Synthesis and conclusions

Autor(en): **Bouwkamp, J.G.**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **10 (1976)**

PDF erstellt am: **25.04.2024**

Persistenter Link: https://doi.org/10.5169/seals-10536

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Synthese und Schlussfolgerungen

J.G. BOUWKAMP
President
Offshore Development Engineering, Inc.
Berkeley, California U.S.A.

Offshore Structures

Mr. Chairman, Ladies and Gentlemen,

We have just heard some additional highly interesting discussions on the subject of offshore structures which further emphasized the complexity of operating in offshore regions.

We would make a serious mistake if we would consider this field as an exclusively structural engineering territory. There is no question that the structural engineering input is of vital importance in developing an ultimately satisfactory structure. However, offshore engineering design requires the input of the oceanographer, who defines the sea state; the ocean engineer, who translates the ocean environment into hydrodynamic loads; the naval architect, who considers the stability and platform motions of both floating drilling and production systems and offshore towers during the towing and upending phases; the geotechnical engineer, who provides the necessary data to develop the foundation design; and the fabricator or contractor, who ultimately creates the system.

Each of these areas represents a challenge to the expert:

Variability and Environmental Influence on Wave Conditions

Most design wave spectra are based on open sea observations or at least, observations taken in areas of relatively open water. Since sea conditions can be strongly affected by bottom and shore topography, some attention should be given to ascertaining how such factors may modify wave conditions in a specific design condition, and to sensitivity studies which are aimed at finding the effect on a structure of anticipated variations about the design wave conditions.

Interaction of Wind Velocity Profile and Waves Impinging on a Structure

If a structure is exposed to storm waves of height similar to the dimensions of the above-water portion of the structure, the wind velocity profile and wind force acting on the structure vary with time. This wave influence on the design wind characteristics will be superimposed on the natural gustiness of the storm wind environment and undoubtedly have an influence on both the mean and time dependent wind forces.

Correlation and Proper Simultaneous Treatment of Waves and Current

Important questions here involve the appropriate way of representing the combined flow field and the computation on bodies exposed simultaneously to waves and currents.

Hydrodynamic Loadings

Hydrodynamic loads, acting on the emerged structural members, are a result of the fluid motion associated with waves and current, and of the body motion induced in response to these forces, as well as earthquake and other external excitation. The combined structure-fluid motion effects are referred to by the terms "fluid-structure interaction" or "relative motion effects". The prediction of these fluid forces requires the solution of the complete fluid equations of motion (Navier-Stokes equations) with complicated boundary conditions, including the free surface, moving rigid boundaries of the structure, and the fixed boundaries, e.g. the ocean bottom. Complete solutions of this problem have been obtained in only a few elementary cases, and often substantial simplifications to the problem have been made. In the case of bodies whose dimensions are of the same order as the wave lengths, viscous forces are greatly exceeded by inertia forces, and may therefore be neglected in determining both the flow kinematics and the forces on the body. For bodies of small cross-section compared to the wave length, the pressure, velocity and acceleration field associated with wave motion is assumed unaffected by the presence of the body. The viscous drag forces and inertia or pressure forces are computed, using these kinematic quantities combined with imperical drag and inertia coefficients; the so-called Morrison formula. However, there is a range of body sizes in which both diffraction and viscous effects are important. It is in this area that a thorough understanding of the relative importance of these effects is essential. Furthermore, members which pierce the mean water surface are subjected to some other forces. These are the time-varying buoyancy and impact or slamming forces. The former is determined by geometric consideration, but the latter is not well understood at present. The wave impact force on above water structural members is similar to the slam force on a ship pitching in heavy seas or the impact of a seaplane when landing. However, it is necessary to recognize the differences between the phenoma which apply on the one hand in the case of a moving body contacting a moving wave surface, and on the other hand, a moving wave impinging on an essentially fixed body.

Wind Loading

Wind action on offshore platforms can contribute significantly to design loads. To evaluate the magnitude of wind loads, it is necessary to first predict the nature of the wind produced at the site, in terms of maximum mean wind velocity and the fluctuation of the wind velocity about this maximum mean value, i.e. gust characteristics, and second to transform these velocities into drag forces. Thi transformation is difficult to achieve realistically due to the very irregular geometry of the platform and its equipment. Conceptually, the wind force transfer function can be characterized as depending on the altitude and air density, time velocity direction characteristics shape and effective area, motion response characteristics of platform, projected area, and variation of the force with velocity.

Ice Loadings

Ice loading on offshore platforms in the Arctic seas can be extremely severe. Ice islands and icebergs, which are of land origin, can easily destroy a platform. Fortunately this danger is limited since these are rare; therefore, no consideration of their effects is given in the design of offshore platforms. On the other hand, sea ice is frequently present and must be considered in the design. This ice, which forms in sheets, can be pushed into ridges, rafts, and hummocks, producing unconsolidated masses which later consolidate upon refreezing. The depth of this ice is highly variable, causing similar variations in the magnitude of force exerted on offshore platforms. This maximum force is limited by failure conditions at the edge of the ice mass; therefore, its magnitude depends on (1) the contact area, as determined by the thickness of the ice sheet and the maximum width of indentation caused by the structure during impact, (2) the aspect ratio of ice thickness to width of structure, (3) the shape of the structure, (4) the strength of the ice in unconfined compression, (5) the elastic properties of the ice, and (6) the conditions of ice as unfrozen or frozen, to the face of the structure.

Soil Loadings

Soil loadings can result from lateral and vertical loadings on foundation elements and develop rapidly, as a result of soil deformations in which the instantaneous and/or accumulative relative deformations are large. Such deformations could be developed from bottom soil movements induced by wave action, earthquakes and other similar flow slides or combination of the same. In addition, settlements, both laterally and vertically can occur during long periods, and may affect the foundation stability over the long time.

Earthquake Loadings

The earthquake loading is similar to the other principle loads acting on offshore structures in that the intensity of loading is influenced strongly by basic characteristics of the structure. However, in the case of the earthquake loading, the input forces depend on the mass and stiffness of the structure rather than on the exterior form, and by adjusting these parameters, particularly the stiffness, the designer can exert a great influence over the seismic loads a structure must resist. This fact is particularly significant in regard to the non-linear behavior of an offshore structure, because damages which occur in the structural system generally lead to reductions of stiffness which allow relaxation of the seismic input intensity. Thus, to a significant extent, earthquake damages tend to be self-limiting processes and the primary concern of the designer is to insure that the vertical load capacity of the structure is maintained as the earthquake damages occur.

Structural Modeling

With the loads defined, a mathematical model of the structural system must be established to permit the three-dimensional analysis of the internal forces and stresses. In the event of high overloads, such as produced by high magnitude earthquakes, this model must properly reflect the inelastic deformations produced. Further, in the interest of providing a suitable working environment, motion of the deck must be predicted realistically. Only through refined and advanced analytical procedures and modeling techniques is it possible to accurately predict the structural response.

Foundation Modeling

To realistically model fixed platforms for three-dimensional analysis purposes, it is necessary that the foundation be properly modeled so that the structure-foundation and direction effects will be included in the results. As in the case of structural modeling, the techniques and methodologies used for this purpose vary considerably in practice. Basically there are three basic forms of foundation modeling for spread footings or mat foundations, namely: (1) constant discrete springs and dashpots for the soil foundation with the spring constants determined from elastic-static half-space theory and the dashpot coefficients having assigned values to represent material damping in the soil, (2) discrete springs and dashpots for the soil foundation with the spring constants and dashpot coefficients being frequency dependent in accordance with the elastic or viscoelastic dynamic half-space theory, and (3) finite element representations of a body of soil at the base of the structure. Foundation modeling for fixed towers supported on piles is most difficult to accomplish realistically. The techniques and methodologies used for this purpose range widely in practice, the simplest form being that of assuming full fixity for the piles at some specified effective depth in calculating lateral stiffness and assuming a distribution of the vertical load transfer from the pile to the soil in calculating vertical and rotational stiffnesses. For firm foundation conditions, the forces applied to the pile cap will be rapidly transferred to the soil with increasing depth into the foundation. In this case, pile cap impedance functions can be approximated using the impedance functions generated for a rigid massless circular disc supported on an elastic or viscoelastic half-space. For softer foundation conditions, the forces applied to the pile cap are transferred to the soil at deeper depths; thus, a more realistic representation of the load transfer from piles to soil is needed. This problem is a topic of basic research at the present time which should yield suitable pile foundation models in the near future.

Analysis Procedures

Dynamic analyses of linear fixed towers can be carried out in either the time domain or the frequency domain. Most analyses of this type, carried out in the past, have used the time domain approach. Recently, however, the frequency domain approach has become comparative through the development of Fast Fourier Transform techniques. If frequency dependent parameters are included in the overall fluid-structure-foundation system (e.g. frequency dependent hydrodynamic drag and inertia coeffecients and/or frequency dependent foundation impedance functions), a time domain solution is not possible, but the frequency domain approach can be used without difficulty.

Performance Criteria

In addition to general loading methodologies and structural and foundation modeling techniques, other criteria related to the detailed structural response (e.g. fatigue, non-linear behavior, failure) are equally essential in the design process. Based on his experience in fields other than offshore engineering, the structural engineer is particularly qualified to establish detailed prototype response criteria for both elements, connections and material properties. Furthermore, the overall design may not only be governed by the ultimate performance aspect, but also by the behavior of the structure during the different phases of construction, tow-out and installation. In the past, these latter phases have been considered as structurally less significant than the actual design phase. However, present offshore developments require structural systems for water depths of 800 to 1,000 feet or more. The remoteness of these regions may require tows covering several thousands of miles between assembly yard and installation site. Also, upending processes at the installation site necessitate a careful assessment of the dynamic response during this stage. It is now essential not only to consider the platform stability, but also the dynamic structural response during these tow-out and upending phases. This aspect becomes particularly significant if one considers the duration of these tows under potentially most adverse weather conditions and the often hostile prevailing sea state at the site. Damages during this phase, be it permanent or of fatigue nature, are factors which need full consideration in formulating the final design.

The previous comments emphasize that offshore structural design reflects the combined effort of many engineering disciplines. To achieve an optimum design for both stationary and floating structures in a mostly hostile, highly random and often insufficiently known environment, requires an integrated approach involving the most advanced technologies.