Preliminary evaluation of seismic risk of earth dams

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Abstract: It is well — known that reservoir is one of the constructions which can probable induce disastrous secondary seismic disaster. In Guandong Province, there are 294 existing large—and medium—size reservoirs, of which 274 have earth dams. These reservoirs have been built for several decades and effect of earthquake was not fully considered during the construction. In order to responce to the call of " International Decade for Natural Disaster Reduction ", the Chinese Authority requires to carry out earthquake damage prediction for these existing earth dams, aiming at making engineering decision scientifically. Obviously, this is an important task with a large amount of work. Thus, a two—step evaluation method is adopted by the authors. In the first step, the seismic risk of earth dams is preliminarlly evaluation; in the second step, those earth dams which have been considered to have high seismic risk in the preliminary evaluation will be evaluated in detail. It is shown from the preliminary evaluation result for 274 earth dams that, there are 33 earth dams of higher seismic risk, which should be further evaluated in detail.

1. PRELIMINARY EVALUATION METHOD FOR SEISMIC RISK OF EARTH DAMS

Seismic risk of earth dams can be determined by use of probability expression as follows:

$$P[S_i] = 1 - exp(\nu_{s\geqslant i}T) \qquad (1)$$

where

$$\nu_{s\geqslant i} = \sum_i P[s_i/I](\nu_I - \nu_{I+1}) \qquad (2)$$

In eq. (1) and (2), P[s_i] is the exceedance probability of seismic risk of earth dams, i. e. occurrence probability of earthquake damage of $\geqslant$ S_i degree to the earth dam; $\nu_{s\geqslant i}$ is the annual occurrence rate of earthquake damage of$\geqslant S_i$ degree; P[S_i/I]is the occurrence probability of earthquake damage of S_i degree to an earth dam in an earthquake of intensity I, i. e. the "vulnerability" of the earth dam; ν_I and ν_{I+1} are the annual occurrence rate of earthquakes of intensity I and I + 1 at the site respectively, i. e. "seismic hazard"; T is the reference period in design.

It is not difficult to show that, seismic risk of an earth dam relates to the vulnerability of the earth dam and the seismic hazard at the site of the dam.

Therefore, prediction of the seismic risk of an earth dam should be performed at the same time with the analysis of seismic hazard at the dam site and vulnerability of the dam.

2. PROBABILISTIC ANALYSIS OF SEISMIC HAZARD AT THE DAM SITE

Three main respects are included in the probability analysis of seismic hazard at a dam site.
(1) Zoning of the potential source region and determination of the seismicity parameters in the region.

The so — called potential source region is referred to the potential region situated in the vicinity of the dam site (region with the site as a centre and a radius of 250 km, hereafter called "effecting area"), in which destructive earthquakes would occur in the future. Zoning of potential region is mainly based on the local seismo—seological conditions, seismicity, geophysical characteristics in the interior of the Earth etc. Based on the above data in the effection area (Long. 108 °——119°E, Lat. 18° ——27°N), the potential source regions are zoned (Tab. 1).
Seismicity parameters of main potential source reions, including β values showing the ratio of

frequencies of great earthquakes to small earthquakes, annual occurrence rate of earthquakes v, the magnitude of which is gerater than the back ground magnitude (M_0 is taken as 4.0) and the upper limit of magnitude, M_u, are listed in Tab. 1 with the statistic results as well.

Tab. 1 Potential source region and its seismicity parameters

NO.	Potential source region	Seismicity parameters		
		β	v	Mu
1	North zhujiang	1.6299	0.0239	5.5
2	South zhujiang	1.6299	0.0121	6.0
3	Zhujiangkou	1.1999	0.0385	7.0
4	Yangjiang	1.1999	0.0356	7.0
5	Zhanjiang	1.1999	0.0182	6.0
6	Xuwen	1.1999	0.0055	6.0
7	Maoming	1.6299	0.0203	6.0
8	Luoding	1.6299	0.0110	5.5
9	Wuzhou	1.6299	0.0186	5.5
10	Yuebei	1.6056	0.0091	6.0
11	Heyuan	1.6056	0.0463	6.0
12	Haifeng	1.1999	0.0098	5.5
13	Nanpeng	1.0233	0.0507	7.5
14	Chaoshan	1.1999	0.0329	7.0
15	Zhangxia	1.1999	0.0453	7.0
16	Xunwu	1.6056	0.0370	6.0
17	Shoal Taiwan	1.0233	0.0211	7.0

（2）Attenuation relation of earthquake ground motion

Based on the statistics of isoseismal data of 16 historical strong earthquakes occurred in the effecting area, the relation of seismic effecting intensity, Is, magnitude, M, and epicentral distance, R, can be obtained as follows:

$$Is = 5.8520 + 1.4899M - 1.9986ln(R + 25) \quad (3)$$

$$\sigma_I = 0.210$$

where σ_I — — standard deviation of intensity I.

By means of the statistical relation between intensity and ground motion acceleration, a, in the west of USA and eq. (3), the attenuation relation of peak acceleration under average soil condition in this effecting area can be deduced:

$$lna = 6.587 + 0.495M - 1.149ln(R + 25) \quad (4)$$

$$\sigma_{lna} = 0.323$$

（3）Probabilistic analysis of seismic hazard

（A）Selection of analytical model. Although there is a variety of analysis methods for seismic hazard, yet, there are two kinds of seismic occurrence model only, i.e. uniform occurrence model and nonuniform occurrence model. Seismicity of this effecting ares is not high, but moderate and small earthquakes occurred frequently and relatively uniformly. Therefore, the uniform Poisson occurrence model is used. As for the potential source, it is considered as an equivalent point source with a fracture of zero length.

（B）Analysis method. Suppose ground motion intensity, S_0, is given, and the annual expected value, n_E, of an event not less than S_0 ($S > S_0$) occurred at the site is also given, we obtain the probability of an event not less than S_0 occurred at least once in the future of t years at the site as follows:

$$P[n \geqslant 1/S_0, t] = 1 - exp[n_E(S > S_0), t] \quad (5)$$

$$n(S > S_0) = v \int_0^R \int_{M_0}^{M_u} K\beta P(S > S_0/m, r)exp[-\beta(m - M_0)]f_R(r)d_m \cdot d_r \quad (6)$$

$$P(S > S_0/m, r) = \varphi(lny - b_1 - b_2M - b_3ln(R + R_0)/\sigma_{lny}) \quad (7)$$

where φ is normal supplementary function, y is ground motion parameter (I or a), b_1, b_2 and b_3 are constants in eq. (3) or (4) respectively, $f_R(r)$ is distribution function of distance.

3. VULNERABILITY OF EARTH DAM

The term $P[S_t/I]$ in eq. (2) is the vulerability of earth dam. In the preliminary evaluation, earthquake damage to 456 earth dams located at regions of different intensities during several strong earthquakes occurred recently in China (including the 1975 Haicheng earthquake of M＝7.3, the 1976 Tangshan earthquake of M＝7.8, etc.) are shown in Tab. 2 in the form of probability matrix, based on the field survey results. Different degree of earthquake damage are described in Tab. 3.

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Tab. 2 Probabilistic matrix of seismic damage to earth dams. P[S_i/I], in %

Seismic intensity	Degree of seismic damage, Si			
	Intact (Si)	Slightly damage (S₂)	Rather seriously damage(S₃)	Seriously damage(S₄)
Ⅵ	58.3 (77)*	33.3 (44)	6.2 (8)	2.3 (3)
Ⅶ	18.7 (53)	48.9 (139)	21.1 (60)	11.3 (32)
Ⅷ	7.1 (2)	39.3 (11)	17.9 (5)	35.7 (10)
Ⅸ	0 (0)	16.7 (2)	16.7 (2)	66.7 (8)

★ Figure in the bracket shows the no. of earth dams surveied

Tab. 3 Description of seismic damage to earth dams

Degree of damage	Description of damage
Intact(S₁)	No obvious damage
Slightly damage(S₂)	Only several longitudinal or transversal cracks, small in size, are found on the earth dam, or settlement and local uplift occurred; cracking in the wave resistant wall; small cracks are found on the pipeline or spillway structure. any kind of damage mentioned above belongs to slightly damage.
Rather seriously damage (S₃)	Seepage in the foundation of the earth dam increases slightly; no. of cracks, either longitudinal or transversal, is under 10 — 20, width and length of cracks not large, or settlement and local uplift occurred at the same time; stone blocks on the sloping blanket loosened slightly; cracking of the wave — resistion wall; structure installed with pipeline switch cracks and inclines slightly; spillway structure cracks etc.
Seriously damage (S₄)	Sliding or cracking in sliding occurred on the earth dam; seepage found on the slope of the dam; seepage in the foundation increases obviously; water sponts and sand blows found; water level of the reservoir decreases; no. of cracks on the dam, either longitudinal or transversal, is above 10—20; width of cracks above 5—10 cm, length, scores to hundred and more metres; serious seepage of the pipeline and in its vicinity, occurred; structure installed with pipleline switch fractured and inclined; affection the switch in use.

4. EXAMPLE FOR THE PRELIMINARY EVALUATION OF SEISMIC RISK OF EARTH DAM

Seismic risk analysis of the earth dam of the Huangshandong reservoir, Boluo Country, Guangdong Province, is given as an example.

Based on the seismic hazard analysis, distribution of the exceedance probability of the intensity at the site is listed in Tab. 4

Tab. 4 Distribution of exceedance probability of intensity at an example site

P	0.9	0.632	0.5	0.3	0.2	0.1	0.07	0.05	0.03	0.02	0.01
I	5.6	6.4	6.6	6.9	7.1	7.4	7.5	7.6	7.7	7.8	8.0

The annual occurrence rate ν_I of different intensities is calculated according to eq. (8)

$$\nu_I = \frac{-\ln(1-P)}{T} \qquad (8)$$

Based on the results in Tab. 4, the annual occurrence rate of different intensities is not difficult to obtain, i. e. , $\nu_6 = 0.024079, \nu_7 = 0.005754, \nu_8 = 0.000201$.

Substituting $P[S_i/I]$ values in Tab. 2 and ν_I values obtained in eq. (1) and (2) respectively, result of the preliminary evalustion for seismic risk of the dam is given in Tab. 5.

Tab. 5 Result of preliminary evaluation of seismic risk for an example dam

	Intensity			vSi	vS≥i	P[Si]
	6	7	8			
νI	0.024079	0.005754	0.000201			
vi-vi+1	0.000201	0.018325	0.005553			
vS1	1.0683E-2	1.038E-3	1.4E-5	1.1735E-2	2.4095E2	0.700
vS2	6.102E-3	2.715E-3	7.9E-5	8.896E-3	1.236E-2	0.461
vS3	1.136E-3	1.172E-3	3.6E-5	2.344E-3	3.464E-3	0.159
vS4	4.21E-4	6.27E-4	7.2E-5	1.12E-3	1.12E-3	0.054

Based on the Chinese Seismic Code for Building Design and the international criterion for basic seismic intensity, the exceedance probability of $P = 0.1$ is taken as a criterion value, therefore, $P[S_i] = 0.1$ is also taken as a criterion in the seismic risk analysis of earth dams. It is not difficult to show that, the seismic risk of the earth dam in the example lies between " rather seriously damage" (S_3) and " seriously damage " (S_4), therefore, in the preliminary evaluation, it is considered that the seismic risk of the dam is comparatively high, and it is necessary to evaluate further in detail.

5. CONCLUSION

By means of preliminary evaluation in the probabilistic analysis of seismic risk of 241 earth dams out of a total of 274 earth dams in Guangdong Province is smaller than "rather seriously damage", therefore further evaluation is not necessary to carry

out for these dams. But there are 33 earth dams, the seismic risk of which is higher than "rather seriously damage", therefore these dams need to be evaluated again in detail. number of earth dams neccessary for further evaluation will be greatly reduced through preliminary evaluation, thus, reducing a lot of work for the strengthening of the dams.

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