Some analysis of 5.12 Wenchuan earthquake influence on the external vertical displacement of Yele dam

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Abstract: Yele Hydropower Station is in the upper reaches of the South Edgeworthia papyrifera river in western of Sichuan Province, which has a lot of complex features, such as its height is 124.5m, the dam's foundation of left and right are serious asymmetry (the foundation of left bank is the quartz diorite, while the foundation of riverbed and right bank are deep covering layer and the largest covering thickness is more than 420m). The basic seismic intensity is up to VIII degrees (fortification intensity is IX degrees). For the reason that it has the difficulty of a world-class, Yele dam has obvious feel at 5.12 Wenchuan earthquake, and it is very important to evaluate the whole operation of the dam that how about the external vertical displacement of the dam Changes at the earthquake. In this paper, it analyses the effects of 5.12 Wenchuan earthquake on the external vertical displacem of Yele dam, which from the variation and distribution of external vertical displace after the earthquake, combining with the results of three-dimensional finite element static and dynamic analysis, according to that it make the evaluation finally.

Key words: 5.12 Wenchuan earthquake  Yele dam  vertical displacement  influence

1 Introduction

Yele Hydropower Station is located in the middle reaches of the Dadu River in Sichuan province on the right bank of the western tributaries of the level – the upstream of Nanya River. This is located in Shimian County and Mianning county of Sichuan province. And which is the leader hydropower station of the Nanya River. Yele Hydropower Station is the second largest power station (2)-type projects, and the maximum height of asphalt concrete core rock-fill dam is 124.5m, which it is the third high dam of the construction of similar projects at home and abroad. And which second only to Turkey 139.0m high Kopru dam and Norway 128.0 m high Storglomvatn dam. The crest elevation is 2654.50m, and the basic earthquake intensity of the project area up to VII degrees (maximum security for IX intensity degrees).
left abutment of the dam is the basis of quartz diorite, thin coverage. And the right bank of the river is deep cover abutment foundation, the thickness of the largest covering more than 420m, which sets a precedent for the high base. The basis of the left and right banks is seriously asymmetry in the dam foundation. There are issues about the leakage of the foundation and abutment, the inhomogeneous deformation of foundation and so on.

Based on the above special structural and geological reasons of Yele dam, taking into account the case of the vertical displacement at the top of the dam when it is not affected by earthquakes, there have been uplift of the left and right banks or asymmetric settlement which would have a negative impact on potential to the safe operation of the dam. Especially under strong deformation, it is pay close attention whether it will endanger the safety of the dam after the operation. The epicenter from Yele dam 258km, Yele project area has obviously felt when the 5.12 Wenchuan earthquake. The paper is based on the changer of before and after and the distribution about the vertical displacement. Combining the analysis results of three-dimensional finite element dynamic we make a brief Analysis and feasibility studies about the 5.12 Wenchuan earthquake whether due to the impact of the external vertical displacement caused by the dam and the potential risk of harm.

2 Analysis of results about the Vertical displacement of the outside dam

2.1 Arrangement of Vertical displacement monitoring instruments

Displacement of the measuring points have arranged at each horse road of Yele dam surface and the top of the dam. One line is arranged at the dam upstream dam surface whose elevation is 2620m. Each line is layout at the top of the dam upstream side (bar) 0-008.80m slope, heart axis and downstream side of the wall (bar) 0+005.20m. Each line is arranged at the downstream dam surface whose elevation each is 2623.30m, 2594.50m and 2564.50m. 7 quasi-lines are arranged all over the dam surface. There are total of 94 points, including of 14 working basis points and 14 checking basis points with the displacement of measuring point arranged roughly 50m intervals of each quasi-line. Then one quasi-line as a temporary observation point is arranged at the upstream dam surface whose elevation is 2620m. And it is observed only during the construction period and prior to water. The working basis points of both ends of each alignment are arranged at the relatively stable points of the location of the two sides. And the working and checking points are checked by the controlling
network. Horizontal displacement is observed by TCA2003 total station with the quasi-line method. Vertical displacement measurement is measured by DNA03 electronic level. Cross section of dam surface displacement points are shown in figure 1.

![Figure 1](image)

**Figure 1** Layout of Yele dam surface cross section measuring point Displacement

### 2.2 Analysis of vertical displacement

Before and after the earthquake, changes and distribution of Yele Dam's external vertical displacement will be similar. Now basis on results of vertical displacement which located in the largest cross-sectional and 8.8m upstream of heart wall, we make an analysis.

Table 1 shows that changes in vertical displacement of 8.8m upstream of heart wall before and after 5.12 earthquake, Figure 2 and 3 are distribution map and processing map of the same part vertical displacement. So from the pictures, maps and data of history monitoring, we realize that:

1. Overall, characteristics of the vertical displacement of outside dam show that place of riverbed sink obviously while Cross-strait subside slightly or raising little. Upon completion of the dam construction changes in vertical displacement are mainly due to the soil’s further consolidation and stability.

2. Before and after the 5.12 earthquake, located in rock-fill of largest cross-sectional and 8.8m upstream of heart wall, change volumes of the vertical displacement are subside with a small number. And its maximum settlement volume is 14.6mm, so this data proves that earthquake has less effect on external vertical displacement of the Yele dam.
Table 1  Vertical displacement results table of upstream 0-008.8m of the top of the dam heart wall before and after the earthquake

<table>
<thead>
<tr>
<th>No.</th>
<th>TL04</th>
<th>TP10</th>
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<tr>
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<td>displacement (mm)</td>
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<tr>
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<td>31.50</td>
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<td>32.60</td>
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<td>123.50</td>
<td>143.40</td>
<td>136.00</td>
<td>114.60</td>
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</table>

Note: The displacement of the table "+" stating the settlement, "-" stating the ascension

Figure 2  Vertical displacement distribution of upstream 0-008.8m of the top of the dam heart wall before and after the earthquake

Figure 3  Vertical displacement processing line of upstream 0-008.8m of the top of the dam heart wall before and after the earthquake

3 Three-dimensional finite element dynamic analysis

Further, combining with the 5.12 earthquake strong motion seismic data obtained on the Yele dam to inverse the dam foundation materials and soil cover parameters. Then making use of the dynamic parameters obtained from the inversion to make three-dimensional non-linear finite element dynamic analysis for the dam. Then to understand the earthquake dynamic response characteristics of the whole dam body through the finite element dynamic analysis.

Yele dam has been laid a total of 9 Strong motion seismographs to monitor the earthquake response of dam. They are situated at ping grouting holes (dam 0-010.00 m), the top of the dam 1st
observation room (dam 0+069.25 m), 4th observation room (dam 0+220.00 m), 10th observation room (dam 0+376.90 m), 11th observation room (dam 0+610.00 m), as well as downstream of the dam surface 3 road 5th (2624.50 m elevation), 6th (2594.50 m elevation), 7th (2564.50 m elevation) of the largest cross-section of dam (dam 0+220.00 m) and the interior of monitoring corridor (2560.00 m elevation). Figure 4 is this.

Figure 4  Strong motion seismograph layout Plan of Yele dam

3.1 Acceleration response of the dam

Figure 5 are the distribution maps of peak acceleration in three directions for the dam surface. The peak is shown in table 2.

As can be seen from the chart that the response of the peak acceleration on the right bank is larger than on the left bank and at the dam crest is larger than the dam feet under the main shock of the 5.12 earthquake. Among them, the maximum peak acceleration of the lateral reaction of the dam surface occurred in the top of the dam on the right bank which is near the 0+440 section, which is 59.25 gal; The maximum acceleration response of the longitudinal reaction occurred in the top of the dam on the right bank which is near the 0+440 section, which is 51.97 gal; the maximum vertical acceleration response occurred in the top of the dam on the right bank, which is 51.31 gal. From the numerical of the acceleration we can see that the acceleration of the lateral reaction of the dam surface is maximum, the acceleration of longitudinal reaction is followed by, vertical acceleration is minimum; From the magnification we can see that the vertical acceleration maximum and the acceleration of the lateral reaction is minimum.

| Table2  Peak accelerations of Yele dam surface |
|-----------------|-----------------|-----------------|-----------------|
| item            | lateral         | longitudinal    | vertical        |
| maximum (gal)   | 59.25           | 51.97           | 51.31           |
| location        | 0+440 section on the right bank near the top of the dam | 0+440 section on the right bank near the top of the dam | The top of the dam on the right bank |


3.2 Displacement response of the dam

Figure 6 shows the maximum dynamic displacement of the dam surface distribution, and table 3 shows the peak values.

As can be seen from the chart, in the role of 5.12 earthquake’s main shock, the three directions of the maximum dynamic displacement response are basically gradually increase from the left bank to the right bank, and the top of the dam is bigger than the foot of the dam. On the dam surface, the consequent stream maximum displacement occurred at the top of the dam on the right bank to 2.52cm; the transversal stream maximum displacement occurred in the right bank near the top of the dam section 0+440 to 1.69cm; the vertical maximum displacement occurred in the top of the dam on the right bank to 1.92cm. From the numerical point of displacement, the consequent stream is to the largest, vertically is to the second, and the transversal stream is to the smallest.

<table>
<thead>
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<th>Table3</th>
<th>Peak displacements of Yele dam surface</th>
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<tr>
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<td>maximum (cm)</td>
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<tr>
<td>location</td>
<td>The top of the dam on the right bank</td>
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</table>
3.3 Destruction of soil stone dam discriminant

Through the finite element method, we can see that dynamic shear strain volume of the Yele dam is about $10^{-5}$ under the main shock of 5.12 earthquakes. Figure 7 and Figure 8 shows that the shear modulus is nearly equal to the maximum shear modulus and damping ratio is very small, which is far from undermining the state when the dynamic shear strain of soil and stone is about $10^{-5}$.

![Figure 6](image)

(a) Lateral  (b) Longitudinal  (c) Vertical

Figure 6 Maximum displacement contours of Yele dam surface (mm)

![Figure 7](image)

![Figure 8](image)

Figure 7 Strain curve of the soil and stone shear modulus with the dynamic shear strain

Figure 8 Strain curve of the soil and stone damping ratio with the dynamic shear strain

4 Conclusion

Through this analysis, we get same understandings to the impact of the 5.12 earthquake on the external vertical displacement of the Yele dam.

(1) The overall settlement of the Yele dam external vertical displacement is larger on the river bed or slightly smaller in cross-strait settlement and raises a little. After the construction of the dam is completed, changes in vertical displacement is mainly due to further consolidation of stability of soil, and the
general changes of the vertical displacement of embankment dams are basically the same.

(2) Before and after the 5.12 earthquake, the external change of the vertical displacement in the volume of the overall is the settlement, and the volume is little. And the biggest change of the settlement is 14.6mm, which is in the largest cross-section at the top of the dam, the rock-fill materials department of the heart wall upstream 8.8m. It’s show that earthquake effect on the external vertical displacement of the Yele dam is little.

(3) The results of the dynamic finite element show that under the effect of the 5.12 earthquake main shock, seismic dynamic response of the Yele dam overall is smaller, and the basic law for the reaction is greater on the top of the dam than the leg of the dam, which consist with the seismic response of the general law of earth-rock dam. However, due to the asymmetry of the dam foundation material, there is a different response to the general rules. Those are the reaction is larger on the left bank than on the right bank, and the reaction on the Yokogawa direction is equal to lateral direction. At the same time, the process of moving seismic shear strain is very small, which is far from undermining the state. So it has a high seismic safety.

The above shows that the impact of the 5.12 earthquake on the external vertical displacement of the Yele dam is extremely small. And after experiencing the earthquake, the operation of the dam is normal.

References
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