I-145 TRADE-OFFS BETWEEN SAFETY AND ECONOMY OF OFFSHORE STRUCTURES

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1. Introduction

Since the implementation of a limit state design(LSD) format and because of increasing prospects for offshore resources in a harsher yet unexplored frontier, the long-postulated reliability-based structural design procedure has become a mandatory working tool rather than a state-of-the-art practice (Ref.1).

Structural design is a decision making process under the inherent uncertainties as well as risks to lives and economy. This article is prepared with the intention to describe the simplicity of the most fundamental reliability design approach as well as its versatility in the analysis of trade-offs between the two prominent design goals, namely the assessment of safety and economy.

Reliability and the trade-off analyses are carried out for the simplest but often most critical mode of failure, namely the sliding of a gravity-type offshore platform against a seismic load. The reliability of a structural system can be assessed by defining the limit state performance function, statistical parameters that describe random variables and the respective nominal conditions specified by the code. Both analyses in this paper are based on a set of rather crude assumptions. However the emphases are placed to clarify the following items of interests:

① clarify the reliability aspects in the existing LSD codes(DnV-Ref2, NBS-Ref3) and compare the results using a simple example.

② perform the expected monetary value(EMV) analysis for various values of failure probabilities(POF), and oil prices and assess the economy in terms of a present worth of sales revenue and initial/damage costs.

2. Limit State Performance Function

A structural performance with respect to a specific limit state can be investigated in terms of a limit state function g(-) which describes the marginal safety against the sliding failure at the interface with the seabed surface. When random variables are chosen to be the foundation soil friction coeffcient ($\tan\phi$) and the horizontal earthquake acceleration (A), the limit state function can be written as :

$$g(\tan\phi, A) = (Fv+Fb-Fu)\cdot\tan\phi - 0.5A(Fv+Fb)\cdot\tan\phi - (Fv+Fb+\Delta Fv)\cdot A$$

in which the first term is the frictional resistance in terms of Fv : deadweight of the structure, Fb : an additinal deadweight due to ballasting, and Fu : up lift due to displaced water, second term is the unstabilizing effect due to vertical component of the acceleration taken conventionally 1/2 of (A) and the third term is the base shear force which includes the effect of hydrodynamic added mass (ΔFv).

3. Statistical Parameters

Two-parameter statistics for the random variables are the normal distribution of N(0.70, 0.12) for the friction coefficient and Type II extreme-value distribution of F(An, k) for the earthquake acceleration. Seismic records were extracted for over 80 years from British Geological Survey for a zone of interest in North Pacific. The Cornell's hazard analysis was applied to obtain the Type II statistical distribution for the earthquake acceleration. The result shows a modal value of $u = 0.014$ and the inverse variance of $k = 2.31$.

Nominal value (An) specified in DnV is the most probable largest value in 100-year return period, or An = 0.102. NBS defines the nominal value (An) to be the mean value in 500-year return period, or An = 0.121. Corresponding distributions are plotted in Fig.1.

4. Code Comparisons

Further to the limit state function described in §.2, NBS introduces coefficients for structural response characteristics, which reduce the third term by 47% assuming the fundamental period of 0.2sec for the structural response as well as the ductility factor of 5.50. Furthermore the limit state function can be normalized with respect to the deadweight of the platform assuming Fu = 0.68Fv, the second term 0.003Fv·tanø, and ΔFv = 0.215Fv. The calculations using a conventional first order second moment analysis on the equivalent normal distributions(NBS) result in the value of the annual probability of failure of 2.5E-3 for DnV and 3.5E-3 for NBS. It should be noted that the difference in the nominal load return periods does not necessarily yield a significant difference in the reliability as a whole.

5. Economic Analysis

Capital cost of the initial investment and the annual costs inclusive of damage cost as well as oil sales revenue can be accounted in the analysis for the net present worth of the profit, which with the failure probabilities can be converted to EMV for different alternatives. Design alternatives are simply the increased amounts of ballasting for improved stability, each of which offers a different failure probability.

EMV analysis was carried out for the peak daily production of 10,000kl/day, and unit oil price of $10, 15, 20/bbl. Capital investment includes costs for the super/sub structures, the installation, well drilling and demolition as well as for the additional ballasting. Annual cost includes maintenance, operation and insurance costs for the undamaged state as well as repair cost for the damaged state.

Relative gain in EMV with respect to the value attained for the no-ballasting alternative(EMV_0) is plotted in Fig.2 for the assumed oil price. The figure also shows a decay in POF due to increased ballasting. Contribution from the reduced POF or the stabilizing effect due to ballasting is cited clearly in the figure. The maximum EMV was achieved with the ballast weight equivalent to 60% of the platform deadweight. Furthermore it should be noted that the benefit is more pronounced for the case with the lower oil price.

6. References

1) E. M. Q. Roren, et al; "IMPLEMENTATION OF RELIABILITY CONCEPTS IN CLASSIFICATION RULES", OMAE Symposium 1986, Tokyo.
2) Det Norske Veritas; "RULES FOR THE DESIGN, CONSTRUCTION AND INSPECTION OF OFFSHORE STRUCTURES, 1977".
3) National Bureau of Standards; "DEVELOPMENT OF A PROBABILITY BASED LOAD CRITERION FOR AMERICAN NATIONAL STANDARD A58", NBS SPECIAL PUBLICATION 577.

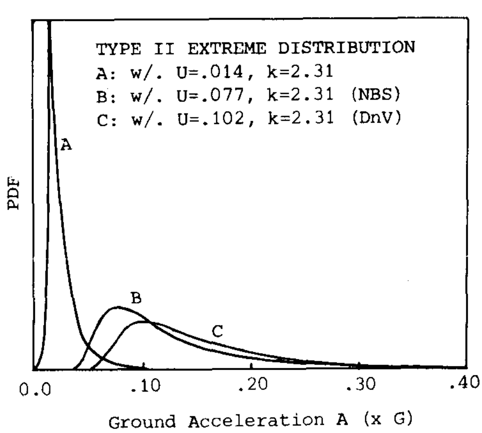

Fig.1 PDF plot for ground acceleration

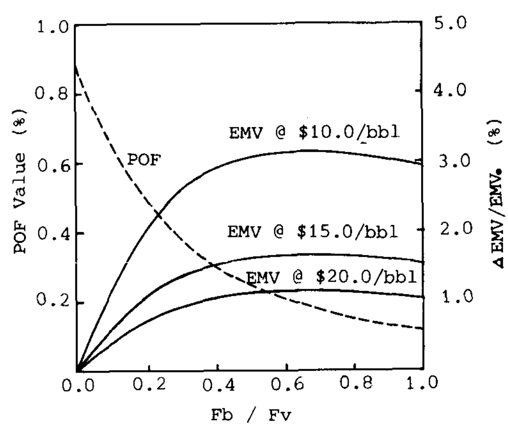

Fig.2 POF and EMV variations due to change in ballast weight