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Performance indexes for seismic analyses of earth dams

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ABSTRACT: The seismic performance of dams must be checked against expected ground motions verifying the possible occurrence of a serviceability or of an ultimate limit state. In this framework it is generally recognised that the earthquake-induced settlement of the dam crest can be assumed as a reliable index of performance since it is representative of the overall seismic response of the dam and is suitable for the evaluation of the level of damage induced by earthquake loading. Accordingly, threshold values of the crest settlement can be introduced to check the occurrence of a given limit state. A large set of data related to 90 case histories of damages produced by seismic events to dams and pertinent facilities was collected and is presented in the paper. The dataset is re-examined to define proper threshold values of the crest settlement to be used as possible reference indexes in performance-based seismic analyses of dams.

1 INTRODUCTION

In the last decades innovative performance-based approaches have been introduced to evaluate the seismic behaviour of dams and to estimate the financial and social risk associated to irreversible damages or failures induced by earthquakes. In this context, appropriate indexes of seismic performance must be introduced, and the exceeding of suitable target values must be checked with reference to different seismic scenarios. According to international standards (FEMA, 2005; USACE, 2004), the seismic performance of dams must be assessed to verify that the stability and serviceability conditions are warranted against expected ground motions characterized by either a relatively low or high probability of occurrence during the dam's life-cycle. This approach permits to avoid catastrophic failures and uncontrolled release of water during extreme (low probable) events and to ensure operational conditions of the dam (and of the overall plant) during less severe (highly probable) earthquakes.

According to these principles the Italian seismic code for dams, NTD14, introduces four limit states associated to different values of the probability of exceedance P_{VR} during a specific time interval V_R: namely, two serviceability (Operational Limit State and Damage Limit State) and two ultimate (Life Safety Limit State and Collapse Limit State) limit states which can be attained depending on the loss of a characteristic condition defined in terms of level of damages induced by earthquake loading and occurrence of uncontrolled release of water.

As shown in Table 1, an Operational Limit State (OLS) is achieved when the normal operating condition is lost due to the occurrence of repairable damages which, however, do not lead to uncontrolled release of water. When the earthquake-induced damages are irreparable, a Damage Limit State (DLS) is attained if the dam overtopping does not occur (no uncontrolled release of water); otherwise, in case of occurrence of uncontrolled release of water, a Life Safety Limit State (LLS) is attained if the dam does not collapse; otherwise, a Collapse Limit State (CLS) is achieved.

These limit states should be checked through appropriate analyses verifying that the corresponding limit condition is not achieved (i.e. a characteristic condition is maintained; Table 1).

Table 1. Limit states introduced by the Italian Code for Dams (NTD14)

Limit state	Operational (OLS)		Damage (DLS)		Life safety (LLS)		Collapse (CLS)
P_{VR} (%)	81		63		10		5
	L	A	L	A	L	A	
Condition to be lost (L) or to be attained (A) for the achievement of the limit state	No damage occurs in the dam and in the facilities (normal operating condition)	Occurrence of repairable damages without uncontrolled release of water		Occurrence of irreparable damages without uncontrolled release of water		Occurrence of irreparable damages producing uncontrolled release of water and/ or risk of loss of human life (Collapse)	

Field evidence and theoretical considerations suggest that the accelerations arising in the dam body and the magnitude of earthquake-induced permanent displacements are useful data to evaluate the dam response to strong ground motions. Specifically, comparison of peak acceleration at the crest of the dam and in the foundation soils, or at the base of the dam body, provides a quantitative assessment of the amplification phenomena occurred during seismic shaking, possibly activating a non-linear response of the dam, with reduction of soil shear stiffness and occurrence of permanent deformations. The crest settlement of the dam, w_c, induced by earthquake loading is well related to the level of damage induced by the seismic event, being thus suitable to represent the overall seismic performance of the dam.

In this paper a large set of data collected from the literature is presented and discussed focusing on the profiles of the peak horizontal acceleration $a_{x,max}$ along the dam centre line, including the peak acceleration $a^c_{x,max}$ at the crest, and on the settlements of the crest of the dam, related to different levels of earthquake-induced damage. The dataset, consisting of field observations and results from numerical analyses, was used to define performance indexes to be used in the prediction of the achievement of a given limit state of a dam subjected to seismic loading.

2 CREST ACCELERATION AND ACCELERATION PROFILES

In Figure 1a the peak horizontal crest acceleration $a^c_{x,max}$ is plotted against the corresponding peak values at the base of the embankment $a^b_{x,max}$. The data refer to different types of earth dams, with height H_d = 40 ÷ 150 m, and encompass post-earthquake observations and results from numerical analyses. For the selected dataset, it is apparent that $a^c_{x,max}$ is always greater than $a^b_{x,max}$ and the average trend can be suitably represented by a power law with correlation coefficient R^2 = 0.88 and standard error σ = 0.158; the Figure also shows the 16th and 84th percentile of the data distribution.

Figure 1 b-c show, for the same data set, the profiles of the ratio $a_{x,max}/a^b_{x,max}$ along the dam centre line; the dark grey area in the figure represents the envelope obtained by Cascone & Rampello (2003) considering published results of ground response analyses of 13 dams: specifically, the results of linear shear beam analyses of an ideal earth dam (Gazetas, 1987) and the results of 2D FE linear-equivalent analyses carried out on ideal earth dams (Prato & Delmastro, 1987 and Makdisi et al 1982), ideal and real rockfill dams (Seed et al 1985 and Gazetas & Dakoulas, 1992), the Sürgü earth dam (zkan et al 1996) and the Santa Juana concrete face gravel dam (Troncoso et al 1999).

The figure also shows the profiles provided by 2D non-linear dynamic analyses carried out for some Italian earth dams with peak acceleration at the base of the embankment $a^b_{x,max} \geq$ 0.25 g (Figure 1b) or $a^b_{x,max} <$ 0.25 g (Figure 1c): the Marana Capacciotti dam (H_d = 48 m - Cascone & Rampello, 2003; Amorosi & Elia, 2008; Rampello et al 2009; Elia & Rouainia, 2013), the dam on the river Melito (H_d = 106 m - Costanzo *et al.* 2011); the Montedoglio dam

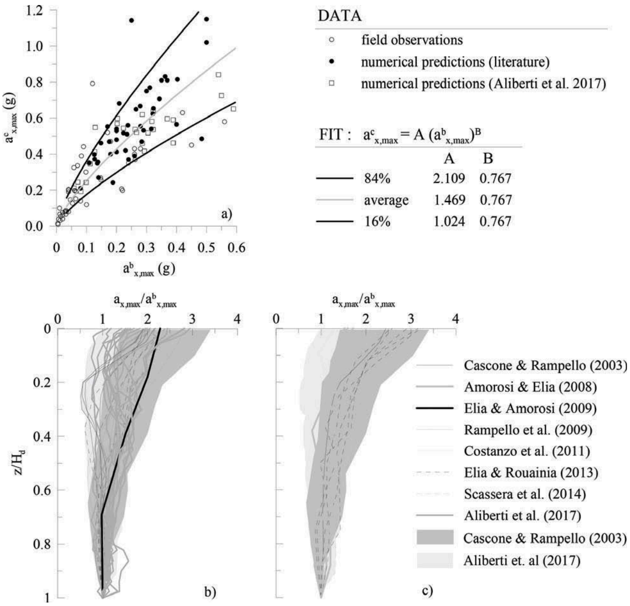

Figure 1. a) Peak horizontal values of crest versus base accelerations; b, c) profiles of the crest to base acceleration ratio $a_{x,max}/a^{b}_{x,max}$ along the dam centre line for $a^{b}_{x,max} \geq 0.25$g (b) and $a^{b}_{x,max} < 0.25$g (c).

(H_d = 64.30 m - Scassera *et al.* 2014) and the San Pietro dam (H_d = 48m - Elia & Amorosi, 2009; Aliberti 2017; Aliberti *et al.* 2016). The dataset allowed widening the range of profiles of peak horizontal acceleration along the dam centre line defined by Cascone & Rampello (2003, dark grey area in Figure 1 b-c) by including lower amplification (or de-amplification) profiles (light grey area in Figure 1 b-c). Depending on the maximum acceleration at the base of the dam, the amplification ratio at the crest varies in a large interval: a close scrutiny of Figure 1 b-c reveals that, for larger seismic events ($a^{b}_{x,max} \geq 0.25$g, Figure 1b), soil non-linear behaviour leads to smaller amplifications. Accordingly, an analysis merely based on the acceleration profiles or on the peak values of acceleration attained at the dam crest is not sufficient, though useful, for a reliable evaluation of the seismic performance. As shown in the next section, the achievement of a limit condition in the dam, or in its components, may be related to earthquake-induced permanent deformations and, specifically, to the crest settlement w_c that represents an index of the seismic performance of the dam, also related to its post-seismic operative conditions.

3 DATABASE OF CREST SETTLEMENTS AND DEFINITION OF DAMAGE LEVELS

In principle, the limit conditions corresponding to the achievement of a serviceability or of an ultimate limit state should be checked considering the different components of the dam. The application of this approach is not straightforward: in fact, it would require the definition of proper performance indexes for each component of the dam influencing the post-seismic serviceability conditions and affecting the repair costs.

Based on a comprehensive review of case histories of earthquake-induced damages to dams, Swaisgood (2003) and Ishihara (2010) concluded that the earthquake-induced settlement w_c of the crest of the dam could be assumed as a reliable index of seismic performance in that it is representative of the overall response of the dam and is suitable for the evaluation of the level of damage induced by earthquake loading.

A large set of data, related to 90 case histories of earthquake-induced damages to various types of dams and related facilities, were collected and examined herein to associate given values of the non-dimensional crest settlement w_c/H to different limit states. The crest settlement is divided by the total height of the dam-foundation system $H = H_d + H_f$ (Figure 2a), defined as the sum of the height of the dam embankment H_d and the thickness of the deformable foundation soils H_f. The case histories include the 69 cases considered by Swaisgood (2003) and the data reported by Sica & Pagano (2009) and Ishihara (2010).

Table 2 provides a summary of the main characteristics of the selected dataset: it refers to 7 concrete/bituminous rockfill (RD) dams, 11 hydraulic fills (HF), 4 tailing dams (TD), 37 homogeneous (HED) and 31 zoned (ZED) earth dams (68 earth dams) with height H in the range of 6.1 to 235 m. The dams were struck by 42 seismic events occurred from 1906 until 2008 with magnitude $M_{RIF} = 5.3 \div 8.2$; epicentral distances R_{ep} of the dam sites varying in the interval $0 \div 260$ km and peak horizontal acceleration at the dam site (recorded or predicted on rock outcropping or at the dam's foundation level) $a_{h,max} = 0.02 \div 0.80\ g$.

For all the selected case histories the documented damages induced by earthquake loading were re-examined to relate the achievement of one of the limit states described in Table 1 with appropriate target values of the settlement ratio w_c/H.

According to Swaisgood (2003), and as reported in USCOLD (1992, 2000), the damage descriptions available for each case history were sorted and classified, with some engineering judgment, into four classes: "none", "minor", "moderate" and "serious" level of damage. Table 3 provides a concise description of each class.

Level of damage "none" was associated to those case histories for which no damages occurred in the dam and in the appurtenant structures and the overall plant remained in normal operating conditions.

When only local instabilities occurred (or were re-activated) in the slopes of the dam embankment, the loss of the freeboard did not occur (no uncontrolled release of water occurred) and only limited and repairable damages were observed (in the dam or in the overall plant), the case history was classified as one of "minor" level of damage.

A "moderate" level of damage was assigned to those cases for which settlements (due to densification of the embankment and/or of the foundation soils), excessive permanent distortions or cracks occurred, these producing irreparable damages (in the dam or in the plant facilities) that affected the capability of controlling the reservoir level even if the overtopping of the dam did not occur.

Finally, a "serious" level of damage was attributed to case histories for which an overall instability of the dam occurred due to: i) the inertial and weakening effects arising in the embankment; ii) liquefaction in the foundation soils or in the shells; iii) lateral spreading and slumping of the embankment; iv) instabilities in the natural slopes surrounding the water basin. In some of these cases a complete failure of the dam, with uncontrolled release of water, occurred producing the flooding of the area downstream of the dam; these cases of collapse were classified as a sub-category of the class of "serious" level of damage.

4 DEFINITION OF INDEXES OF SEISMIC PERFORMANCE

The dataset obtained following the classification described above is represented in Figure 2 where the arrows denote the intervals of settlement ratio suggested by Swaisgood (2003) for each level of damage. Table 4 supplements the description of the selected dataset.

Table 2. Main characteristics of the selected case histories

Dam type	n.	H (m)	w_c/H (%)	M	R_{ep} (km)	$a_{h,max}$ (g)
Concrete/bituminous rockfill (RD)	7	66.5÷132	0.001÷0.445	5.6÷7.9	7÷260	0.03÷0.37
Hydraulic fill (HF)	11	6.1÷63	0.003÷20.866	5.3÷7.3	1÷151	0.05÷0.60
Homogeneous earth (HED)	37	10.7÷100	0.002÷16.667	5.3÷8.2	0÷77	0.02÷0.80
Zoned earth (ZED)	31	46.9÷235	0.001÷3.799	5.3÷8.1	5÷150	0.04÷0.58
Tailing dams (TD)	4	10÷32.5	7.900÷98.462	7.0÷8.0	8÷80	0.25÷0.80
All	90	6.1÷235	0.001÷98.462	5.3÷8.2	0÷260	0.02÷0.80
Earth (HED, ZED)	68	10.7÷235	0.001÷16.667	5.3÷8.2	0÷150	0.02÷0.80

No damage (Figure 2b) was generally observed for $w_c/H < 0.11$ % for both the whole set of data (26 cases) and the subset of 23 earth (zoned and homogeneous) dams. For this level of damage, the average non-dimensional crest settlement (≅ 0.019% irrespective of the dam type)

Table 3. Description of the levels of damage and definition of the performance index

Level of damage	Description	Limit state	Target performance index
None	No damages in the dam and in the appurtenant structures and equipment. The plant remains in a normal operating condition	Operational limit state (OLS)	$w_{c,y}/H < 0.1\%$ $w_{c,y}$ < freeboard
Minor	Downstream and upstream slopes suffer local instabilities, but overall stability of the dam embankment is ensured. The normal operating condition is lost due to the occurrence of repairable damages that do not lead to uncontrolled release of water (crest settlement lower than freeboard)	Damage limit state (DLS)	$w_{c,y}/H < 0.4\%$ $w_{c,y}$ < freeboard
Moderate	Occurrence of cracks and/or excessive permanent deformations and settlements in the embankment and/or in the foundation soils, producing irreparable damages without uncontrolled release of water (crest settlement lower than freeboard).	Life safety limit state (LLS)	$w_{c,y}/H < 1.0\%$ $w_{c,y}$ < freeboard
Serious	Overall instability of the embankment and/or in the basin slopes, occurrence of soil liquefaction (in the embankment and/or in the foundation soils). Uncontrolled release of water (crest settlement greater than freeboard) and even dam collapse	Collapse limit state (CLS)	$w_{c,y}/H < 2.5\%$ w_c < freeboard

Table 4. Definition of target values for the performance index

	Dam		w_c/H (%)		
D.L.	Typology	number	minimum	maximum	average
None	all (ZED, HED, RD, HF, TD)	26	0.0009	0.1096	0.0189
	earth (ZED, HED)	23	0.0009	0.1096	0.0326
Minor	all (ZED, HED, RD, HF, TD)	33	0.0196	1.2116	0.136
	earth (ZED, HED)	28	0.0196	1.2116	0.180
Moderate	all (ZED, HED, RD, HF, TD)	16 (13)[a]	0.0198 (0.0833)[a]	13.79 (5.6075)[a]	1.425 (0.6226)[a]
	earth (ZED, HED)	10 (8)[a]	0.0198 (0.0833)[a]	13.79 (5.6075)[a]	2.422 (1.3011)[a]
Serious (Collapse)	all (ZED, HED, RD, HF, TD)	15 (11)[b]	0.5249 (0.8209)[b]	98.462 (20.866)[b]	14.235 (6.658)[b]
	earth (ZED, HED)	7 (6)[b]	0.8209	20.866	8.162 (6.947)[b]

a with exclusion of 3 cases: HED (H_d = 11.6 m, w_c = 1.6 m) with w_c/H = 13.8 %; HF (H_d =6.1 m, w_c = 60 cm) with w_c/H = 9.8 %; HED (H_d =55.5 m, w_c = 1.1 cm) with w_c/H = 0.02 %.
b with exclusion of 3 cases of collapse (1 HED, 2 TDs) and of 1 case with w_c/H = 0.525 % (< 20 cm).

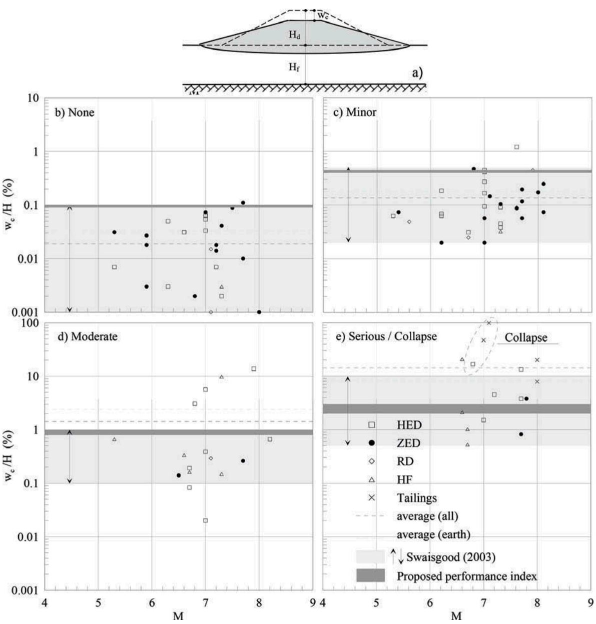

Figure 2. Dataset considered to define threshold values of the non-dimensional crest settlement.

is not representative due to the large scattering of the data that, however, are enclosed in the interval (w_c/H = 0.001 % ÷ 0.1 %) proposed by Swaisgood (2003).

From the data plotted in Figure 2b, a suitable upper bound of the settlement ratio can be detected in the range 0.09% ÷ 0.10% (dark grey area) for the level of damage "none" that encompasses more than about 95% of the selected cases.

A "minor" damage, observed for 33 case histories, 28 of which being earth dams, occurred for non-dimensional crest settlement of 0.02% to 1.2% (Figure 2c). The interval (w_c/H = 0.02 ÷ 0.5%) suggested by Swaisgood (2003) includes almost all the data that provide an average ratio w_c/H < 0.14%. For this level of damage, an upper bound of the non-dimensional crest settlement can be identified in the range 0.4% ÷ 0.45% which is very close to the value w_c/H = 0.5 % proposed by Swaisgood (2003).

A "moderate" level of damage was recognised for settlement ratios varying in a very large interval (Figure 2d): 0.02 % ÷ 13.79 % for all the dataset (16 case histories) and also with reference to the subset of 10 earth dams. The largest value of w_c/H = 13.79% was observed for a very small homogeneous earth dam (HED) with H_d = 11.6 m and w_c = 1.6 m. Excluding this case and the two further cases of a very small hydraulic fill with H_d = 6.1 m and w_c = 60 cm (w_c/H = 9.8%) and of a dam suffering very small settlements ($w_c \cong$ 1 cm, leading to w_c/H = 0.02 %), a "moderate" level of damage is seen to occur for w_c/H generally lower than about 5.6 % and a value in the range 0.8 % ÷ 1.0 % (dark grey area in Figure 2d) represents an upper bound for about 85% of data.

The level of "serious" damage (Figure 2e) encompasses 15 case histories including 3 cases of collapse for which it was w_c/H > 17%. Excluding these cases and the one related to damages reported as serious for a value of w_c/H < 0.6%, in the remaining 11 cases (including 6 earth dams), a "serious" level of damage was observed for non-dimensional crest settlements $w_c/H \geq$ 0.82%. Conversely, for the whole dataset the maximum settlement ratio is w_c/H = 20.9%, while for the earth dams only it is w_c/H = 13.3%. It is worth mentioning that for a "serious" level of damage, the definition of an upper bound of the non-dimensional crest settlement requires conservativism because of the large scatter of the data and of the unavoidable approximation in the procedure adopted to sort the damage descriptions available for each dam. Thus, an upper bound of the settlement ratio w_c/H is assumed in the range of 2% - 3%.

The following ranges of variation can then be defined for each of the four classes of damage:

- w_c/H = 0.09% ÷ 0.10% encompasses more than about 95% of the data for which level of damage "none" was observed (Figure 2b);
- w_c/H = 0.4% ÷ 0.45% represents a suitable upper bound for the cases of "minor" damage (Figure 2c);
- w_c/H = 0.8 % ÷ 1.00 % can be assumed as a reliable upper bound for about 85% of the cases for wich "moderate" damage was observed (Figure 2d);
- w_c/H = 2% - 3% represents a conservative upper bound of the cases for which a "serious" damage was identified (Figure 2e);
- w_c/H > 10% represents a conservative lower bound for the observed collapses (Figure 2e).

These data permitted to associate to each level of damage the threshold values of crest settlement ratio $w_{c,y}/H$ listed in Table 3, assumed as representative of the achievement of the limit states described in Table 1. Specifically, for the seismic analyses of earth dams, values of $w_{c,y}/H$ = 0.1%, 0.4%, 1.0% and 2.5% were assumed to check the occurrence of an Operative (OLS), Damage (DLS), Life Safety (LLS) and Collapse (CLS) limit state, respectively. As usual, the seismic performance must also be checked with reference to the freeboard f of the dam, so that the condition $w_c < f$ must be verified for each limit state (Table 3).

5 CONCLUDING REMARKS

A large set of data of the acceleration levels and the crest settlement attained in dams subjected to strong ground motions were collected from the literature including field observations and results of seismic response analyses.

Despite useful to understand the main features of the seismic response, the acceleration levels and the corresponding amplification ratios do not represent suitable parameters to provide a reliable evaluation of the seismic performance of a dam. Conversely, earthquake-induced crest settlements represent an appropriate measure of the level of damage induced by earthquake loading.

For each of the limit states to be checked in the seismic analysis of a dam, target values of the non-dimensional crest settlement were identified starting from a critical review of a large set of data consisting of 90 case histories of dams subjected to 42 large earthquakes. For these dams, the well documented damages induced by the seismic events were re-examined and sorted, with some engineering judgment, to relate threshold values of the settlement ratio $w_{c,y}/H$ to the achievement of a given limit state. Careful exam of the data permitted to associate threshold ratios $w_{c,y}/H$ = 0.1%, 0.4%, 1.0% and 2.5% to the occurrence of the Operational, Damage, Life Safety and Collapse limit states, respectively.

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REFERENCES

Aliberti, D. 2017. Valutazione delle condizioni di stabilità sismica di una diga in terra zonata. Tesi di dottorato in Ingegneria Civile, Ambientale e della Sicurezza. Università degli Studi Mediterranea di Reggio Calabria.

Aliberti D., Cascone E., Biondi G., 2016. Seismic performance of San Pietro Dam. *Procedia Engineering*. Vol. 158, 2016, p. 362–367. 6th Italian Conf. Researchers in Geotechnical Engineering, CNRIG 2016, 22–23 September, Bologna, Italy.
Aliberti D., Cascone E., Biondi G., 2017. Valutazione della risposta sismica di una diga in terra zonata. *In atti del XXVI Convegno Nazionale di Geotecnica*. Roma, Italy.
Amorosi, A. & Elia, G. 2008. Analisi dinamica accoppiata della diga Marana Capacciotti. *Italian Geotechnical Journal* 4: 78–96.
Cascone, E. & Rampello, S. 2003. Decoupled seismic analysis of an earth dam. *Soil Dynamics and Earthquake Engineering*, 23: 349–365
Costanzo A., Sica S., Silvestri F. 2011. Verifica della sicurezza in condizioni sismiche della diga sul fiume Melito (CZ). *Italian Geotechnical Journal* 2 (11): 38–67.
Elia, G. & Amorosi, A. 2009. Class A prediction of the dynamic behaviour of the San Pietro dam. *Proc. 2nd International Conference on Long Term Behaviour of Dams*, Graz.
Elia, G. & Rouainia, M. 2013. Seismic performance of earth embankment using simple and advanced numerical approaches. *Journal of Geotechnical and Geoenvironmental Engineering*, 139 (7): 1115–1129.
FEMA 2005. Federal Guidelines for Dam Safety, Earthquake Analysis and Design of Dams. http://www.fema.gov/media-library-data/20130726-1500-20490-5113/fema-65.pdf.
Gazetas, G. 1987. Seismic response of earth dams: some recent developments. *Soil Dynamics and Earthquake Engineering*, 6: 2–47.
Gazetas, G. & Dakoulas, P. 1992. Seismic analysis and design of rockfill dams: state-of-the-art. *Soil Dynamics and Earthquake Engineering*, 11: 27–61.
Ishihara, K. 2010. Performance of rockfill dams during recent large earthquakes. *5th Int. Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, (p. 1–11). San Diego, California.
Makdisi F.I., Kagawa T., Seed HB. 1982. Seismic response of earth dams in triangular canyons. *J Geotech Eng, ASCE*, 108(10): 1328–1337.
NTD14. Norme Tecniche per la progettazione e la costruzione degli sbarramenti di ritenuta (dighe e traverse). June 26, 2014. G.U. n.156, July 8, 2014 (in Italian).
zkan MY., Erdik M., Tunçer MA., Yilmaz Ç. 1996. An evaluation of Sürgü dam response during 5 May 1986 earthquake. *Soil Dynamics and Earthquake Engineering*,15: 1–10.
Prato, CA. & Delmastro E. 1987. 1-D Seismic analysis of embankment dams. *J Geotech Eng, ASCE*, 113 (8): 904–909.
Rampello S., Cascone E., Grosso N. 2009. Evaluation of the seismic response of a homogeneous earth dam. *Soil Dynamics and Earthquake Engineering*, 29 (5): 782–798.
Scasserra G., Pagliaroli A., Lanzo G. 2014. Verifica sismica di una diga in terra: confronto tra analisi dinamiche complete e agli spostamenti. *Incontro Annuale Ricercatori di Geotecnica*. Chieti, Italy.
Seed HB., Seed RB., Lai SS., Khamenehpour B. 1985. Seismic design of concrete faced rockfill dams. *Concrete face rockfill dams—design, construction and performance, ASCE*, p. 459–478.
Sica,S. & Pagano L. 2009. Performance-based analysis of earth dams: procedures and application to a sample case. *Soils and Foundations*, Vol. 49, No. 6, pp. 921–939.
Swaisgood, J. 2003. Embankment dam deformations caused by earthquakes. Proceedings of Pacific conference on earthquake engineering.
Troncoso JH., Krause AJ., Corser PG. 1999. Seismic design of lined face earth dams. Proceedings of Second International Conference on Earthquake Geotechnical Engineering, Lisbon: Balkema; p.703–709.
USACE 2004. General Design and Construction Considerations for Earth and Rock-Fill Dams, US Army Corps of Engineers, http://www.publications.usace.army.mil/Portals/76/Publications/Engineer%20Manuals/EM_1110-2-2300.pdf.
USCOLD 1992. United States Committee on Large Dams. Observed Performance of Dams during Earthquakes, Volume I.
USCOLD 2000. United States Committee on Large Dams. Observed Performance of Dams during Earthquakes, Volume II.