Design of the Lom Pangar dam in Cameroon

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Abstract. The Lom Pangar dam is a hydro project built by China International Water&Electric Corp which responds well to the Belt and Road Initiative. The author took part in the design of Lom Pangar dam and calculated the seepage and stability in different situations with several software. Several advices about the use of software are carried out. The results show that Lom Pangar dam has good stability even in the extreme situation.

1. Introduction

The Lom Pangar site is a hydro project in Cameroon, in central Africa, which is located approximately 350 km north to Yaounde in the eastern province, and approximately 120 km north to the town of Bertoua. The dam itself is located on the river of Lom, nearly 4 km downstream of its confluence with the Pangar river and about 13 km to the east of the confluence of the Lom and Djerem river.

The Lom Pangar dam reservoir will adjust the flow of the Sanaga river for the optimization of the existing power generations and create conducive conditions to the development of new sites. The project is the center piece of the government's strategy for medium-and-long-term. With the support of international institutions, the government is working to ensure the safety of facilities and focus on the environmental, social and economic impacts of the project.
The project includes:
- Establishment of a dam with a flow control structure of a water intake facility, a flood spillway.
- Development, construction, and operation of a reservoir of 6 billion m$^3$ and 540 km².
- Establishment of a 30 Megawatts hydroelectric power plant.
- Installation of a 90 kV transmission line at a length of approximately 120 km from the site to Bertoua.

The main dam with a height of 46 meters is of the mixed type. It includes a section on the river which consists of the concrete (called retaining wall), two wings which provide closure of the land bank (called embankment dam) and two transition dams connecting the retaining wall and embankment dam. It is complemented by a saddle dam on the right bank of the main dam. The reservoir have a maximum surface area of 590 km$^2$ with a storage capacity of 6 billion m$^3$. The authorities have decided to carry out a power plant equipped with four groups of 7.4 MW power unit at the same time as the construction of the dam.

The dam is consisted of four parts: transition dam, embankment dam, saddle dam and retaining wall. The main features of the dam are shown in Tab.1.

| Type                  | Transition dam | Embankment dam | Saddle dam | Retaining wall |
|-----------------------|----------------|----------------|------------|----------------|
| Type                  | Rocks with impervious core | Embankment zone with vertical core | Embankment zone with vertical core | Concrete |
| Maximum height        | 41.55 m        | 41.55 m        | 18.55 m    | 30 m           |
| Lowest altitude       | 636.0 m        | 636.0 m        | 659.0 m    | 635.0 m        |
| Highest altitude      | 677.55 m       | 677.55 m       | 677.55 m   | 665.0 m        |
| Crest length          | 75 m           | 350 m          | 435 m      | 160 m          |
| the width of the ridge.| 8.60 m         | 8.60 m         | 8.60 m     | 5 m            |
| Slope of upper side   | 1.7 H / 1.0 V - | 3.5 H / 1.0 V  | 3.5 H / 1.0 V | 0.45 H / 1.0 V |
| Slope of lower side   | 1.7 H / 1.0 V  - | 3.0 H / 1.0 V  | 3.0 H / 1.0 V | 0.45 H / 1.0 V |

The project is completed by China International Water & Electric Corp in July 2017 and it responses well to the Belt and Road Initiative. The design of the project is carried out by ISL. ISL is a French
studio of 50 engineers who worked for 30 years in the field of hydropower, dams, water projects and energy. The authors worked in ISL and took part in the design of Lom Pangar site.

2. Situations studied

We will consider the seepage and stability of its upstream and downstream slopes for the following situations:

1. Standard operating situation.
   This situation corresponds to the score achieved in the deduction for the normal operation status, the level 672.7 m. At the level below the dam, we will consider the level associated with the 100 years flood \( q = 1580 \text{ m}^3/\text{s} \), 641.8 m.

2. Situation at the end of construction.
   As an earthen dam, this situation theoretically corresponds to the end of the embankment construction, as the pore water pressures are not fully resolved.

3. Situation with rapid transient discharge.
   This is to verify the conditions of stability of the slope in saturated conditions. A case in which the discharge level declines rapidly to the selected level 649.0 m (minimum holding of restraint), while the core is completely saturated.

4. Situation with rare flood.
   In the situation of rare flood is a symbol of restraint is equal to the highest water level (673.8 m). And the level of the downstream, we use the value millennial peak flow, 643.5 m.

5. Situation with special flood.
   The unique situation of special flood is a case that the rated level of highest water level is exceptional, 674.3 m. In the downstream of the dam, we can take a value associated with the passage of flood for which we have the millennial off failure of a valve surface, as 643.8 m.

6. Situation with extreme flood.
   The situation of extreme flood corresponds to a degree of restraint at the side of the maximum flood level of the project, the 674.3 m. And the level of the downstream, we take the value associated with the passage of the flood peak, 644.6 m.

7. Accidentally seismic situation.
   It is in this case that we verify the conditions of stability of the dam under the action of the earthquake associated with the normal level of restraint 672.7 m.

The upstream and downstream water levels are given in the following table for each situation considered.

| Situation                                      | Event                        | Peak flow \( \text{(m}^3/\text{s)} \) | Laminated flow \( \text{(m}^3/\text{s)} \) | Upstream \( \text{(m)} \) | Downstream \( \text{(m)} \) |
|------------------------------------------------|------------------------------|--------------------------------------|--------------------------------------|-------------------------|-------------------------|
| Standard operating situation – case a          | Minimum flow                 | 25                                   | 25                                   | 672.7                   | 635.4                   |
| Standard operating situation – case b          | Q100                         | 1580                                 | 1580                                 | 672.7                   | 641.8                   |
| Highest water level                            | Q10000                       | 3475                                 | 2500                                 | 673.8                   | 643.5                   |
| Exceptional high water level                   | Q10000 + failure of a valve surface | 3475                               | 2700                                 | 674.3                   | 643.8                   |
| Danger water level (CD)                        | Flood                        | 4140                                 | 3200                                 | 675.2                   | 644.6                   |
| Void                                          | Rapid decline of water level | -                                    | -                                    | 649.0                   | 635.4                   |

3. Modelling and results

We studied both Ultimate Limit State and Service Limit State in each situation. However, limited by the length of article, only the modelling of standard operation situation is introduced here.
The software used in the design includes: GEOSEEP/W, GEOSLOPE / W, PLAXIS, ANSYS. The software STAB3D developed by ISL was also used in this design in order to calculate the stability of dam sections.

3.1. Modelling of saddle dam
We mixed up the model of saddle dam in the following way:
1. An intermediate section located between two bridges the drainage is chosen. It is assumed that the section of the drain at the foot of the core is perfect (no losses), and all were evacuated by the seepage.
2. A view of the Seep /W model used for the study of the intermediate section is presented below.
3. The upper level is set to a condition of forming load, 672.7 m, for example. Similarly, the output level is set by a constant equal to the load line of the natural ground.
4. The basic model is a flow line (neither in nor out flow at this level).
5. The slope of the dam is defined as a seepage face.

The view of saddle dam is shown in Fig.3 while the model and result of Seep/W and Slope/W is shown in Fig.4~Fig.6.
The results show that the seep and stability of saddle dam in each situation satisfy the need of the project.

3.2. Modelling of embankment dam

The modelling method of embankment dam is the same as that of saddle dam.

Similar results are obtained showing that the embankment has a good stability.

3.3. Modelling of retaining wall

The stability of retaining wall is the key point of this design, so two methods- Plaxis and ANSYS are applied to well calculate it.
3.3.1. Plaxis Method
The model of Plaxis is shown as Fig.9 and we model the upstream end of the wall rock by a transition slope 2/1 in order to address potential problems of boundary conditions.

A stability of the fracture is calculated in Plaxis. The software reduces the mechanical properties (cohesion and friction angle) of the materials of the model up to failure. The safety factor is defined as the ratio between the actual value (initial) of the mechanical characteristics and its value at the moment of rupture.

The Fig.10 shows the value of displacement (standard) at the time of failure. The maximum displacement appears at the top of the rock slope, and at the top of the retaining wall.

The elastoplastic fracture occurs with an inclined line in the body of the wall in the BCR, which is appropriate for this type of structure.

The factor of safety calculated by Plaxis is 1.77.

![Plaxis model of retaining wall](image)

Figure 9. Plaxis model of retaining wall

![Plaxis result of retaining wall](image)

Figure 10. Plaxis result of retaining wall

3.3.2. ANSYS Method
We are concerned primarily with the deformation and the stress field of the retaining wall on both side. According to the symmetry of the structure, we can build a model of half part of retaining wall.

We chose SOLID 186 as the type of mesh volume element and SURF154 component as the type of mesh surface.

According to the main symmetry, the displacement in the direction of the axis of the dam (axis X in Ansys) is zero.
The height of the structure is 41.55 meters, and the depth where the structure may influence is no more than 4 times of its height, i.e., 166m. So, it makes sense that there is no vertical displacement caused by the dam at the depth of 200 meters.

![Figure 11. ANSYS model of retaining wall](image1)

Similarly, we consider the region where is 200 meters away from the dam is far enough (in order to reduce the number of elements and the computational time).

According to the results of calculation, we can see that the movement in the 60 meters in depth regions tends to zero, which indicates that our assumption is correct. It can be concluded that the influence of the dam is limited in 100 meters deep. The maximum displacement occurs in the middle of the dam, 5.7 mm, nearly 0.01% of the height of the dam.

![Figure 12. Global displacement of retaining wall](image2)

It is found that the maximum displacement in the direction of the axis of the dam is upstream from the retaining wall is 2mm, as shown in Fig.13.

The maximum vertical displacement is at the crest of the retaining wall, is 4.1mm, as shown in Fig.14.
Figure 13. Displacement in the direction of the axis of the dam

Figure 14. Vertical displacement of the dam

Figure 15. Minor principal stress of the dam
According to the result of the minor principal stress, we can see that most of the retaining wall in the BCR is compressed due to gravity. The part with the traction is at the bottom of the retaining wall, the intersection of the vertical wall in the BCV and the foundation. So, we should be careful in constructing this part.

According to the result of the major principal stress, we can see that most of the retaining wall in the BCR is compressed due to gravity. The maximum compression is 3979 KPa, near to 4 MPa, which did not exceed the compressive strength of concrete (8mpa).

![Figure 16. Major principal stress of the dam](image)

The main conclusions of the study of the stability of retaining wall are the following:

- The wall is stable in every situation.
- There's no traction in the majority of the structure, and the wall is only in compression.
- The maximum displacement occurs at the crest of the dam and is 5.7 mm.
- The maximum compression is at the foot of retaining wall and is 4mpa does not exceed the compressive strength of concrete (8mpa)
- There is little interaction between the retaining wall and dam

### 3.4. Modelling of main dam

We study the different sections of the Lom Pangar dam as a function of the geometry and the role of the plot. Limited by the page, here only the results of sections 9-9 is presented.

The safety factor of the landslide calculated taking the partial coefficients of the foundation material into account is minimal (634.0m) and is equal to 2.1. The stability of the shift in the plot is better when the spillway flows.
Figure 17. Plan view of the study sections of the dam

Figure 18. Stab3D Model of section 9-9 of the dam

Figure 19. Stab3D result of section 9-9 of the dam
4. Conclusions
The design of Lom Pangar shows that it is necessary to prepare the model prior to start the calculation. Here are a few points to note:

1. The mesh size is the key link for the modelling. in ANSYS, the mesh size is more complex. First of all, we must choose the type of mesh according to the model after deeply considering the scope of application of each type. The size of the grid must be determined carefully: if the mesh is too dense, the computation takes more time; if they are loose, the result is not accurate. The generation of the mesh must be important, if the abnormal points are generated, the result is not accurate.

2. The limit condition is vital for the hydraulic model, the boundary conditions include the level, the load, the flow rate and hydraulic gradient. For example, using the software GEoseep, you need to think carefully before use the option 'potential seepage face review’. For the dynamic model, the boundary conditions include displacement, deformation, etc.

3. Materials used to construct dams in contrast to other types of artificial structures, especially unsaturated soil, are much more complicated. It is a pity that the tests for unsaturated soils are rare for in geotechnical investigation. Of course, this is partially due to the immature theory of unsaturated soil. The extensive earthworks on the retaining wall, the consolidation of embankment dam and the stability of rock blocks are also great issues to investigate.

In short, no matter how the software is advanced, it is just a tool for the engineer. As a real engineer, it is important to master the theories model of the project carefully, to deal with the issue and the results obtained. Otherwise, the engineer is just a computer without a brain.

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