The conventional steel transition rings between the MSF and the shafts are eliminated as the steel MSF is placed directly on the concrete shaft. Furthermore the deck is supported on only two, respectively three, supports on each shaft resulting in savings in steel for the MSF. To absorb the high compression forces incurred by few supports and to optimize the design of the walls and the shafts, high strength concrete with quality C65 is necessary.The entire cells up to a level of 48 m are constructed in dry dock. To get sufficient buoyancy out of dock, the four foundation areas are cast in light weight aggregate concrete LC65.

In the following chapters bond strength for slipformed concrete structures will be discussed as well as dimensioning of post-tensioning and application of T-headed bars in cell walls. Shear and fatigue aspects are furthermore reviewed.

2 CONCRETE STRENGTH

2.1 Design strength of concrete

The design strength of concrete should correspond to the concrete strength as obtained in the structure (structural strength) reduced by an appropriate factor of safety to account for undertainties in material characteristics, quality of construction and uncertainties related to prediction of capacity and mode of failure /5/.

The format for the design strength used in the Norwegian concrete design code NS3473 /10/ refers to "structural strength" and differs in this way from the CEB-FIP format. However, the design value is close to that of CEB-FIP 1990.

The grade of concrete - eg C60 - refers in some codes to the cube strength (eg. NS3473) and in others to the cylinder strength. (eg. CEP-FIP, ACI318 and CAN3-A23.3). Uniformity on this simple point is welcome.

2.2 Effects on strength from slipforming

Slipform construction has long tradition. For tower type structures slipforming has been common. Since 1971 slipforming has been used for construction of large offshore structures in the North Sea. The Sleipner A platform described in /4/ which has been in construction since 1989, is shown in Figures 1 and 2.

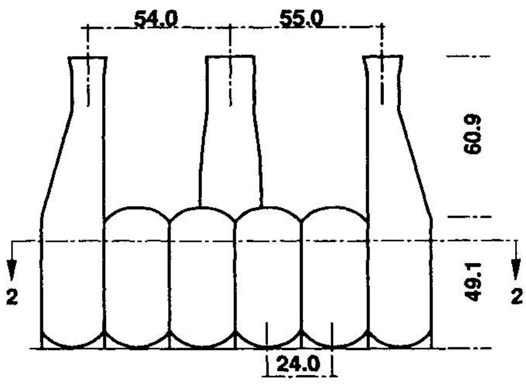

Fig.1 ***SECTION 1-1***

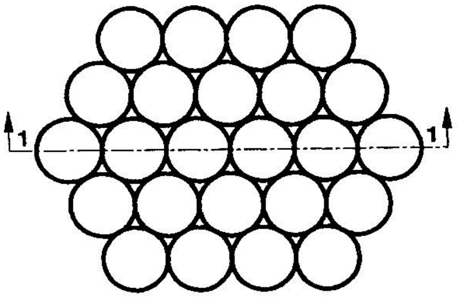

Fig.2 ***SECTION 2-2***

The slipform construction employed for offshore platforms has given high quality well compacted concrete. In /5/ the result of in-situ tests of 1042 cores and 808 cubes from 3 platforms are described. The concrete compressive strength was 5 to 10% higher than for none slipformed parts. There were no indications that the tensile and bond strength should not follow the compression strength. Tests of bond strength of concrete from slipformed structures in Germany, indicate the opposite results. /6/ . The conclusion of the German tests is that the ratio of the computed bond lengths (slipform/ordinary formwork) was found to be 2 for vertical bars and 4 for horizontal bars.

The different results in Germany and Norway indicate that the quality of concrete may be sensitive to the slipform technique. The effective bond length will depend on workmanship and slipform technique as well as wall thickness and specific weight of the concrete.

Statoil is, however confident in using slipform construction with the high quality control of the work maintained for construction of the North Sea structures.

3. PRESTRESSING

Prestressing has been used in the construction of all North Sea concrete structures. The advantages of using prestressing are listed in /2/. Of special importance for offshore platforms is the possibility to reduce structural dimensions and to limit crack widths. According to Statoil requirements, cracks are limited to 0,15mm in the splash zone and 0,30 mm in the submerged zone. Prestressing will also improve the fatigue resistance, due to the better fatigue resistance of the concrete when only exposed to compression.
Global forces (membrane tension) are covered by prestressing imposed by post-tensioned tendons and also by hydrostatic loading. Local moments are taken up by normal reinforcement. Cables are typically located at top and base of shafts and in the ringbeam in the upper and lower domes. Normally, the shafts are also prestressed vertically.

NS 3473, does not prescribe different computational methodology for ordinary reinforced and prestressed concrete. The problems with different design methods for ordinary reinforced and prestressed concrete are thus eliminated, see /1/ and /2/. In determination of capacity in flexure and combination of flexure and membrane action the residual strength of the prestressing steel (the top part of the stress-strain curve not utilized for pretensioning) may be used. This may in many cases, especially for heavy shell structures lead do considerable savings in ordinary reinforcement and avoide congestion of reinforcement. Thus, ensuring better concreting and a better structure.

4. SHEAR

Regarding the Sleipner A platform, several locations are exposed to high shear forces requiring shear reinforcement; the transition areas between the domes and the cell wall as well as in the so called star walls, see Figure 2.

The determination of shear capacity varies between most codes. Also the value of load and material factors are treated differently in the most codes. A comparative study of the shear capacity from the concrete is reported in /8/. According to NS3473 the shear capacity can be calculated by a simplified method, by the truss model method or by a general method for inplane shear. The truss model method is less used in the design of offshore concrete structures. It was first included in NS 3473 in the 1989 edition. The practical use of it in computerized design is more complicated than the simplified method due to the necessity of having in principal one truss model for each load case and the general complexity of the method.The simplified design method given in NS 3473 is partly modifications of the CEB/FIP Model code 1978. The tensile strength is by NS3473 lower than by CIB/FIP Model code 1978 for high strength concrete, /7/.

Shear tests reported in /7/ show that NS3473 predicts well the variation of the diagonal cracking strength for beams with different types of high strength concrete.The determination of ultimate shear strength for high strength concrete above a cylinder strength of 80 MPa is however less well defined. Results reported in /7/ show that shear capacity of high strength concrete beams is more influenced by the scale than beams of normal strength. The more brittle behavior of high strength concrete and the lesser aggregate interlock due to fracture of the aggregate may be part of the reason for reduced shear strength. Further work appears necessary on this subject.

Results reported by M.P.Collins /9/ from a series of thirty-one tests involving concrete panels reinforced in only one direction and loaded in various combinations of tension and shear, provide most valuable information.Use of Collins modified compression field theory on available test results show that the existing reinforced concrete design codes typically are very conservative in their estimate of the shear strengt of elements subjected to combined tension and shear.The modified compression field theory represent the state of the art. The theory takes into account the contribution of the concrete aggregate interlock mechanism in a rational manner. However, as discussed in /3/ the method appears complicated since there is no simple procedure for obtaining transverse strain.
A rational and simple method to predict shear compression and tension based on M.P. Collins theory should be developed in order to get a simple, accurate and economical dimensioning method for shear.

5. FATIGUE

The subject of resistance to fatigue of structural concrete to random loads was first codified in DnV Rules for Offshore Structures 1977. Through joint industrial R and D projects, S-N curves were established for reinforced concrete, normal weight (NW) and light weight (LW) in compression - compression and tension - compression, including the effects of water. During the last 10 years considerable advancement has been made on the subject in terms of refinements of the S-N curves as the data base has been expanded.

At present fatigue of structural concrete is covered in two design codes - i.e. CEB-FIP Model Code 1990 and in NS3473 - for the following modes of loading:

- compression - compression
- compression - tension
- tension - tension

Procedure for estimating the fatigue life for transverse shear and bond based on extrapolations of the unaxial test data are also given. The S-N curves given in CEB-FIP 1990 and in NS3473 differs in some respect. A main difference is the way the stress range or rather the minimum stress is introduced. The NS3473 has also introduced an endurance limit, while the S-N formulation of CEB-FIP assumes a straight S-log N relation.The calculation procedures given in NS3473 is basically a further development of the DnV-77 method, and it is in some respect more detailed than the procedure of CEB-FIP 1990.Recent Norwegian tests on air dry and wet high strength concrete specimens - normal density and light weight tested in cyclic compression are reported in /13/. It is noted that the natural moisture contained in sealed concrete is enough to reduce the fatigue strength to that of wet concrete. Recommended S-N curves including endurance limits for various levels of minimum stress are given in /13/ for concrete in compression. The state of the art is reported in /14/.

Test data and improved computational models should be developed for the following areas:

- out of plane shear action
- 2D cyclic action alternating in tension-compression
- local 3D effects in joints including reinforcement detailing.

6. T-HEADED STIRRUP BARS

Structural elements subject to high out-of- plan shear and those needing confinement for ductility in the post-elastic range require concentrated transverse reinforcement. The traditional hoops of bent stirrups are difficult to place, especially if the tails must be bent back into the core. These conventional stirrups are also relatively inefficient.A T-headed bar with plate anchor at the ends has therefore been developed for use as transverse shear reinforcement. The use of T-headed bars is cost efficient compared to stirrups.Tests described in /11,12/ show these bars to have excellent anchorage under ultimate loads, providing exceptional confinement and ductility to the member, with test specimens yielding displacement ductility factors of over 40. Also tests have indicated that confining effects from T-headed bars have yielded enhancement of concrete strength in the order of 10% as compared to the use of 90° hooked bars. As to the use of 90° hooks these will open up during ultimate strength situations and loose its capacity. Use of 90°- hooks should be limited to ø 12 mm bars.

Structures to be used in the arctic must withstand intense punching shears from the impact from sea ice and iceberg. Offshore structures must withstand the impact from boats and barges, and the base slab and other connecting elements of offshore platforms may have to resist high shear from concentrated reactions. Other extreme load effects that may have to be considered are large earthquakes, explosions, or impact from falling objects. To provide the required strength and ductility the percentages of transverse steel may reach 1.5 to 2.5 % (15000 to 25000 mm^2 /m^2). Such reinforcement percentage can only be provided by use of heavy bars fully anchored.

Use of T-headed bar is an effective and structurally reliable method of providing transverse reinforcement to resist shears and to provide confinment of the concrete core. T-headed bars have been used in the North Sea offshore structures, the Gullfaks A and Sleipner A and the Ekofisk Protective Wall.

7 CONCLUSIONS

Slipformed high strength concrete is an excellent material for constructing of offshore platform support structures.

REFERENCES

1. BREEN J.E., Why Structural Concrete.Introductory Report, IABSE Collegium Structural Concrete 1991 Stuttgart.

2. BRUGGELING A.S.G., An Engineering Model of Structural Concrete, Introductory Report, I.B.S.E Collegium.Structural Concrete 1991 Stuttgart.

3. MACGREGOR J.G., Dimensioning Detailing, Introductory Report, IABSE Collegium Structural Concrete 1991 Stuttgart.

4. GUDMESTAD O.T.G., and COKER J.W.A., The Sleipner Platform: An Efficient Gas and Condensate Installation. SPE European Petroleum Conference, London 1988.

5. HAUG A.K. and JAKOBSEN B., In-Site and Design Strength for Concrete in Offshore Platforms, Second International Symposium on Utilization of High Strength Concrete, San Francisco 1990.

6. DEUTCHER AUSSCHUSS FÜR STAHLBETON, Heft 378, Test on the Behavior of Deformed Bars in Slipform Concreted Structures, Berlin 1986

7. THORENFELDT E. and DRANGSHOLT G., Shear Capacity if Reinforced High Strength Concrete Beams, Second International Symposium on Utilization of High Strength Concrete, San Francisco 1990.

8. LEIVESTAD S, VIK B., EKEBERG P.K., The Utilization of High Strength Concrete, a Survey of international Codes and Regulations, International Symposium on Utilization of High Strength Concrete, Stavanger June 1987.

9. BHIDE S.B. and COLLINS M.P. Reinforced Concrete Elements in Shear and Tension University of Toronto, Publication no 87-02.,ISBN 0-7727-7089-1.

10. NORGES STANDARDISERINGSFORBUND: NS3473, Prosjektering av betongkonstruksjoner. Beregning og konstruksjonsregler, 1989.(English version to appear).

11. Gerwik, BenC, Inc. Pheripheral Concrete Wall design Optimization Study - Phase II, Standard Oil Production Company Sponsor AOGA, NO 324, 1987.

12. Hove, Knut, "Ductility Performance of Offshore Concrete Structures" Joint Industry Project (Høvik Norway). Subrestricted D- Column Tests - C90 Concrete, Veritec Report No 86-3689 Vol. 1 and 2, 1987.

13. Gordon Pethovic, Rolf Lenschow, Hans Stensland and Svein Rosseland "Fatigue of High Strength Concrete". Second Symposium on High strength concrete" University of California, Berkely May, 1990.

14. CEB Bulletin No 188 "Fatigue Strength of Concrete Structures" state of the art report 1988.