

Reliability of Jackets: Beyond-Static-Capacity

D. G. Schmucker¹ and C. A. Cornell²

Abstract

A robust, explicit expression of the failure probability of an offshore structure under extreme wave loads is used to demonstrate the potential benefits (reducing the estimated annual likelihood of failure, for instance) of considering the beyond-static-capacity response of jacket platforms. For structures possessing ductile failure modes, peak dynamic loads may be resisted that exceed static capacity by considerable margins. An advantage of the explicit reliability formulation is the ease with which the effects of the “additional” capacity may be evaluated.

Introduction

Current re-assessment and re-qualification guidelines for offshore structures responding to the “quasi-static” extreme wave environment include the static ultimate strength analysis as one method for predicting a platform’s non-linear/near-failure behavior (Krieger, *et.al.*, 1994). Assessments that ignore inertial effects and ductility capacity beyond ultimate strength may, however, ignore considerable additional “force” reserves beyond static capacity. This may occur despite the fact that most of these have natural periods (~ 1 sec) a factor of ten below the predominant wave period (10-23 sec). On the other hand, in the range of the static ultimate strength, the structure softens and dynamic effects may cause larger displacements than a traditional static analysis would imply.

Bea and Young (1993) considered these reserves with a capacity modifier, F_ν , that estimated dynamic-transient loading effects. Schmucker (1996) developed a similar factor, $S_{\mu=\mu_{cap}}$, that resulted from considering the “first principles” of beyond-static-capacity response. This factor accounts for the combined effects of inertial resistance, ductility capacity (μ_{cap}), and persistence of global force resistance. Initially based upon simple structure and load models, $S_{\mu=\mu_{cap}}$ was verified/calibrated for 3-D, non-linear, dynamic models of jacket platforms.

¹Civil and Env. Eng. Dept., Penn. State University, University Park, PA 16802 USA

²Civil Eng. Dept., Stanford University, Stanford, CA 94305 USA

Beyond-Static-Capacity Characterization

Salient structural features that aid in determining $S_{\mu=\mu_{cap}}$ may be obtained from a static pushover analysis. These are defined in Fig. 1 and are: F_{ult} , Ω , Ω_x , and μ_{cap} . When $S_{\mu=\mu_{cap}}$ is multiplied by F_{ult} , the product represents the “effective” force capacity. The implication is that a load history that has a peak value equal to this product induces a ductility demand equal to μ_{cap} .

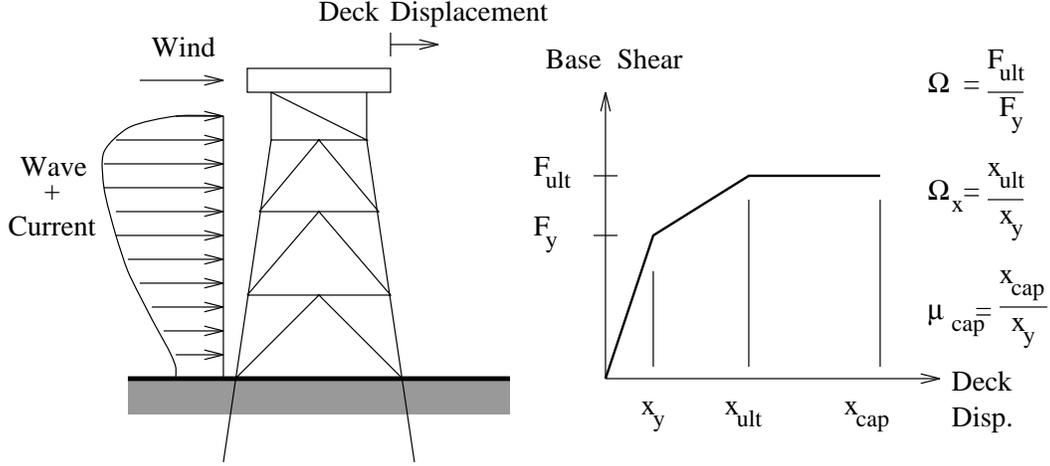


Figure 1: Example Case Static Pushover Analysis

Schmucker (1996) found that a structure’s beyond-static-capacity behavior may be estimated by the form:

$$S_{\mu=\mu_{cap}} = S' + a_1 \left(\frac{1}{4\pi^2} \left(\frac{T}{t_d} \right)^2 \left(\frac{\mu_{cap} - \Omega_x}{\Omega} \right) \right)^{b_1} \quad (1)$$

where S' represents the load for which $\mu = \Omega_x$. When the structure responds quasi-statically to the load environment, $S' \simeq 1$. This form results from considering elasto-plastic systems ($\Omega = \Omega_x = 1$) responding to a squared-sinusoidally varying load history. It can also be shown that $a_1 = 2.25$ and $b_1 = 0.5$ for these systems. The presence of T , the structure’s natural period, in (1) indicates the effect of the structure’s mass, or inertial resistance; note here that larger inertia (T) increases the effective capacity $S_{\mu=\mu_{cap}}$. The effect of load duration is captured by the characteristic time scale of the load, t_d , e.g., the duration of the wave/current induced base shear of interest.

For pushover behavior such as in Fig. 1, S' , a_1 , and b_1 are dependent on Ω , Ω_x , and t_d/T (Schmucker (1996)). It was found that pre-ultimate non-linearities as characterized by Ω and $\Omega_x > 1$ indicate that inertial effects may become more important than is suggested by familiar linear analyses (where typical dynamic amplifications (DAF) for shallow to moderate water depths are less than 1.05). The result is that at least a (small) series of single-degree-of-freedom, dynamic

analyses must be performed to establish the relationship between peak dynamic loads and the subsequent ductility demand. The parameters a_1 and b_1 are then determined from best fits to the data. For the structure of Fig. 1 with $\Omega = 1.56$, $\Omega_x = 3.2$, and $t_d/T = 5.5$, it may be shown that $S' = 0.89$, $a_1 = 5.34$ and $b_1 = 0.558$. Note that this S' value indicates that force and ductility demands equivalent to static capacity are dynamically induced by a peak load only 89% of static capacity, implying an “effective DAF” of more than 1.1.

A Direct Reliability Expression

An important benefit of the response property $S_{\mu=\mu_{cap}}$ is its relatively simple inclusion in the assessment of structural reliability. A robust, simple expression for the failure probability, p_f , that includes both load and capacity variability is shown in Cornell (1995) to be:

$$p_f \simeq H(\hat{R}) \exp [1/2(k_1 \delta_R)^2] \quad (2)$$

in which $H(\hat{R})$ is the CCDF of the base shear evaluated at the median capacity, \hat{R} ; the capacity is given by $R = S_{\mu=\mu_{cap}} \cdot F_{ult}$; δ_R is the COV of the capacity; and k_1 is a slope parameter of H and is an (inverse) measure of the variability of the load. This simple form results from approximating the CCDF in the region of interest by $H \simeq k_o x^{-k_1}$. Typical values of k_1 are about 4 to 8 for drag-dominated wave/current-induced base shears. δ_R depends on the COV of F_{ult} and, through $S_{\mu=\mu_{cap}}$, on the COV's of t_d and μ_{cap} ; typical values of δ_R might be about 0.2-0.25. Not included here is the (potentially considerable) increase in effective capacity identified in Schmucker (1996) related to the difference between the absolute and relative velocity formulations of Morison's wave force equation. Again, this difference is not important in the linear domain.

Design/Re-Assessment Format

The reliability implications of accounting for $S_{\mu=\mu_{cap}}$ are easily evaluated via (2). If we denote p_{fs} as the failure probability associated with the load exceeding the *static* capacity, then the reduction in the estimated p_f by including $S_{\mu=\mu_{cap}}$ is:

$$(p_{fo}/p_{fs}) = (S_{\mu=\mu_{cap}})^{-k_1} \quad (3)$$

For the structure of Fig. 1, the effect of different ductility capacities on p_{fo}/p_{fs} through $S_{\mu=\mu_{cap}}$ are shown in Table 1. The mean value of t_d/T has been taken as 5.5, and $k_1 = 6$. Note that when $\mu_{cap} = \Omega_x$, the actual (peak) dynamic load that induces this demand is *not* the statically predicted value of F_{ult} . Rather, it is a force that is 89% of F_{ult} . This implies that a simple static basis would underestimate the p_f by a factor of 2 if μ_{cap} is limited to Ω_x . Despite these pre-ultimate inertial effects, if this system has sufficient ductility capacity ($\mu_{cap} = 10$), there may be a reduction in the estimated failure probability of 0.5 from that of the static-based estimate. Reductions much beyond this value require somewhat unrealistic values of μ_{cap} . Indeed, certain structural configurations may not be able to support displacements beyond $\mu_{cap} = \Omega_x$.

Given μ_{cap}	3.2	5.0	6.2	10	16
$S_{\mu=\mu_{cap}}$	0.89	1	1.04	1.12	1.22
p_{fo} / p_{fs}	2	1	0.8	0.5	0.3

Table 1: Example Case Reductions in Estimated Failure Probability by Including Beyond-Static-Capacity

Summary

An explicit failure expression allows for a relatively simple approach by which effects of beyond-static-capacity may be included in the estimate of the failure probability. Inertial effects prior to “static” capacity may in some cases indicate cause the failure estimate based solely upon quasi-static behavior to be unconservative. Structures with ductile failure modes, however, may still have potential increases in “effective” capacities as much as 10% or more. Subsequent reductions in the estimated failure probability may be 0.5. This effective force capacity, however, is obtained at the cost of potentially significant ductility demands.

References

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