Offshore structures

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Objekttyp: **Article**

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

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

PDF erstellt am: **12.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-10532

Comments by the Author of the Introductory Report

Remarques de l'auteur du rapport introductif

Bemerkungen des Verfassers des Einführungsberichtes

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Offshore Structures

Mr. Chairman, Ladies and Gentlemen,

The contributions to the theme, Offshore Structures, as published in the Preliminary Report, covered not only general design aspects of both steel and concrete structures, but also focused on at least one of the more significant design details, namely tubular joints.

The contributions by Roret and Ciolina on steel structures, and Gerbault and Xercavins on concrete structures, give an up-to-date general review of several structural systems which have been developed for the exploration and production of hydrocarbon deposits in offshore regions. Unfortunately, space limitations prevented discussion in depth of detailed technical problems associated with the design, construction and installation of these structural systems. Most problems are related to the dynamic behavior of the structures under the effects of waves, currents, wind, ice and earthquakes, and require full consideration of the soil-foundation-structure-fluid interaction. For instance, soil conditions are a major factor in evaluating both the short- and long-term dynamic response of gravity platforms under cyclic, wave-induced loads. Equally significant is the dynamic behavior of steel tubular trusses and their connections under such load conditions. In addition to the response to extreme waves and winds, earthquakes are another important factor. One of the most significant elements in the structural design of steel tubular trussed towers is the tubular joint. It was, therefore, particularly fortunate that the contributions of Kurobane, et al, and Okumura, et al, were addressed to the performance of tubular joints. In light of my own experience in this subject, I would like to focus on this particular aspect in greater depth. However, first I would like to note the contributions by Shimada and Yamamoto, and Coulard. Although the authors focused on harbor and coastal structures, rather than offshore structures, they do draw attention to the fact that offshore developments are not complete without the necessary onshore facilities for equipment maintenance and transfer of oil and gas to shore.

The history of tubular joint fatigue research goes back almost twenty years. At that time the primary focus was directed towards developing joint design criteria which would assure the overall structural integrity of a tower structure under extreme wave and wind conditions.(1,2,3,4) These criteria reflected the environmental conditions in the relatively shallow waters of the Gulf of Mexico where extreme waves were the critical design condition. The resulting design criteria based on the "punching shear" strength concept resulted in joints which were capable of withstanding these extreme load conditions, even when applied for a limited number of loading cycles. Consequently, in the initial studies, consideration was given to the low-cycle fatigue resistance of these joints. The design was typically a jacket-type multi-legged trussed tower with tubular members. Joints normally consisted of 42 to 48 inch diameter column members and tubular brace members of approximately 16 to 24 inches in diameter. The design of these joints was typically based on extreme load conditions which would produce a nominal stress reversal in the diagonal members of 28 ksi.

These studies readily indicated that the flexibility of the column member wall was the main source of stress concentrations and consequently resulted in early fatigue failure; "hot spot" stresses were identified. In order to stiffen the column wall, one considered increasing the column wall thickness, using external ring stiffners or in-plane gusset plates, or possibly, overlapping and interwelding the web members.(5,6,7,8,9) Comparative studies clearly indicated that a joint with a thickened column wall and non-overlapping web or branch members was superior from the point of view of strength and low-cycle fatigue resistance. These initial studies successfully guided the design of tubular joints under these particular environmental conditions (extreme waves). However, these design rules became inadequate where offshore developments moved into more hostile regions. Not only the extreme sea state, but also the repeated cyclic low-forcing wave effects became significant design considerations. Hence, a more general approach to fatigue and cumulative fatigue damage became necessary.

Comparative studies of the type noted before could no longer provide sufficient input to determine the structural response resulting from the broad load spectrum which now had to be considered in design. Consequently, other theories and their applicability had to be evaluated. Miner's linear cumulative fatigue damage hypothesis was used in establishing the effect of cumulative fatigue damage. Equally important, however, was the need of determining the stress versus number-of-cycles, or "S-N", curves necessary to determine the ultimate fatigue resistance for given stress levels. Considering the complex environmental conditions and material response, different theories have been considered and their application to tubular joint design evaluated. In this respect, a linear-elastic fracture mechanics approach to determine theoretical S-N curves has been found to yield a satisfactory correlation between theoretically predicted and experimentally observed fatigue crack behavior.(10)

In principle, this type of approach is needed in order to develop design criteria for the many different systems which are designed to operate in the often hostile offshore regions now considered for development. The severity of the environmental loads requires a new approach to tubular joint design considering both joint strength, joint stiffness and fatigue reisitance. There is no doubt that solutions can be obtained. However, it will require the most advanced integrated approach of loading methodologies, computer modeling techniques, analysis, fabrication and material science. Not only material properties affecting the ultimate response are significant, but also the prediction of the highly complex dynamic response of offshore structures, both stationery and floating, steel or concrete. In that instance, the combined effects of waves, currents, winds, soil conditions and earthquake loadings should be fully considered. Only a highly advanced approach in analyzing the anticipated performance will provide the basis for a satisfactory design.

I noted in the last paragraph, concrete structures as well. While I did address myself to the fatigue aspect of tubular joints and the overall design requirements of steel platforms, concrete or pre-stressed concrete structures require an equally rigorous design approach. Consequently, the engineer's total understanding of the many environmental and structural performance aspects in every phase of design, is essential. Extending knowledge and performance data to structures similar in concept, but located in different environments, does require the utmost of engineering attention in order to prevent the potentially catastrophic outcome of extending the "present state-of-the-art" to new regions without full consideration of all factors involved. In that respect, I hope that the subsequent discussions and future contributions published by the IABSE on this subject may aid the profession in a field which , because of the short history and engineering complexity, requires our fullest attention.

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