DYNAMIC ANALYSIS FOR POWER HOUSE SECTION OF THREE GORGES DAM

Li Zhengnong
(Wuhan University of Hydraulic and Electric Engineering, PR. China, 430072)
Li Guiqing
(Wuhan University of Technology, PR. China, 430070)
Meng Jifu
(Wuhan University of Hydraulic and Electric Engineering, PR. China, 430072)

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ABSTRACT

By means of three dimension finite element method this paper does three dimension dynamic analysis for the power house section of Three Gorge Dam, calculate the dynamic characteristic and the dynamic stress response in the different conditions, and make a special effort to analysis the earthquake response of the power house section of Three Gorge dam.

KEYWORDS :
Dam; Earthquake; Dynamic response;

PREFACE

Three Gorge Dam Engineering is a huge hydro-junction of very important significance, its many quotas are the first on the world, for example: the opening diameter of the generating power penstock of the power house section reaches 12.4 m, it will be of the larger affection to the dam dynamic characteristic and stress response. On account the fact that the dam safety relates closely to the life and property of a few hundred million people in the down reach, so that it is very necessary to do the dynamic analysis to it. We do three dimension dynamic analysis to the power house section of Three Gorges Dam by means of three dimension finite element method, and make a special effort to study its dynamic characteristic and dynamic stress response on condition of the earthquake load , therefore provide the effective basis for the engineering design..

DYNAMIC ANALYSIS METHOD

1. Calculating Condition

1). Geometric condition: Dam top elevation is 185.000m; dam base elevation is 27.000m; reservoir water level is 180.400m; width of each dam piece is 25m; length of dam along river axis is 25m(dam top), 118m(dam base).

2). Material data: Dam body concrete elastic modulus is 26GPa(static), 34GPa(dynamic), poisson ratio is 0.167, volume weight is 2.45t/m^3; dam base rock elastic modulus is 35GPa(static), 45.5GPa(dynamic), poisson ratio is 0.3, volume weight is 2.7t/m^3(volume weight take zero in the actual calculation); power penstock steel cushion elastic modulus is 210GPa, poisson ratio is 0.30, volume weight is 7.8t/m^3; reinforced bar elastic modulus is 200GPa, poisson ratio is 0.30, cushion elastic modulus is 1MPa, poisson ratio is 0.35; elastic modulus of the concrete circumscribing the penstock is 28.5GPa(static), E_d=1.3E, volume weight is 2.5t/m^3, poisson ratio is 0.167.

3). Earthquake data: According to the hydraulic structure anti-seismic standard(in 1978), when earthquake intensity is 7 degree, horizontal earthquake acceleration is 0.1g, vertical earthquake acceleration takes two third of horizontal one, maximal earthquake acceleration response spectrum value β_{max}=2.0, damping ratio takes 0.1, structure comprehensive active coefficient takes Cz=0.25.

2. Calculating model

1). Network divide: Divides dam body into four stratum along dam axis direction, each stratum thickness is 6.25m; Dam axis direction takes X axis, River axis direction takes Y axis, vertical direction takes Z axis; make use of five and six side cube elements, dam body is divided into 844 elements, dam base is divided into 788 elements, the sum is 1632 elements and 2223 nodes. Dam base limit is that upper reach extends 242m, down reach extends 176m, and depth takes 267m. Dam base restraint conditions are that two sides along X axis takes X direction, direction along river axis takes X and Y directions, and base part takes X, Y and Z directions.

2). Dynamic water pressure: Use the WESTERGUARD method, consider water affection in reservoir, reservoir water additional quality of i node in the dam upper reach side is :

$$M_{wi} = \tfrac{7}{8}\rho\sqrt{Hy_i}\,A_i \qquad (1)$$

ρ is water volume weight, H is water depth of dam front, Y_i is distance from i node to water surface, A_i is area contribution of the i node; water quality in dam intake power penstock is averagely distributed to each node inside penstock.

3). Cushion: Two sides of the power penstock section and upper side of part power penstock section behind dam set up the cushion, it Divides into 56 elements.

4). Pressure penstock: Steel cushion merged with its periphery concrete does calculation, their elastic modulus and quality exchange separately. The penstock section is divided into four parts of the different elastic modulus and volume weight, the sum has 108 elements of three dimension five side or six side cube.

CALAULATING RESULT AND ANALYSIS

There are four calculating projects as below: empty reservoir and rigid base, full reservoir and rigid base, empty reservoir and elastic base, and full reservoir and elastic base. each project of them calculates its structural natural vibration characteristic and earthquake dynamic stress.

1. Natural vibration characteristic

According to the requirement of three dimension dynamic analysis, dynamic reliability analysis and the structure character of the gravity dam, each of four projects calculates out ahead 20 frequency and vibration mode of dam body structure system(see table 1)

Table 1

No	Empty Reservoir Rigid Base		Full Reservoir Rigid Base		Empty Reservoir Elastic Base		Full Reservoir Elastic Base	
	Vibration Frequency (Hz)	Vibration Main Direction	Vibration Frequency (Hz)	Vibration Main Direction	Vibration Frequency (Hz)	Vibration Main Direction	Vibration Frequency (Hz)	Vibration Main Direction
1	0.932	x	0.925	x	0.859	x	0.852	x
2	2.419	y	1.983	y	2.128	y	1.728	y
3	3.619	x	3.53	x	3.335	x	3.25	x
4	4.639	x	4.23	x	4.416	x	3.84	y
5	5.947	y	4.82	y	4.674	y	4.06	x
6	7.453	z	7.28	z	5.220	z	5.12	z
7	7.864	x	7.30	x	7.170	x	6.71	x
8	8.218	x	8.00	x	7.859	x	7.09	y
9	10.17	x	8.62	y	8.459	y	7.67	x
10	10.87	y	9.52	x	9.320	x	8.75	x
11	13.43	x	12.5	y	11.63	z	10.8	y
12	14.74	x	12.8	x	12.84	x	11.2	z
13	15.21	y	13.2	x	13.04	y	12.3	x
14	16.42	x	14.0	x	14.06	x	12.8	x
15	16.79	z	15.2	z	15.86	x	13.5	x
16	17.55	x	15.9	y	15.93	z	13.7	y
17	18.74	z	16.2	z	16.80	x	14.9	y
18	20.60	x	16.3	x	18.27	y	15.1	z
19	22.03	z	17.4	x	18.64	x	15.7	x
20	22.06	x	18.0	y	20.38	x	16.9	x

According to table 1, we known that vibration of dam axis direction owns the greater part in ahead 20 vibration modes. secondary along river direction in three dimension analysis, because the rigidity of dam axis direction is relatively less, for example: among ahead 20 vibration modes of the full reservoir and elastic base project, the vibration of dam axis direction takes 11, 6 along river direction, only 3 in vertical direction. Natural vibration period extends as dam base flexible. natural vibration period of elastic dam base extends separately more 8.6 percent and 8.5 percent in empty reservoir and full reservoir than that of rigid dam base. Water has also certain affection to natural vibration character, natural vibration period of dam body Y direction of full reservoir extends separately 14.8 percent and 13.7 percent than that of empty reservoir in elastic base and rigid base.

Calculating results of each kind project have below law :

1). Vibration of dam axis direction is leading in first vibration mode, vibration along river direction is leading in second vibration mode, main vibration direction of ahead three vibration modes is the same one.

2). When the vibration along river direction or vertical direction is leading, the displacement of dam axis direction is very small; When the vibration in dam axis direction is leading, the displacement along river direction and vertical direction is very small.

3). That the elastic dam base has reaction to dam body can make the vibration displacement enlarge, vibration mode node move downward, and the contacting surface of the dam body and the dam base have the larger vibration mode displacement. Shown from our calculating results, participation factor of the X direction in first vibration mode is about 1.9, however participation factor of second vibration mode(e.g. along river direction) is slightly more than 2.0, maximal value is 2.1, it is slightly less than that of the general gravity dam, this shows that the rigidity ratio of the upper part and down part on calculating dam section is proper. The above conclusion is fundamentally the same as the reference [3]. This show that the calculating result in this paper is in keeping with the practice condition, has higher reliability.

2. Dynamic magnification factor of dam top

Dynamic magnification factor of dam top can be calculated in accordance with the below quotation, dynamic magnification factor of i node is :

$$u_i = \left[\sum_{k=1}^{L} \sum_{j=1}^{3} \phi_{ikj}^2 \beta_k^2 \eta_{kj}^2 f_j^2 \right]^{1/2} \qquad (2)$$

In the above quotation, ϕ_{ijk} is the vibration mode characteristic value of k vibration mode of i node in the j direction, β_k is the magnification times of the earthquake response spectrum of k vibration mode, η_{kj} is the participation factor of k vibration mode in the j direction, f_j is a fixed value, $f_x = f_y = 1$, $f_Z = 2/3$.

The above quotation is the popularization of that in the reference [2], e.g. it popularizes from one dimension to three dimensions. When considering the earthquake movement of three directions and calculating in according with the above quotation, the dynamic magnifying coefficient of dam top is as table 2:

Table 2

	Empty Reservoir and Rigid Base	Empty Reservoir and Elastic Base	Full Reservoir and Rigid Base	Full Reservoir and Elastic Base
Dynamic magnification factor of dam top	5.75	5.61	5.50	5.03

The above calculating result is similar to the reference [2], e.g. the dynamic magnification factor of rigid base is more than that of elastic base, but it is just contrary to the reference [3]; Dynamic magnification factor value of dam top is slightly less than that of the general gravity dam [2], which belongs to normal limit.

3. Earthquake stress of dam

When the movement of the ground takes X and Y direction, according to the earthquake response spectrum of the hydraulic standard(in 1978) we calculate out the stress of every part of the dam body as table 3 .

We can obtain as below conclusions from the above calculating result.

1). The maximal stress is located in the intake opening, when it is the full reservoir and rigid base; however the maximal stress is located in the upward curving section of the penstock, when it is the full reservoir and elastic base. The maximal stress is located in the upward curving section of the penstock, when it is the empty reservoir.

Table 3

Project	Empty Reservoir Rigid Base σ_{MAX} (MPa)	Empty Reservoir Rigid Base σ_{MIN} (MPa)	Full Reservoir Rgid Base σ_{MAX} (MPa)	Full Reservoir Rgid Base σ_{MIN} (MPa)	Empty Reservoir Eastic Base σ_{MAX} (MPa)	Empty Reservoir Eastic Base σ_{MIN} (MPa)	Full Reservoir Eastic Base σ_{MAX} (MPa)	Full Reservoir Eastic Base σ_{MIN} (MPa)
Penstock Intake Opening	0.360	0.364	0.550	0.650	0.385	0.439	0.425	0.507
Refract Slope of Down Reach	0.351	0.306	0.554	0.212	0.391	0.308	0.484	0.300
Dam heel	0.225	0.08	0.242	0.223	0.338	0.064	0.400	0.090
Dam toe	0.065	0.160	0.127	0.169	0.146	0.235	0.135	0.280
Down-ward Curving of Penstock	0.08	0.250	0.258	0.200	0.110	0.230	0.096	0.316
Upward Curving of Penstock	0.170	0.456	0.564	0.205	0.361	0.447	0.415	0.566

2). The maximal stress of the dam heel, the dam toe and the downward curving section in the elastic base is more than that in the rigid base, which is why the deformation of the above several locations in the elastic base is more than that in the rigid base.

3). The dam body stress in the full reservoir is universally more than that in the empty reservoir because of the action of the dynamic water pressure.

4). Except the location joined its upward curving section with the dam body, the stress of the back penstock behind the dam is relatively little. Except the location joined the intake opening and upward curving section with the dam body, whole penstock don't appear the centralized stress phenomenon, but the stress of the upward curving section is more than that of the downward curving section, which is contrary to the reference [3].

5). The dynamic magnification factor of the dam top in the empty reservoir is more than that in the full reservoir, which is why the ahead several one of natural vibration frequency in the empty reservoir is closely the peak value of the earthquake response spectrum than that in the full reservoir.

4. Safety analysis of anti-seismic strength

According to the requirement of the hydraulic structure anti- seismic design standard(china), when it studying the safety factor of the anti-seismic strength calculation, the concrete permissible stress can do the proper enhancement, but it can't overtake 30 percent; the temporary tensile stress is permitted to appear in the strength calculation of the gravity dam, but it must calculate the tensile stress caused by the earthquake load, and the safety factor of the concrete tensile strength can't be less than 2.5. According to the concrete test data of the Danjangkou hydro-junction where it is close to three Gorge Dam and was also designed and built by the Yangtze River Reaches projecting committee, the tensile stress of the C25 concrete is u=2.51 MPa, however the maximal value of the concrete main stress that we calculate out is σ =0.65 MPa, so that the stress safety factor of the power house section of the Three Gorge Dam is 3.86, and can meet the standard requirement.

CONCLUSION

a. By means of the finite element method we do three dimension calculation for the power house section of the Three Gorge Dam, and obtain the ahead 20 natural frequency and their vibration mode on the four load conditions of The dam body.
b. The mode participation factor of the first and second vibration mode is separately slightly less than 2.0 and slightly more than 2.0, and lower than the general gravity dam.
c. The dynamic magnification factor of the dam top is 5.61 on the condition of the full reservoir and rigid base, is 5.03 on the condition of the full reservoir and elastic base(no mass), and belongs to the normal limit. The dynamic magnification factor of the rigid base is slightly more than that of the elastic base, whichis fundamentally as same as the general gravity dam.
4. The rigidity ratio of the dam body is moderate comparatively.
5. The maximal dynamic stress of the dam body is at the intake water opening of the power penstock(full reservoir and rigid base) and in the upward curving section of the power penstock(full reservoir and elastic base). Minimal main stress is 0.65 MPa, maximal main stress is 0.564 MPa, the strength safety factor of the dam body can meet the standard requirement.
6. The stress on the elastic base is slightly higher than that on the rigid base.

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