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Paper No. 1022. *(quote when citing this article)*
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

Dynamic Reliability Analysis For Power House Section Of Three Gorges Dam

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ABSTRACT

This paper does the three dimension dynamic reliability analysis for the power house section of the Three Gorges Dam by means of the three dimension finite element method and the earthquake response spectrum method, and calculate the dynamic reliability of the dam section in the different conditions. The calculating result is reliable, which show that the above calculating method is a better method in analyzing the dynamic reliability of the gravity dam.

KEYWORDS:

Dam; Dynamic; Reliability; Earthquake:

PREFACE

The gravity dam is a kind of large volume concrete structure, whether it is safe relates to the safety of many people life and property. The static reliability analysis was generally done in the former reliability analysis of the gravity dam, the dynamic reliability analysis was done only on condition of two dimension plain[1]. The main caution first is that the calculating work load doing three dimension analysis is too much, secondly is that some questions involved in the dynamic reliability analysis of the gravity dam, for example, the dam body acting with the reservoir water and the base, the structural destroying principle of the dam, is realized not enough, and the above method is hard to be mastered in the active work, so that the dynamic reliability analysis of the gravity dam was explored only in the simple condition, and the actual example used to the engineering has not been seen.

This paper propose a dynamic reliability analysis method of the gravity dam anti-earthquake by means of the dynamic reliability theory, the finite element method and the response spectrum theory., the main point of the above method is that the earthquake stress and response of the dam body is obtained by using the finite element method and in accordance with the earthquake response spectrum, then it is converted into the variance of the structure stress response, and eventually the dynamic reliability of each point in the gravity dam body is obtained in accordance with the structure dynamic reliability theory. The calculating work load of the above method in analyzing the structure dynamic reliability can be much less than that of the time-history analysis method, and can be calculated on the personal computer.

We do the earthquake dynamic reliability analysis to the power house section of three gorge dam using the above method just, provide the important basis for appraising the reliability of the dam section in the earthquake, and can meet the design requirement.

BASIC METHOD

1. Basic calculating method

According to the structure dynamics and random vibration theory, the probability distribution function of the equivalent random earthquake static load s_{ki} is:

$$P_{S_{KI}}(F) = \exp\{-v_K \tau \exp(-\frac{S^2}{2\sigma^2{}_{S_{KI}}})\} \tag{1}$$

F_{KI} is stress of the i node point in the k vibration mode, v_k is cross zero ratio

$$v_k = \frac{1}{\pi}\frac{\sigma_{\dot{s}k}}{\sigma_{s_k}} \tag{2}$$

$$s_{ik} = p_k \ \sigma_{ik} \tag{3}$$

$$\sigma_{s_{ik}} = f_k \sigma_{ik} \tag{4}$$

s_{ik} is the even value of the maximal stress on the k vibration mode of the i node, $\sigma_{s_{ik}}$ is its standard deviation, σ_{ik} is the standard deviation of the stress on the k vibration mode of the i node.

$$p_k = \sqrt{2\ln(v_k \tau)} + \frac{0.5772}{\sqrt{2\ln(v_k \tau)}} \tag{5}$$

$$f_k = \frac{\pi}{\sqrt{6}} \frac{1}{\sqrt{2\ln(v_k \tau)}} \tag{6}$$

$$v_k \approx \frac{\omega_k}{\pi} \tag{7}$$

τ is duration of the earthquake.

$$\sigma_{\dot{s}ik} = \omega_k \sigma_{s_{ik}} \tag{8}$$

According to the combination principle of the square root of the sum of square, the even combination value s_i of the maximal stress on i element is:

$$s_i = \left[\sum_{k=1}^{L} s_{ik}^2\right]^{1/2} \tag{9}$$

L is the vibration mode sum.

$$\sigma_{s_i} = \left[\sum_{k=1}^{L} S_{ik}^2 \right]^{1/2} \quad (10)$$

$$\sigma_{\dot{s}i} = \left[\sum_{k=1}^{L} \omega_k^2 \sigma_{ik}^2 \right]^{\frac{1}{2}} \quad (11)$$

2. The dynamic reliability analysis based on the first passage time criterion principle.

1). Fixing limit: When the times of crossing the assume with the limit x=b obey the poisson distribution, there is the below formula in the single side limit.

$$P_s(b) = \exp\{-\frac{\sigma_{\dot{s}}\tau}{2\pi\sigma_s}\exp(-\frac{b^2}{2\sigma_s^2})\} \quad (12)$$

Because the concrete compressive limit is far more than the its tensile limit, and is also far more than the compressive stress of the dam body, the tensile stress side is taken as the damage limit.

2). Random limit: There is the below formula in considering the random process of the damage limit.

$$P_s(b) = \exp\{-\frac{\tau}{2\pi}\frac{\sigma_{\dot{s}}}{\sqrt{\sigma_s^2+\sigma_b^2}}\exp[-\frac{b^2}{2(\sigma_s^2+\sigma_b^2)}]\} \quad (13)$$

In the above formula, σ_b is the standard deviation of the limit value b. In the formula (12), (13), σ_s and $\sigma_{\dot{s}}$ are calculated based on the formula (3), (5), (8), (10), (11).

3.Reliability index

β value generally used in the engineering expresses the structure reliability. When the structure resisting force is R and its standard deviation is σ_R, when the structure stress is S and its standard deviation is σ_S, the below formula express the structure reliability index β :

$$\beta = \frac{R-S}{\sqrt{\sigma_R^2+\sigma_S^2}} \quad (14)$$

Its reliability is :

$$P_S = \Phi(\beta) \quad (15)$$

R and σ_R are set based on the actual measurement value and experience in the above formula. S and σ_S can be obtained by the above method.

4. Affirmation of the damage limit

According to the data of the Danjiangkou hydro-junction closing to the Three Gorges Dam, we can obtain the below limit:

anti-tensile stress:	u=2.510	normal distribution
coefficient of variation:	v=0.111	

The above data is the structure maximal permissible anti-tensile strength, but the multi-kind limit must be taken in the actual engineering. According to the design strength value formulated in the concrete structure design standard, we can take the below limit:

anti-tensile stress:	u=1.100 MPa	normal distribution

coefficient of variation: v=0.111

Besides, according to the data of other organizations, we can take the below limit:

anti-tensile stress: u=1.760 MPa normal distribution

coefficient of variation: v=0.250

5. Calculating results and analysis

We calculate the structure dynamic reliability value in the four conditions which are the rigid base and full reservoir, rigid base and empty reservoir, elastic base and full reservoir, and elastic base and empty reservoir in the seven degree earthquake. Two group limit value is separately obtained as below :

u=1.10 MPa, v=0.111

u=1.76 MPa, v=0.250

The calculating results are as below:

1). First passage time criterion principle(see table 1):

Table 1

	Elastic base and full reservoir			Elastic base and empty reservoir			Rigid base and full reservoir			Rigid base and empty reservoir		
	P_0	$P_{.1}$	$P_{1.7}$	P_0	$P_{1.1}$	$P_{1.7}$	P_0	$P_{1.1}$	$P_{1.7}$	P_0	$P_{1.1}$	$P_{1.7}$
Inlet pipe	1.0	0.999975	0.989240	1.0	0.999999	0.992362	0.999950	0.998784	0.976160	1.0	1.0	0.991781
Fold slop	1.0	0.999995	0.988700	1.0	1.0	0.993080	1.0	0.999919	0.983718	1.0	1.0	0.992515
Dam heel	1.0	1.0	0.994600	1.0	1.0	0.995630	1.0	1.0	0.991657	1.0	1.0	0.997158
Dam toe	1.0	1.0	0.997490	1.0	1.0	0.997600	1.0	1.0	0.996633	1.0	1.0	0.997946
Up-ward curv-ing	0.999996	0.999996	0.990690	1.0	0.999980	0.004694	0.999998	0.999836	0.989473	1.0	0.999997	0.990308
Down-ward curv-ing	1.0	1.0	1.0	1.0	1.0	0.998260	1.0	1.0	0.997385	1.0	1.0	0.996790

P_0, when the limit is fixing and limit value is u=1.1 MPa; $P_{1.1}$ when the limit is random and limit value is u=1.1 MPa, v=0.111; $P_{1.7}$ when the limit is random and limit value is u=1.76MPa, v=0.250;

2). Reliability index (see table 2):

$\beta_{1.1}$ when the limit is random and limit value is u=1.1 MPa, v=0.111; $\beta_{1.7}$ when the limit is random and limit value is u=1.76MPa, v=0.250;

Table 2

	Elastic base and full reservoir		Elastic base and empty reservoir		Rigid base and full reservoir		Rigid base and empty reservoir	
	$\beta_{1.1}$	$\beta_{1.7}$	$\beta_{1.1}$	$\beta_{1.7}$	$\beta_{1.1}$	$\beta_{1.7}$	$\beta_{1.1}$	$\beta_{1.7}$
Inlet pipe	4.10	2.81	4.77	2.97	2.93	2.47	5.54	3.14
Fold slop	4.50	2.87	5.37	3.09	3.76	2.70	5.80	3.18
Dam heel	5.11	3.06	5.81	3.21	6.85	3.44	6.99	3.63
Dam toe	6.36	3.35	6.86	3.46	7.56	3.61	7.65	3.63
Upward curve-ing	3.45	2.65	4.63	2.95	3.52	2.65	4.62	2.92
Down-ward curv-ing	5.94	3.26	6.83	3.45	6.50	3.40	6.73	3.41

The calculating results analysis as below:
It is shown that the distribution of the dam body reliability is unified with the distribution of the dam body stress in according with the analysis result of the dynamic reliability. The larger the stress of any point in dam body is, the lower its reliability, conversely, the higher its reliability. That is to say that the reliability index β is inverse ratio with the stress S. In our calculating four conditions the reliability of the power penstock upward curving section is lowest, secondly the inlet of power penstock (the both reliability index value is just inverse, but the difference is very little), and then the dam back fold slope position, but the difference of the reliability index on the above three positions is very little. The reliability index of the dam heel, the dam toe and the power penstock downward curving position is higher, β value is more than 3.0 in the four conditions and u=1.76, v=0.25, value of three position is of very little difference. On the whole, the reliability on the dam body rigid base is less than that on the dam body elastic base in the full reservoir, but the reliability on the dam body rigid base is higher than that on the dam body elastic base in the empty reservoir, the reliability in the power penstock section is no much difference in the rigid or elastic base. Except the above five positions the rest field reliability is higher, it is separately $\beta_{1.1}>5.5$ and $\beta_{1.7}>3.4$ in the full reservoir, it is separately $\beta_{1.1}>5.8$ and $\beta_{1.7}>3.2$ in the empty reservoir, and the points of lower reliability among them is also near the above several positions.

CONCLUSION

According to the requirement of the hydraulic structure anti-earthquake design standard(in 1978), it need to calculate the tensile stress caused by the earthquake load, and the tensile safety factor of the concrete must not be less than 2.5. The maximal tensile stress(in full reservoir and rigid base) on the actual calculation is 0.65 MPa, its 2.5 time is 1.625 MPa, and is less than the standard strength 1.75 MPa of the C_{25} concrete, so that it can meet the standard requirement. That the safety factor 2.5 represent how large reliability is not a very clear question, because it involve the damage limit value and its standard deviation. As the front conclusion, the reliability index calculated in the limit u=1.76 MPa, v=0.25 is far less than that in the limit u=1.1 MPa, v=0.111, so that it is a question which deserve to be further studied.

About the question of the reliability limit value, we realize that the stress limit value must take the limit tensile strength value when the static stress superposes with the dynamic stress, that the stress limit value must not be too high and the strength design value is taken comparative proper in considering dynamic stress(actually, the static calculating result show that the mostparts of the dam body belongs to the compressive stress condition, the part position of the dam heel and the power penstock inside dam appear the tensile stress only). It must indict that the limit value permits to take the limit tensile strength and only require that the safety coefficient is not less than 2.5 in the twenty- second item of the concrete structure design standard.

According to the new standard and the research result of the correlation structure, that the safety coefficient is 2.5 is equal to β=3.2~4.2 on the whole. Our research result indicates that a few elements of the intake opening appear β=2.93 in the rigid base and full reservoir only, that every elements of the dam body appear β>3.4 in other conditions when the limit value is u=1.1 MPa, v=0.11, so that the structure reliability of the dam body can meet the standard requirement.

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