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Team Control Number

71884

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2017
ICM
Summary Sheet
Short-time Benefit or Long-term Safety?

Abstract

For requirement I ,We come up with assessment criterions and then make an analysis of three options.Through multicriterion analysis,we draw a conslusion.

According to the conclusion from requirement I ,we argue that the meaning of studying option 3 is to assure a long-term safety for Zambezi River. Otherwise, the decision-makers will only choose option 1 which can save money and deal with the emergency for a short time.

Therefore,we take long-term safety as our first principle in modeling for requirement II.First,we choose the safe location for building the dam systerm according to the topography.Then we analyze the dam system through Bernoulli equation and continuity equation of fluid in hydraulics.Next, we use our model and some assumption to get calculation results. Finally,we analyze our results and give a strategy to face with emergency.

After modeling the dam system,we give an assessment of our model for weaknesses and strenghths.

Short-time Benefit or Long-term Safety?

Control#71884

February 12, 2018

Contents

1 Introduction

The Kariba Dam is located in the Kariba Gorge of the Zambezi River Basin between Zambia and Zimbabwe. The dam was constructed between 1956 and 1959 and supplies water to two underground hydropower plants located on the north bank in Zambia and on the south bank in Zimbabwe. In the first 20 years after the dam was constructed there were sustained heavy spillage episodes resulting in erosion of the bedrock to 80 m below the normal water level. This has resulted in instability of the plunge pool making the dam wall unstable and unsafe[1].

There are three available options for Zambezi River Authority(ZRA) to deal with the problem. We make a brief assessment considering the potential costs and benefits associated with each option. Three methods are as follows:

(Option 1)Repairing the existing Kariba Dam

(Option 2) Rebuilding the existing Kariba Dam

(Option 3)Removing the Kariba Dam and replacing it with a series of ten to twenty smaller dams along the Zambezi River

After making a brief assessment of three options,we focus on the option 3 and analyze the implement of this method. We model the topographic map of middle of the Zambezi River through the data from satellite and choose the appropriate location for building dams through our evaluation criterion.Then we analysze the dam system model and calculate the water capacity of every dam according to the location data.Then, we get the height,width,length of new dam and concrete materials which is used to building the dam.Besides,we come up with a strategy to deal with the potential emergency such as flooding,drought and earthquake to assure a long-term safety for Zambezi River.

Finally, we make an assessment of our dam system model and analyze the advantages and disadvantages.

2 Assessments Report of Three Options

2.1 The criterion of assessment

The assessment of three options require comprehensive criterions according to the reality.Considering that the time is limited,our team just come up with some important factors which will influence the cost and potential benefits in this paper.

The factors of every option's cost include economic cost,time cost,maintenance cost ,environment cost.

The factors of potential benefits include risk management,hydropower generation, social benefit, economic benefit,and environmental benefit.

2.2 Multicriterion analysis of repairing the Kariba Dam

(Cost) The report of Kariba Dam Rehabilitation Project[2] from authority says that the project is assumed to costs $ 294.2 million and costs 8 years to finish the whole project .Moreover,the Kariba Dam need to maintenance its nomal work after the rehebalitation project.The cost of maintenance is much money every year.As for the environmental cost,repairing the dam won't change the environment around the Zambezi River for now.

(Benefit) The benefit of repairing will prevent the failure of Kariba dam for now.The other aspects for hydropower generation,social benefit,economic and envionmental benefit won't change too much compared with the current situation.

Therefore,repairing the Kariba Dam is an effective method to deal with the current problem in a short run,at least for decades of years without considering emergent siatuation.

2.3 Multicriterion analysis of rebuilding the Kariba Dam

According to the Kariba Dam Zambia and Zambabwe[3] ,The old Kariba Dam was built in 2 stages.One satge was to built the dam wall and the Kariba South power cavren which costs $1320 million.The other stage built the Kariba Nouth power cavren which costs $480 million.And it took 5 years to finish the whole Kariba Dam project.

(Cost) Therefore,The expense of the old dam constructure except the hydropower project is about $840 million.The hydro power devise can work very well for now.If the Zambezi River Authrity rebuild the Kariba Dam,they just need to rebuild the dam and its cost is almost as much as 840 million.And we haven't consider the cost of removing the old Kairba Dam.In a conclusion,the total expense of rebuilding the dam is over 900 million and the time costs about 4 years.After rebuilding the dam,it still costs about every year to maintain the new big dam nomal function.

(Benefit) The potential benefits brought by the rebuilding the Kariba dam is the labor opportunity compared with option 1 because its workload is several times more than the option 1.As to the other benefits in the aspect of hydropower generation,social and environmental influence,there is no obvious change compared with repairing the Kariba dam.

Through analyzing the impact of rebuilding a new Kariba Dam,we conclude that it's not a wise choice for Zombezi River Authority to solve the current problem.

2.4 Multicriterion analysis of the new dam system

(Cost) The economic cost of this optin depends on the number and scale of new dams.It will approximately take 3 to 5 years to finish this project.Every new dam need to maintain but small dam costs less money than big dam.After the construction of new dam system,the environment of Zambezi will change grealty.The environmental cost is hard to estimate.

(Benefit) The benefit of this option is to deal with the emergent situation and promise the Zambezi River safety in a long term at least much longer than the old Kariba Dam.The water capacity will be enhenced and the dam system can generate more hydropower than old dam.Moreover,it can bring a lot of other benefits for social,economic and environmental benefis.

This project will cost much money and labour force.It will bring great change for Zambezi River and ensure the safety for a long term compared with option 1.

2.5 Report conclusion

Through our analysis,we conclude that the option 1 is the most effective method to deal with the failure of Kariba Dam for a short term and opton 3 is the safest method for a long term.The option 2 is not a wise choice for Zambezi River Authority.

Learning that the Kariba Lake has changed the surrounding geology situation and it locates around East African Great Rift Valley Seismic Belt,earthquake is a great threat for the Zambezi River safety.Therefore,we take the safety of long term as our first principle for the model of dam system.

Otherwise,The Zambezi River Authority will implement method 1 for safety of short time and our model and analysis for dam system is totally meaningless. The aim of our dam systerm model is to avoid the great damage and reduce the risk.

3 Assumptions

To simplify our model , we shall make some assumptions below:

a. We choose arch dams as the planned type. An arch dam consists of two main parts. One is the main concrete structure which is arch shaped, the other is the spillways to let water through.

b. There is only one spillway in one dam;

c. Water is incompressible and its lose while flowing is negligible;

d. The flow of water is steady and almost uniform which means within a reservoir the level of water is constant and the velocity of water is the same everywhere except for which near the spillway;

e. We omit the gain or loss of energy when water spills down from outlet of a spillway to the next reservoir;

f. Other factors such as the effect of temperature and all resistance acting on water are not under consideration.

4 The Definition of Symbols

We use a function $s(h, x)$ to describe the shape of the river where x stands for the distance from a chosen location to the outlet of Kariba lake along the river, h for the vertical distance from the river bottom to the chosen location and $s(h, x)$ for the width of the river correspondingly.

Symbol	Explanation
D_i	the ith dam
h_{i2}	the level of downstream for the ith dam (namely the height of the spillway)
v_{i1}	flow velocity of upstream for the ith dam
v_{i2}	flow velocity of downstream for the ith dam
Q	the whole rate of flow
x_i	the location of ith dam
U_i	the storage between the $i-1$th dam and the ith dam
$L(x)$	width of the river at x
$H(x)$	depth of the river at x
r_i	defined as $\frac{L(x_i)}{H(x_i)}$
η_i	defined as $\frac{L_{i-1}}{L_i}$
H_i	structural height
T_{iC}	sam thickness at crest
T_{iB}	dam thickness at base
$T_{i0.45H}$	dam thickness of crown cantilever at $0.45H$ above base
USP_i	upstream projection is a distance measured from the axis of the dam
DSP_i	downstream projection measured from the axis

USP_{iC}	USP at the crest
USP_{iB}	USP at the base
L_{i1}	straight line distance at crest elevation between abutments excavated to sound rock
L_{i2}	straight line distance at 0.15H above base between abutments excavated to sound rock
V_i	estimated volume of dam concrete
R_{iaxis}	horizontal distance at the crest from the axis to the line of centers
R_{i3C}	same as R_{iaxis} except measured to the outer line of centers

5 The Dam System Model

5.1 Topographic map model of Zambezi River

We use Google Earth to get the geographic information of the Zambezi River and then we analyze these data through Matlab and simulate the watercourse and bank of the Zambezi River.

Because of the topography is too complicated and it's very hard to calculate,we simplify the watercourse and use three trustum of pyramid pyramidals to calculate its volume.

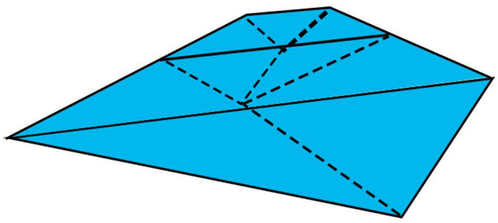

Figure 1: The model of watercourse

5.2 Choice of Dam location

Safety is the first principle of our model and we consider the earthquake threat in our model.Therefore,the location of every dam is vitally important for the whole dam system.We come up with some criterions that must be taken account into our model.

Criterions are as follows:

1. The location must avoid the East African Great Rift Valley Seismic Belt.

2. The location should be evenly distributed among the midstream of Zambezi River or diveded into several group to reduce the risk of emergency such as earthquake and flood for the whole dam system.

3. Every dam should be located between two mountains in order to save concrete material and enhance stability.

4. The area before the dam location should be open which means it can store water as much as possible.

5. The number of dam must be controled into 10-20 to avoid causing great damage to the local environment and species.

Through these 5 criterions,we choose the proper location through our topographic map.We select 11 locations to build small dams including the location of old Kariba Dam.These location is not evenly distributed because the topography is complicated. Therefore,we divided the 11 locations into 4 groups.Our aim is that each dam can face with emergency along with the dam in the same group and every group can work together.Eventually,they can avoid the great damage brought by flood,drought,earquake and other disaster to ensure the safety for a long term at least 100 years.

The detailed information of the locations is as follows:

Group	Number	longitude	latitude	altitude
Group 1	Dam 1	17°54′28″	26°10′32	582
	Dam 2	17°55′06″	26°16′38″	572
	Dam 3	17°57′47″	26°27′18″	533
Group 2	Dam 4	18°01′13″	26°45′50″	493
	Dam 5	17°59′22″	26°53′19″	495
	Dam 6	17°57′17″	27°01′01″	489
Group 3	Dam 7	16°31′19″	28°45′41″	488
	Dam 8	16°26′19″	28°49′04″	438
Group 4	Dam 9	15°38′19″	30°01′25″	337
	Dam 10	15°37′55″	30°10′52″	334
	Dam 11	15°38′49″	30°17′25″	328

Table 1: The detailed location information of 11 dams.

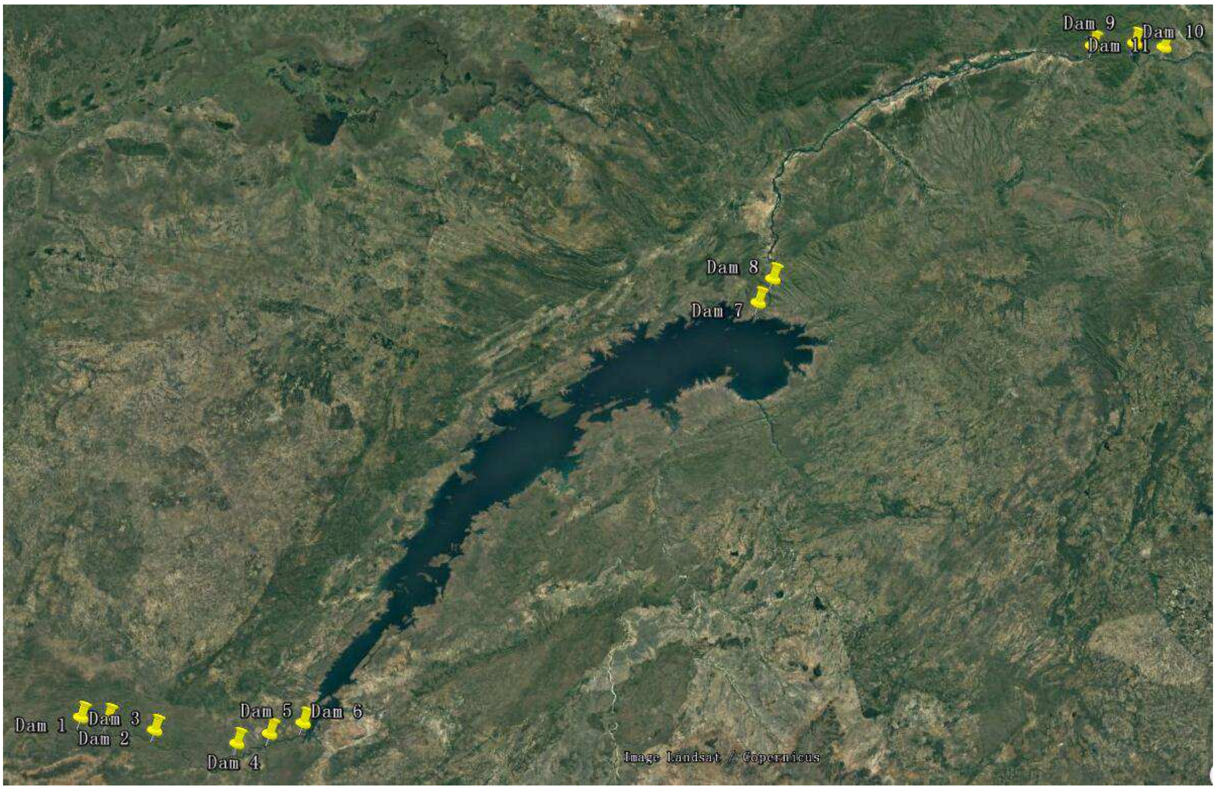

Figure 2: The location of 11 dams

5.3 Analysis of dam system model

From Bernoulli equation we can derive the relation between the level of water and the flow velocity, which states as

$$h_1 + \frac{v_1^2}{2g} + \frac{p_1}{\rho g} = h_2 + \frac{v_2^2}{2g} + \frac{p_2}{\rho g} \tag{1}$$

Details of this equation and symbols used can be found in [3]. To use it for our calculation, for the ith dam we choose section 1-1 and 2-2 as showed in the picture below. The pressure is considered to be the same at both 1-1 and 2-2. Thus we have

$$h_{i1} + \frac{v_{i1}^2}{2g} = h_{i2} + \frac{v_{i2}^2}{2g} \tag{2}$$

According to the fact, we assume that the whole rate of flow Q is the same before and after new dams are built. And according to continuity equation of fluid, Q is a constant number. The formula below is easily derived:

$$Q = v(x) \int_0^{h(x)} s(h, x) dh, \tag{3}$$

where $h(x)$ means the level of water. As a special case, for downstream $Q = v_{i2} S_i$ is satisfied. All n dams that we plan to build are marked as $D_1,\ D_2, \cdots D_n$. And now, we have the following:

$$\begin{cases} h_{i1} + \frac{v_{i1}^2}{2g} = h_{i2} + \frac{v_{i2}^2}{2g} \\ Q = v_{i2} S_i \\ Q = v_{i1} \int_0^{h(x_i)} s(h, x_i) dh \end{cases} \tag{4}$$

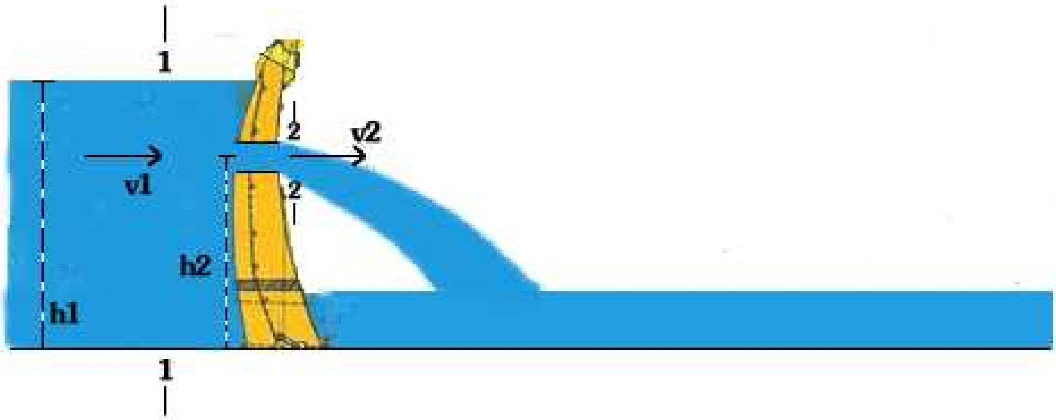

Figure 3: Using Bernoulli equation

for i from 1 to n, where x_i means the location of ith dam.

For the storage U_i between the $i-1$th dam and the ith dam, using integral we simply have

$$U_i = \int_{x_{i-1}}^{x_i} \int_0^{h(x)} s(h,x)dh\, dx \tag{5}$$

From the equations just listed above, if Q, $h(x)$, h_{i2}, S_i, x_i and $s(h,x)$ are given, we will be able to determine h_{i1}, v_{i1} and U_i.

Due to the difficulty of determining the shape of the river, we shall assume that the section of the river beyond the lake area is triangle shaped, described by the width $L(x)$ and the depth $H(x)$, pictured as below.

$$h_{i1} + \frac{v_{i1}^2}{2g} = h_{i2} + \frac{v_{i2}^2}{2g} \tag{6}$$

Further more, we suppose both $L(x)$ and $H(x)$ to be piecewise linearly changing and we define $\frac{L(x_i)}{H(x_i)}$ as r_i). Under these assumptions, we have ($\eta_i = \frac{L_{i-1}}{L_i}$) :

$$\begin{cases} s(h,x) = rh \\ U_i = \frac{(1-\eta^3)h_{i1}r(x_i-x_{i-1})}{3(1-\eta)} \end{cases} \tag{7}$$

as well as

$$Q = \frac{h_i^2 v_{i1} r}{2} \tag{8}$$

and

$$h_{i1} + \frac{v_{i1}^2}{2g} = h_{i2} + \frac{Q^2}{2gS_i^2} \tag{9}$$

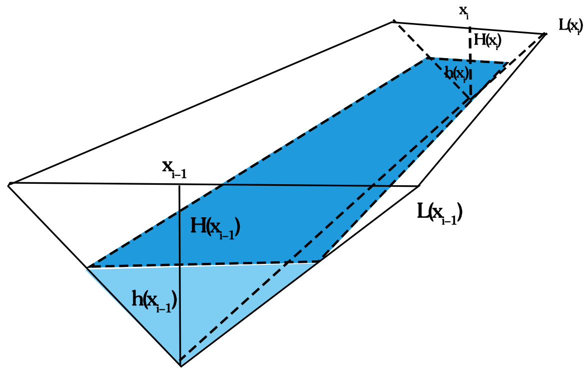

Figure 4: The shape of section

From equation (7), (8) and (6) we can solve out the maximum height h_{i1} and the capacity U_i of the ith dam.

Now let us deal with the structure of arch dams [4]. The picture below shows the structure of an arch dam. Arch dams are made of concrete materials. For the purpose of optimize the strength of concrete, they are designed to be arch to diffuse forces loaded upon them. The thickness of arch dams varies at different places. To determine all parameters of the ith dam, these are needed:

1. The structural height H_i chosen to be 1.2 times the maximum water level h_i;

2. The cross-canyon distance to the original ground surface between the abutments at the crest of the dam L_{i1}, chosen to be $r_i H_i$;

3. The cross-canyon distance L_{i2} to the original ground surface between abutments at the lowest theoretical arch elevation at 0.15H, chosen to be $0.15 r_i H_i$;

And now we have:

Crest thickness: $T_{iC} = 0.01(H_i + 1.2L_{i1})$

At $0.45H$: $T_{i0.45H} = 0.95T_{iB}$ $max.USP_i = 0.95T_{iB}$ $min.DSP_i = 0.0$

For the base: $T_{iB} = \sqrt{0.0012 H_i L_{i1} L_{i2} (\frac{H_i}{400})^{\frac{H_i}{400}}}$ $USP_i = 0.67T_{iB}$

$DSP_i = 0.33T_{iB}$.

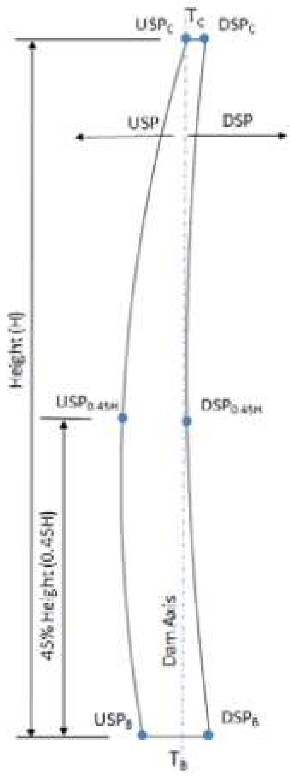

Figure 5: Structure of an arch dam

To compute the volume of concrete that we use to build a dam, we use:

$$V_i = 0.000002H_i^2 L_{i2}\frac{(H_i + 0.8L_{i1})^2}{L_{i1} - L_{i2}} + 0.0004H_i L_{i1}(H_i + 1.1L_{i1}) \tag{10}$$

For the sake of convenience of calculation, we let $h_{i2} = 0.8h_{i1}, S_i = 3.14(0.1h_{i1})^2, H_i = 1.2h_{i1}$

5.4 Analysis of model calculation data

We learn that the water capacity of the Kariba Dam is 180 Km^3[5] and the average discharge is 3400 m^3/s[6].In our calculation,we make the water capacity of the dam system is 180 Km^3 and the average dischage is 4000 m^3/s to assure the safety of the system.

The gravitational constant value is 9.6 Nm^2/kg^2 in our calculation.

Through the analysis of the dam system and the data from the Google Earth and the Internet,we get the calculation result.The deepest of every resevior is about 68.57m and the height of all of 11 dams is about 82.2m which has taken the risk height into account.The detailed information of every dam is as follows:

Through the calculation results,we can assure the water capacity is better than old Kariba dam but its concrete volume is more than old constructure which means these

Dam	Concrete Volume(m^3)	Water capacity(Km^3)
Dam 1	1.922×10^4	0.21
Dam 2	3.657×10^4	0.441
Dam 3	1.773×10^4	0.212
Dam 4	1.537×10^4	0.574
Dam 5	3.87×10^4	1.446
Dam 6	6.017×10^4	0.61
Dam 7	5.236×10^4	110.3
Dam 8	5.055×10^4	0.159
Dam 9	4.946×10^4	74.8
Dam 10	2.465×10^4	0.43
Dam 11	3.438×10^4	0.45

Table 2: The concrete volume and water capacity of every dam

dams cost much more than the Kariba Dam.And we draw a picture of the Zanbezi River after finishing this dam system.You can find the obvious change compared with initial situation(Figure 2).

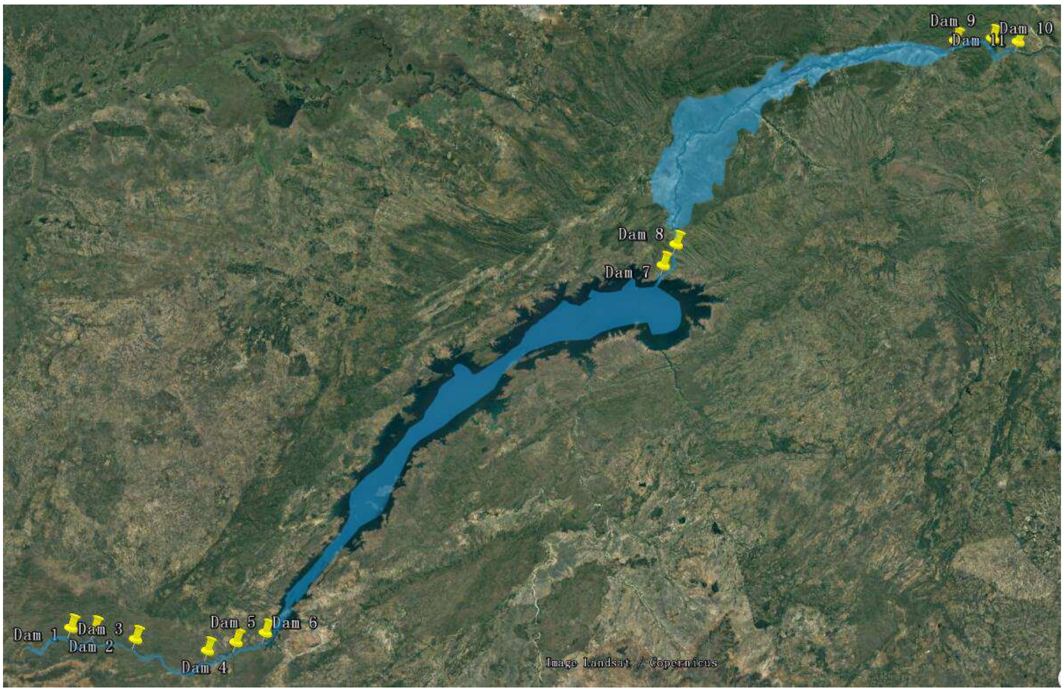

Figure 6: Structure of an arch dam

5.5 The impact on water cycle and environment

After finishing this dam system,the environment will hava great change compared with the past environment.The process of water evaporation will be enhanced because of the expand of the reservior.Therefore,the water cycle will reinforce and the rainfall will increase.

As for the impact for other aspects,we don't explain the change in this paper considering the complication.

5.6 Strategy for long term safety

From beginning,we divided the 11 dams into 4 groups in order to aviod the damage caused by disaster in the Zambezi River.Besides,the location is fairly safe for every dam.In the meanwhile,we increase the average discharge of Zambezi River in our calculation.The system almost can face with all kinds of emergency.If meeting with flood,the dams in the first and second group can absorb part of the flood at first to reduce the damage of flood.The third group and four group can almost absorb the left flood because of their great water capacity.Moreover,The water capacity of the whole dam system can deal with drought .Even the earthquake won't cause great loss for the Zambezi River.

Therefore,our strategy is to cooperate all the dams to deal with any situation especially in the help high-tech equipment.We believe this system can assure a long-term safety for Zambezi River at least for 100 years.

6 Assessment on the Model

6.1 Weaknesses

1. The choice of every dam location is based on the data from the satelilate and Internet.The accuracy of these data is not enough for considering such complicated project.In fact,we need to the most accurate data.

2. The model ignore many factors which have important influence on the real construction of dam such as wind power.

3. Our calculation of water capacity is simplified to three trustum of a pyramid. Therefore,the real water capacity is different from our results.

4. The model of water flow is simplified to a constant situation.In fact, the flow velocity is complex in different places.

5. We don't take the hydropower generation into account in our model because of the lack of relevent data.And this problem should be considered in reality.

6. The materials which are used to build these damsand the cost of the dam system is underestimated.The real project will cost more than our calculation.

6.2 Strengths

1. We take the safety for a long term as our first principle because we believe the decision-makers will choose option 1 if they want to save cost and deal with the failure of Kariba Dam.

The authoritative report says that the Rehabilitation Project can promise the safety for a while.Therefore,the meaning of our model is mainly aimed at aviod any emergency situation in a long term at least for 100 years.In this case,the decision-makers will consider the value of dam system.

2. In the process of modeling,we spend a lot of time to search the accurate data from the Internet because we want to get the real information.However,these accurate data is not available.Then we adjust our idea in time and simplify the calculation model and use the data from Google Earth to get the last results.

3. We divided the dams to 4 groups and divided their water capacity task through the different topography to make the water capacity
2.

[1]https://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/Multinational_-_Kariba_Dam_Rehabilitation_Project_-__ESIA_Summary_-_11_2015.pdf

[2]https://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/Multinational_-_Kariba_Dam_Rehabilitation_Project_-__ESIA_Summary_-_11_2015.pdf

[3] http://share.nanjing-school.com/dpgeography/files/2013/05/World_Commission_on_Dams_2000_Case_Study_Kariba_Dam_Final_Report_November_2000-2etc5lv.pdf

[4] https://en.wikipedia.org/wiki/Bernoulli's_principle

[5] https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/Arch_Dam_EM_36_1019-2012_Final%20Draft.pdf

[6]https://en.wikipedia.org/wiki/Kariba_Dam

[7]https://en.wikipedia.org/wiki/Zambezi