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Performance-Based Seismic Response of Continues Buried Steel Pipelines Under Near-Field Ground Motion Effects

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ABSTRACT: Performance-Based Earthquake Engineering (PBEE) attempts to improve seismic risk through assessment and design methods that are more informative than current approaches. However, little work has been performed investigating the seismic response of buried steel pipelines within a performance-based framework. In this paper the seismic response of buried steel pipelines was studied in a performance-based context. Multiple nonlinear dynamic analyses of three buried steel pipes with different diameter to thickness and burial depth to diameter ratios, steel grade and various soil characteristics carried out using an ensemble of near-field ground motion records were scaled to various intensities to capture the behavior of buried pipeline in the range of elastic response to dynamic instability. Peak axial compressive strain in critical section of the pipe was considered as engineering demand parameter (EDP) of pipelines. Several ground motion intensity measures (IMs) are considered to investigate their correlation with EDP. Using the regression analysis in logarithmic space, the efficiency and sufficiency of investigated IMs are studied. Among the models investigated in this study, it was seen that a combined IM, PGV and SMV were the most sufficient IMS. For buried steel pipelines investigated in this study, it was concluded that PGD is the most sufficient IM for near-field ground motions. It was seen that the combined IM followed by SMV were the optimal IM for buried steel pipelines under near-field ground motions based on both efficiency and sufficiency conceptions.

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1- Introduction

An important component in performance-based earthquake engineering (PBEE) is seismic demand estimation. The uncertainties in earthquake records and the nonlinear response of structures lead to utilization of probabilistic seismic demand analysis [1]. Probabilistic seismic demand analysis is used for estimating the mean annual frequency of exceedance of a given value of an engineering demand parameter (EDP). By using intensity measures (IMs) the uncertainties in PBEE are removed. The use of an IM forces careful attention of its efficiency [2] and sufficiency [3]. Adopting an efficient IM results in smaller variability in the structural response for any particular IM [3]. The use of a sufficient IM results in an EDP that is conditionally independent of earthquake magnitude (M) and the source to the site distance (R) [3].

The efficiency and sufficiency of some candidate IMs were investigated by Shakib and Jahangiri [4].They used only far-field earthquake records for the study, but it was concluded that for underground structures, the effects of near-field earthquakes are higher than far-field ones [5]. Thus in the current study, the efficiency and sufficiency of some potential intensity measures for estimation of the seismic response of buried steel pipelines subjected to near-field ground motions were investigated.

2- Methodology

The seismic demand is usually assumed in the form of power Equation [6]:

$$EDP=a(IM)^{b} \tag{1}$$

The efficiency was shown by the dispersion of the residuals. The dispersion was measured by the standard deviation of the residuals, herein represented by σ. The small dispersion value for an IM denotes its higher efficiency.

Determination of the sufficiency of the IM was performed by using the regression analysis of EDP on M or R. Sufficiency was determined by the p-value obtained from F-test. The IMs with a small p-value e.g., smaller than about 0.05 were insufficient and the ones with high p-values were the most sufficient IMs [7].

3- Results and Discussion

In this study, three buried pipelines of API 5L were designed according to the American Lifeline Alliance [8] and used in incremental dynamic analysis (IDA) using a suite of twenty pulse-like earthquake records, as are

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In Table 1, D, t and H are diameter, thickness and burial depth of the pipes, and Φ, c and γ are friction angle, cohesion and density of the soils, respectively.

Table 1. The considered models

Parameter	Model		
	M1	M2	M3
Grade	X60	X65	X80
D (mm)	508	508	914
t (mm)	11.1	8.7	7.9
D/t	45.8	58.4	115.7
H (m)	1.5	2	1.69
H/D	3.0	3.9	1.8
Φ (°)	0	0	29
c (KPa)	75	37	0
γ (kg/m3)	1800	1500	1700

In this study, 18 IMs used in the work of Shakib and Jahangir [4] were considered as potential intensity measures. Through the regression analysis approach, the efficiency and sufficiency of the IMs were investigated. The achieved results are presented and discussed as follow.

Table 2. Dispersion values of all IMs

IM	σ		
	M1	M2	M3
PGA	1.55	1.80	1.59
PGV	0.9	1.22	1.14
PGD	1.12	1.39	1.09
PGV^2/PGA	1.11	1.34	1.17
RMS_a	1.38	1.64	1.45
RMS_v	0.97	1.25	1.11
RMS_d	1.36	1.58	1.28
I_a	1.28	1.58	1.40
CAV	1.17	1.51	1.33
ASI	1.49	1.76	1.54
VSI	1.31	1.56	1.42
SMA	1.37	1.65	1.42
SMV	0.89	1.29	1.04
S_a	1.55	1.76	1.60
S_v	1.59	1.84	1.63
S_d	1.56	1.76	1.60
PGD^2/RMS_d	1.26	1.52	1.23
$\sqrt{VSI[\omega_1(PGD+RMS_d)]}$	0.8	1.15	1.03

Table 3. P-values of all IMs

IM	P-Value					
	M1		M2		M3	
	M	R	M	R	M	R
PGA	0.001	0.060	0.953	0.972	0.014	0.726
PGV	0.000	0.104	0.693	0.867	0.001	0.173
PGD	0.165	0.699	0.956	0.946	0.151	0.340
PGV^2/PGA	0.274	0.038	0.923	0.638	0.290	0.003
RMS_a	0.000	0.342	0.863	0.994	0.001	0.299
RMS_v	0.000	0.722	0.600	0.999	0.000	0.350
RMS_d	0.884	0.009	0.906	0.659	0.901	0.124
I_a	0.002	0.231	0.968	0.941	0.015	0.371
CAV	0.032	0.461	0.922	0.969	0.173	0.693
ASI	0.001	0.410	0.997	0.949	0.019	0.542
VSI	0.005	0.262	0.825	0.945	0.029	0.398
SMA	0.000	0.089	0.984	0.934	0.002	0.107
SMV	0.029	0.117	0.916	0.979	0.078	0.125
S_a	0.003	0.380	0.979	0.960	0.123	0.768
S_v	0.006	0.234	0.937	0.945	0.0086	0.600
S_d	0.003	0.377	0.978	0.961	0.123	0.767
PGD^2/RMS_d	0.020	0.003	0.908	0.950	0.028	0.001
$\sqrt{VSI[\omega_1(PGD+RMS_d)]}$	0.002	0.295	0.828	0.929	0.010	0.233

Dispersion values (σ) of the investigated IMs that obtained from the regression analysis are presented in Table 3. It can be seen that , SMV, PGV, and had the lowest dispersion values among all IMS, for M1. According to Table 2, the minimum values of σ among all IMS belonged to , PGV, and SMV that were 1.15, 1.22, 1.25 and 1.29, respectively.

The sufficiency of all investigated IMs for all models is presented in Table 3 in terms of P-value. It can be seen that for M1 case, and were sufficient IMs only in terms of M. The PGA, PGV, , , Ia, CAV, ASI, VSI, SMA, SMV, Sa, Sv, Sd and were sufficient IMs in terms of only R for M1. PGD was a sufficient IM in terms of M and R for M1. The combined intensity measure was also a sufficient IM with respect to M and R with p-values of 0.98 and 0.343, respectively. According to Table 3, it can be seen that the sufficiency exhibited for PGD, , CAV, SMV, Sa, Sv and Sd was significantly high in terms of both M and R for M3.

4- Conclusions

Based on the studied models, it can be concluded that the efficient and sufficient IMs for predicting seismic demands of buried steel pipelines under near-field pulse-like ground motions were followed by SMV.

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