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Sensitivity analysis on seismic life-cycle cost of a fixed-steel offshore platform structure

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ABSTRACT

In this study sensitivity analyses were conducted to investigate the relative importance of different uncertain variables on the life-cycle cost (LCC) estimation of a steel jacket offshore platform subjected to seismic loads. The sensitivity analysis was conducted using different methods such as tornado diagram analysis (TDA), first-order second-moment (FOSM) and Latin hypercube sampling (LHS). The analysis results showed that the uncertain variables related to loss estimation and seismic hazard had a more dominant influence on the LCC variability compared to the other variables. Among the structural uncertain parameters, the variability in plastic hinge strength and modal damping ratio had the most significant impact on the LCC. Variability in the initial cost showed higher impact on LCC estimations compared to other cost component variables. It was also observed that the application of members with energy dissipation capability resulted in more economical design compared to use of conventional members.

1. Introduction

Life-cycle cost (LCC) evaluation of a structure is generally carried out to determine a rational design, retrofit, or maintenance scheme among many possible options. For accurate life cycle cost (LCC) estimation of structures, the uncertainties associated with design variables need to be investigated properly. The more knowledge we have regarding these uncertain variables and their variations, the more reliable and accurate LCC estimations can be obtained. Sensitivity analysis is a useful tool for highlighting the relative impact of input variables on corresponding output response. Life-cycle cost-benefit assessment of seismic risk mitigation activities requires accurate estimation of LCC. These activities provide important source of decision-making supporting information (Goda et al., 2010; Takahashi et al., 2005; Goda and Hong, 2006; Hanai et al., 2003). In addition, accurate LCC assessment plays an important role in performance-based and consequence-based earthquake engineering (Ellingwood and Wen, 2005).

Most of LCC studies have focused on incorporating LCC as an objective function for achieving optimum designs of structures (e.g. Liu et al., 2005; Zou et al., 2007; Wen and Kang, 2001a, 2001b). Other studies are dedicated to using LCC in seismic assessment (e.g. Lagaros, 2007; Gencturk, 2013; Lamprou et al., 2013). However, less attention has been paid to the sensitivity of LCC for different input parameters. Moreover, most of the seismic LCC studies found in literature have focused on conventional structural systems designed using force-based seismic design (e.g. Liu et al., 2004; Ang and Lee, 2001; Beck et al., 2003). In addition, most of current studies give less concern to the impact of soil-pile-structure interaction (SPSI). However, consideration of SPSI significantly affects the seismic fragility of pile-founded structure (Kwon and Elnashai, 2010) which has a direct effect on the LCC estimation.

Sensitivity analysis is generally performed to identify the relative importance of design variables. Padgett and DesRoches (2007) studied the sensitivity of a multi-span simply supported steel girder bridge. Kim et al. (2011) studied the sensitivity of design parameters of steel buildings subjected to progressive collapse. Celarec et al. (2012) investigated the sensitivity of seismic response parameters to the uncertain modeling variables of four infilled RC frames using pushover analysis. Zona et al. (2012) conducted a response sensitivity analysis to study the effects of brace over-strength distributions of steel frames with buckling-restrained braces (BRBs) on the expected maximum reduction of seismic performance as measured by local and global engineering demand parameters (EDPs). Recently, Nour El-Din and Kim (2014) conducted a sensitivity analysis of pile-founded fixed steel jacket platforms subjected to seismic loads.

They also conducted seismic performance evaluation of jacket platforms with various bracing types (NourEldin and Kim, 2015).

In the current study, a steel jacket offshore platform in Gulf of

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Notations

a and b	are the regression coefficients for linear regression of drift demand D on intensity S_a in logarithmic space
k_o and k	are the coefficients for linear regression of hazard $H(s_a)$ on intensity S_a in proximity of limit state probability (region of interest) in logarithmic space.
C_i	corresponding cost of exceeding a specific limit state
C_o	initial construction cost which will be related to the material cost in the current study
$\hat{D}$	median drift demand
D_1	damage index of the platform, which can be expressed as the ratio between the actual and allowable maximum inter story drift ratios.
D_R	repairable damage index
EDP_j	LCC estimated at the jth simulation
$K_{i,j}$	prescribed correlation coefficients between the random variables X_i and X_j
N_{Sim}	number of simulations
N_{Var}	number of random variables
P_{LS}	annual probability of exceeding a specific limit state
Q_d	pile ultimate bearing capacity
Q_f	pile skin friction resistance
Q_p	pile total end bearing
R_C	replacement cost
S_a^C	spectral acceleration corresponding to the median drift capacity
S_a	elastic spectral acceleration (measure of ground motion intensity)
S_a	spectral acceleration (measure of ground motion intensity);
$S_{i,j}$	generated correlation coefficients between the random variables X_i and X_j
$x_{j,i}$	value of the i^{th} input random variable for the jth simulation
β_C,	drift capacity dispersion measure
$\beta_{D\|S_a}$	drift demand dispersion measure
ρ_i	Spearman rank-order correlation coefficient
[R]	Matrix of ranking coefficients
[S1]	matrix of correlation
BRB	buckling restrained brace
C_m	maintenance cost
COV	coefficient of variation
CP	collapse prevention limit state
E	norm measuring the difference between the generated and the prescribed correlation matrices
$E[C_{SD}]$	annual expected seismic damage cost
EDP	engineering demand parameter
FB-BRB	steel jacket structural model of the platform that designed using buckling-restrained bracing
FB-Conv	steel jacket structural model of the platform designed using the conventional bracing
FOSM	first-order second-moment
F_y	specified minimum yield strength of steel
$H(s_a)$	hazard function of spectral acceleration, annual probability that intensity S_a at site will equal or exceed s_a
IO	immediate occupancy limit state
L	service life of the structure
LCC	life-cycle cost
LHS	Latin hypercube sampling
LS	life safety limit state
MCE	maximum considered earthquake
N	total number of limit-states considered,
N_{Sim}	number of simulation
p	lateral soil reaction (p) per unit length of the pile
PGA	peak ground acceleration
P_i	total probability that the structure is in the ith damage state throughout its lifetime,
P_u	required axial strength
P_{ysc}	design strength of a steel cross section.
R	rank of the jth sample value of the input random variable
R	response modification factor according to ASCE-7 (2010)
R_y	over strength factor
S_{D1}	design, five percent damped, spectral response acceleration parameter at a period of 1 second
S_{DS}	design, five percent damped, spectral response acceleration parameter at short periods
SPSI	soil-pile-structure interaction
TDA	tornado diagram analysis
X	the sample matrix of the random variables, where the number of rows and columns are representing the number of simulations and number of input variables, respectively
$X_{bearing}$	random variable of pile end bearing
X_{cyclic}	random variable of cyclic nature of the loading
X_{delay}	random variable of set-up or effect of time since the pile is driven or last disturbed
$X_{friction}$	random variable of shaft friction between soil and pile
y	lateral pile displacement
α	discount factor which is equal
β	compression adjustment factor
$\Delta_{C,i}$	is the structural capacity, represented in terms of drift ratio, defining the ith damage state
Δ_D	earthquake demand, represented in terms of drift ratio
ϕ	strength reduction factor
λ	annual discount rate, and
ω	strain hardening adjustment factor

Moattam, offshore of Myanmar, designed considering soil-pile structure interaction, is used as a case study. Different bracing types, such as buckling-restraint braces and conventional braces, are applied in the platform design to investigate their effect on the seismic LCC of the platform structures. Sensitivity analysis is performed using tornado diagram analysis (TDA), first-order second-moment (FOSM), and Latin hypercube sampling (LHS) techniques. The effects of both aleatory and epistemic uncertainty on LCC have been investigated for this platform. The sources of uncertainty considered in the present sensitivity study are categorized into different categories: (1) the structure capacity and modeling, e.g. related to stiffness or damping characteristics, etc.; (2) the SPSI modeling, e.g. soil-pile friction capacity, pile end-bearing capacity, etc.; (3) the seismic hazard, e.g. the probability of occurrence; (4) the loss-estimation socioeconomic criteria and cost components, e.g. damage limit states, initial cost, limit state exceedance cost, annual discount rate, etc.

2. Sensitivity analysis methods applied

In order to have enough confidence in any sensitivity analysis results, it is important to monitor the variation of the input