Ocean Engineering 137 (2017) 151–165

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

A study on the fatigue analysis for a vertical caisson on FPSO subjected to the nonlinear wave loading

MinJu Gam[a], Beom-Seon Jang[b,*], JungHo Park[a]

[a] Department of Naval Architecture and Ocean Engineering, College of Engineering, Seoul National University, Seoul, Korea
[b] Research Institute of Marine Systems Engineering, Dept. of Naval Architecture and Ocean Engineering, Seoul National University, Seoul, Korea

ARTICLE INFO

Keywords:
Morison load
Seawater caisson
Fatigue analysis
Time domain analysis
Frequency domain analysis
Linearization
Linearization coefficient

ABSTRACT

A cylindrical type hull appurtenance attached to the side hull like a seawater caisson or a riser tube is subject to the drag force and inertia force defined by the Morison equation, as well as global hull girder loads. When performing fatigue analysis for a structure subject to Morison load, the nonlinearity of drag term in the Morison equation should be taken into account for an exact structural safety assessment in an appropriate way. This research proposes a time domain approach (Level II method) in order to take into account the nonlinearity, as well as a proper combination of local hotspot stress induced by the Morison load and global hull girder stress. It is based on a representation of irregular wave as a combination of a large number of regular waves. It enables for reflecting phase angle differences of particle velocities along the vertical tube. The phase difference with global stress is also taken into account. The method also includes the vertical motion of the caisson and the wave elevation above the mean water line. The nonlinearity of drag term can be treated by linearizing the drag term in the frequency domain analysis. For the frequency domain approach, Level I method using a linearization coefficient is proposed to yield a fatigue damage equivalent to the time domain analysis. It incorporates the different contributions of horizontal velocities along the vertical tube on the hotspot stress at a connecting bracket on the side hull. The proposed methods are verified through a caisson in FPSO example and various comparative studies. Various comparative studies are performed for a verification of spectral code, an evaluation of rain flow counting effect and the combination of motion and stretching effect, a verification of rain flow counting(RFC) code and linearization coefficient. Through these case studies, it is found that the proposed spectral fatigue analysis with linearized Morison's force results in a good agreement with time domain analysis with a drastic reduction of computational time. In this paper, a FPSO model with a seawater caisson is used as a verification example. The proposed methods are expected to be applied to many similar tubular structures on the side of floating offshore structure, such as, riser guide tube, protection frame for riser guide tube, collision protector and so on. In addition, jacket or jack-up rig consisting of tubular members could be good applications.

1. Introduction

Generally, a cylindrical type hull appurtenance attached to the side hull, such as a sea water caisson in FPSO (see Fig. 1), is subject to the drag force and inertia force defined by the Morison equation. The supporting structure of the caisson is also affected by hull girder bending. Therefore, the local hotspot stress induced by the Morison load and hull girder global stress should be properly combined in the fatigue strength assessment.

Overall, a stochastic fatigue analysis has been performed in the frequency domain using the linearized drag term of the Morison equation (Karadeniz, 1992). This enables for a combination of fatigue damages by global and local hotspot stresses on the stress level. However, the linearized approach can lead to an inaccurate and non-conservative assessment (Lee et al., 1999). Recent studies, such as, for example, Karadeniz (1994) and Choi et al. (1995), conducted the fatigue analysis in the time domain considering the nonlinearity of the Morison equation. In many cases, those studies focused on a fixed structure, like an offshore jacket structure. The calculation of wave load on the fixed structure is simpler than a floating structure, since the wetted area is only affected by wave elevation and not by its motion; also, the load to be considered is only Morison load, without any global hull girder load like FPSO.

Several types of methods have been used to calculate the lineariza-

---

Abbreviation: RFC, Rain Flow Counting; RAO, Response Amplitude Operator; FPSO, Floating Production Storage Offloading; DOF, Degree of Freedom

[*] Corresponding author.

E-mail address: seanjang@snu.ac.kr (B.-S. Jang).

http://dx.doi.org/10.1016/j.oceaneng.2017.03.057
Received 13 June 2016; Received in revised form 1 December 2016; Accepted 27 March 2017
0029-8018/ © 2017 Elsevier Ltd. All rights reserved.

Nomenclature

$a_j(t)$	Time history of relative acceleration for irregular wave at jth depth
$\bar{a}$	Parameter of one-slope SN curve
$\bar{a}_1$, $\bar{a}_2$	Parameters of two-slope SN curve
A	Area of the caisson
A_i	Amplitude of ith regular component wave
C	Linearization coefficient X over the standard deviation of the velocity
C_a	Added mass coefficient
C_D	Drag coefficient in the Morison equation
C_M	Inertia coefficient in the Morison equation
d	Diameter of the caisson
D	Accumulated fatigue damage considering all sea states and heading angles
D_{ij}	Fatigue damage ratio for i^{th} sea state and jth heading angle
$E[F_p^m]$	Expectation value of F^m calculated using the nonlinear equation
$E[F_{pl}^m]$	Expectation value of F^m calculated using a linearization coefficient
$f(u_a)$	Probability density function of u_a
F	Morison load
F'	Approximate Morison load
F_D	Drag force
F_I	Inertia force
$F_j(t)$	Time history of Morison load at jth depth
H_s	Significant wave height
i	Index for regular component wave
j	Index for water depth defined in the global coordinate
k	Index for location from the bottom of the caisson defined in the local coordinate or number of stress blocks
K	Parameter indicating the ratio of magnitude of drag term to that of inertia term in the Morison equation
K_D	Constants including drag coefficient
K_M	Constants including inertia coefficient
$l(t)$	Time history of the submerged length of the caisson
m	Parameter of one-slope SN curve
m_1, m_2	Parameters of two-slope SN curve
m_{0ij}, m_{2ij}	0th and 2nd moment of the combined principal stress spectrum for ith sea state and jth heading angle
m_k	kth moment of the spectrum
n	The number of regular waves
n_i	Number of stress cycles in stress block i
N_i	Number of cycles to failure at the constant stress range $\Delta\sigma_i$
p_{ij}	Occurrence probability for ith sea state and jth heading angle
Q	Least square value
$S(\omega_i)$	Wave spectral energy density for angular frequency
S_0	Stress range at which the slope of SN curve changes
SF	Stress influence factor
$S_v(\omega)$	Relative velocity spectrum
T_d	Design life expressed in seconds
T_H	Time for analysis
T_z	Zero up-crossing period
u_a	Peak values of velocity
$u_j(t)$	Time history of relative velocity for irregular wave at jth depth
$u_{Re,ij}$, $u_{Im,ij}$	Real, imaginary part of relative velocity RAO for ith regular component wave at jth depth
V	Time history of vertical displacement at the bottom of the caisson
$VD(t)$	Time history of vertical displacement at the bottom of the caisson
$VD_{Re,i}$, $VD_{Im,i}$	Real, imaginary part of vertical displacement RAO for ith regular component wave
$VL(t)$	Time history of vertical location of the bottom of the caisson
x	x coordinate values in the global coordinate
X	x directional linearization coefficient
$\overline{X}$	x directional equivalent linearization coefficient by Method I
$\hat{X}$	x directional equivalent linearization coefficient by Method II
y	y coordinate values in the global coordinate
Y	y directional linearization coefficient
$\overline{Y}$	y directional equivalent linearization coefficient by Method I
z	z coordinate values in the global coordinate
$\gamma(s, x)$	Lower incomplete gamma function
$\Gamma(s, x)$	Upper incomplete gamma function
$\Gamma(s)$	Ordinary gamma function
Δh	Discretized height of the caisson
$\Delta\omega$	Angular frequency interval
$\zeta(t)$	Time history of irregular wave elevation
η_1, η_2, η_3, η_4, η_5, η_6	Surge, sway, heave, roll, pitch, yaw at the origin of global coordinate
ν_{ij}	Average zero crossing frequency of the combined principal stress for i^{th} sea state and j^{th} heading angle
ξ	Displacement
ξ_1, ξ_2, ξ_3	x, y, z directional displacement for a specific point
ξ_{re}, ξ_{im}	Real, imaginary part of displacement
$\dot{\xi}$	Velocity
$\dot{\xi}_{re}$, $\dot{\xi}_{im}$	Real, imaginary part of velocity
ρ	Sea water density
σ	Standard deviation of the particle velocity
σ_1, σ_2	First, second principal stress
$\sigma_{glo}(t)$	Time history of global hotspot stress
$\sigma_{glo_{Re,i}}$, $\sigma_{glo_{Im,i}}$	Real, imaginary part of the global stress RAO for ith regular wave component
$\sigma_{loc}(t)$	Time history of total local hotspot stress
$\sigma_{loc,k}(t)$	Time history of contribution of the Morison load at k^{th} location to local hotspot stress
σ_u	Standard deviation of relative velocity at a specific point
σ_x	x directional normal stress
σ_y	y directional normal stress
τ_{xy}	Shear stress in xy plane
v	Particle velocity
$\varnothing_{wave,i}$	Randomly generated phase angle of ith regular component wave
ω	Angular frequency of incoming wave
ω_i	Angular frequency of ith regular component wave
ω_{mv}	Mean value of zero crossing frequency of the relative velocity normal to the caisson

tion coefficient for the drag term in the Morison equation. Among them, a fundamental and basic one is the equivalent linearization method proposed by Borgman (1972). In this method, the least square approach to minimize the error between the nonlinear formula of drag force and the linearized one is adopted. Considering that the regular wave elevation is a Gaussian random process, the particle velocity of wave can be also regarded as a Gaussian process. Therefore, the least square value Q is expressed as shown in the following formula. X is the linearization coefficient and σ is the standard deviation of the particle velocity, v.

Download English Version:

https://daneshyari.com/en/article/5474243

Download Persian Version:

https://daneshyari.com/article/5474243

Daneshyari.com