UNIVERSITI PUTRA MALAYSIA

SAFETY EVALUATION OF BAKUN CONCRETE FACED ROCKFILL DAM

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By

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ABSTRACT

This study deals with a 2-D plane strain finite element analysis of elastic linear (Hooke's law) and non-linear lastest Duncan-Chang Hyperbolic Model to study the structural response of the dam in respect to the deformation and stresses of Main Dam of Bakun's Concrete face Rockfill Dam (CFRD) project which is currently under construction located in Sarawak, Malaysia as the second highest CFRD in the world when completed. Dead, Birth and Ghost element technique was used to simulate sequences of construction of the dam. The comparison of rigid and flexible foundation on the behaviour of the dam was discussed. In the finite element modeling the concrete slab on the upstream was represented through six-noded element, while the interface characteristic between dam body and concrete slab was modeled using interface element. The maximum settlement and stresses of the cross section was founded and the distribution of them were discussed and tabulated in form of graphs and contours. The effect of reservoir filling loading have gradual effect to the dam response behavior. The computed results by the present method were found to be in good agreement with the comparison of value to the existing dams in the world.

PENILAIAN KESELAMATAN EMPANGAN BATUAN BERPERMUKAAN KONKRIT BAKUN

Oleh

HILTON @ MOHD HILTON BIN AHMAD

ABSTRAK

Kajian ini merangkumi analisis unsur terhingga 2-dimensi terikan dasar linear kenyal (hukum Hooke) dan Model tidak linear Hiperbola Duncan-Chang untuk mengkaji reaksi perlakuan struktur empangan terhadap anjakan dan tegasan. Untuk struktur utama projek Empangan batuan berpemukaan konkrit (CFRD) di mana pada masa ini masih dalam proses pembinaan yang terletak di Sarawak, Malaysia sebagai CFRD yang kedua terbesar di dunia apabila siap kelak. Teknik unsur Dead-Birth-Ghost digunakan untuk memulakan turutan pembinaan empangan ini. Perbandingan antara perlakuan empangan ini dengan asas dan tanpa asas terhadap perlakuan empangan ini juga dibincangkan. Dalam model unsur terhingga, papak konkrit pada sebelah hulu empangan diwakili oleh unsur enam-nod, manakala ciri antara-muka empangan and papak konkrit dimodelkan menggunakan unsur antara-muka. Anjakan dan tegasan maksimum untuk keratan rentas empangan telah diperolehi dan pengagihannya telah dibincangkan dan digambarkan dalam bentuk graf dan kontur. Kesan bebanan daripada tadahan air mempunyai kesan terhadap reaksi perlakuan empangan tersebut. Keputusan yang diperolehi mempunyai persefahaman yang baik dengan perbandingan keputusan daripada empangan yang sedia ada.

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APPROVAL FORM

The project attached hereto entitled, **"Safety Evaluation of Bakun Concrete Faced Rockfill Dam"** prepared and submitted by Hilton @ Mohd Hilton Bin Ahmad in partial fulfillment of the requirements for the Degree of Master of Structural and Construction Engineering is hereby approved.

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(Assoc. Prof. Dr. Jamaloddin Noorzaei) **Date**

Project Supervisor

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(Assoc. Prof. Ir. Dr. Mohammad Saleh Jaafar) **Date**

Panel Examiner

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(Assoc. Prof Ir. Dr Razali Abdul Kadir) **Date**

Panel Examiner

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CHAPTER 1

INTRODUCTION

1.1 General introduction

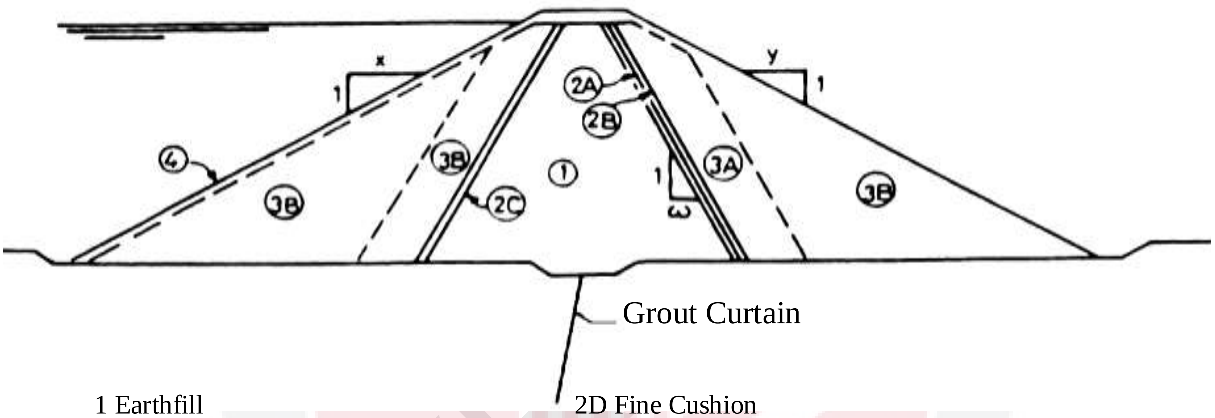
Malaysia, which comprises Peninsular Malaysia, Sabah and Sarawak, is located between latitudes 1° and 7° North and longitudes 100° and 119° East. It covers a total land area of over 330,000 km2. With rapid population growth and accelerating economic development, much of the world's natural resources are being depleted at an unsustainable rate. One of these resources is WATER. Previously seen as an infinite renewable source, the situation is now reserved: WATER is a precious and finite resource, which requires urgent attention to ensure sustainable use.

Dams form part of a controlled irrigation system but they also have other roles to play, i.e. flood control, hydroelectric power generation and also as soil conservation. There are a few factors need to be taken care of when designing a dam, i.e. safety, economy, efficiency and appearance. Safety and economy are factors that contradict to each other; however, we may design an economical dam without sacrificing the safety of the dam. In this report, Bakun Dam which is the third biggest Concrete Faced Concrete Dam (CFRD) in the world today is analyzed to its safety by using finite element method. Dam structure often store huge quantity of water at great potential energy and if in the case of failure does pose an imminent threat to population and property downstream. There are many cases reported due to dam failure and it cause very severe damages.

Dams are designed to withstand all applied loads, e.g. gravity load, hydrostatic, hydrodynamic pressures etc. The biggest loads on dam are the gravity load due to its massive self weight and also earthquake loads. The accuracy of the estimation of dam safety under static and earthquake (dynamic) and the design work require a good understanding of structural response of dam under both cases. As far as the design aspect concerns, static load and dynamic load are contradicts as in static we need to design the stiffest structure, however, in dynamic it is required to design the structure most flexible. Therefore, the engineers should be aware of both criteria and fulfills to its optimum dam design.

1.2 <u>Development in Rockfill Dam</u>

In first half of 20th century, most rockfill dam were of loosely dumped quarried rock with some version of core or upstream facing including wooden planking, concrete, or hand-placed rock dry-wall as well as only few impervious core rockfill dams was built prior to the 1940, (Maranha,1991). Leakage due to high fill deformation and opening of the joints in these types of dams has become obvious. From thence up until the 1950's, the design and construction of rockfill dams were a matter of empiricism. Then, dam engineers diverted towards the earth core rockfill for the following 20 years.



1 Earthfill
2A Fine filter (or filter drain)
2B Coarse Filter layer
2C (i) Upstream filter
(ii) Filter under Rip Rap
2D Fine Cushion
2E Coarse Cushion layer
3B Coarse Rockfill

Figure 1.1: Types of Earth and Rockfill Dam with Core. (Robin et al., 1992)

The transition to compacted rockfill for both earth-core and concrete-face dams occurred during the period 1955-1965 (Cooke 1984) as shown in Figure 1.2. This transition was possible because of the advent of heavy rollers and was particularly spurred Terzaghi's criticism of dumped rockfill for its excessive compressibility as well as more compatible with the needs for an impervious concrete membrane. Comparison between rates of post-construction at the crest settlement between dumped and compacted rockfill are shown in Table 1.1

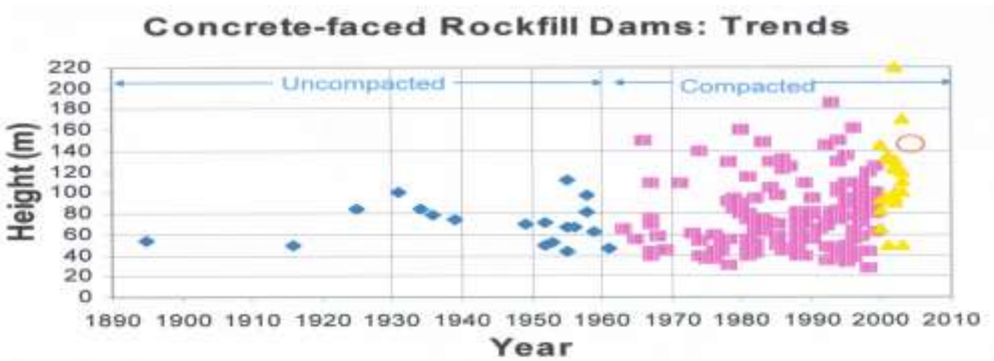


Figure 1.2: Trends in CFRDs over the past years

Table 1.1: Rates of post-construction crest settlement of dumped and compacted rockfills in CFRDs (Sherard and Cooke, 1987)

	Approximate Rate of Crest Settlement for 100m High CFRD (mm/year)		
Type	**After 5 years**	**After 10 years**	**After 30 years**
Compacted Rockfill	3.5	1.5	0.6
Dumped Rockfill	45	30	10

The leakages has been controlled to very reasonable levels, gradually the concrete faced rockfill dam (CFRD) resumed its place among rockfill dams. In this type of dam the foundation requirements being essentially the same as for the central core dam, other attributes such as simpler construction logistics, less cost, more compact layout, easier river handling solutions, shorter construction time, have been weighing in its favor. (Maranha, 1991) and (Robin et al., 1992).The cross section of concrete faced rockfill dam is shown in Figure 1.2.

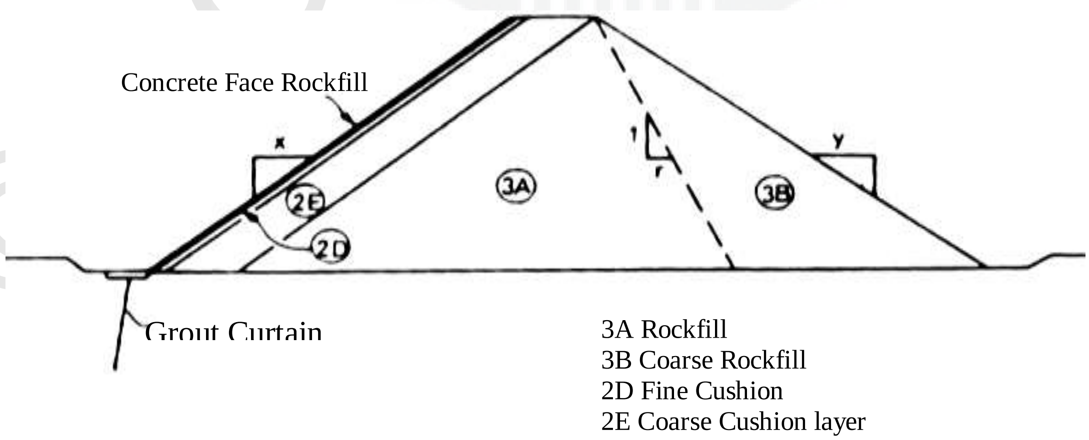


Figure 1.3: Type of Concrete Face Rockfill Dam (Robin et al., 1992)

Since dams are considered to be as mega projects, and infrastructures for any nation, hence, many international organization (International and National Commission on Large Dams (ICOLDS)), are involved in the documentation data of the concrete faced rockfill dam which was designed and constructed. After the evaluation of their implementations and operations, the legislation and guidelines on dam safety are issued, accordingly, to be followed by the owner of dams, consultants and construction dam industries. The history of CFRD development are tabulated in Table 1.2.

Table 1.2: Historical summary of rockfill usage in embankment design (Galloway 1939, Cooke 1984, Cooke 1993).

Approximate Time Period	Method of Placement and Characteristics of Rockfill	Comments
Concrete Face Rockfill Dams		
Mid to late 1800's to early 1900's	Dumped rockfill with timber facing	Early embankments constructed with timber facing. Typically of very steep slopes (up to 0.5 to 0.75H to IV). First usage of concrete facing in the 1890's. Height limited to about 25 m.
1920's to 1930's	Main rockfill zone dumped in high lifts (up to 20 to 50 m) and sluiced, although the sluicing was relatively ineffective. A hand or derrick placed rockfill zone was used upstream.	Rockfill typically sound and not subject to disintegration. Dam heights reaching 80 to 100 m. For high dams, cracking of the lacing slab and joint openings resulted in high leakage rates (2700 I/sec Dix River, 3600 I/sec Cogswell, 570 I/sec Salt Springs).
Late 1930'sto 1960's	High pressure sluicing used for the main rockfill zone. Rockfill still very coarse.	Cracking office slab, particularly at the perimeter joint, and high leakage rates a significant issue with higher dams (3100 I/sec at Wishon, 1300 I/sec at Courtright).
From late 1960's	Rockfill placed in 1 to 2 m lifts, watered and compacted. Reduction in particle size. Usage of gravels and lower strength rock.	Significant reduction in post-construction deformations due to low compressibility of compacted rockfill Significant reduction in leakage rates; maximum rates typically less than SO to 100 I/sec. Continued improvement in plinth design and facing details to reduce cracking and leakage.
Earth and Rockfill Dams		
1900 to 1930	Dumped rockfill	Use of concrete cores with dumped rockfill shoulders at angle of repose. Limited use of earth cores. Dam heights up to 50 to 70m.
1930'sto 1960's	Earth core (sloping and central) with dumped rockfill shoulders.	Use of earth cores significant from the 1940's due to the difficulties with leakage of C'FRD. Increasing dam heights up to 150 m.
From 1960's	Use of compacted rockfill. Typically placed in 1 to 2 m lifts, watered and compacted with rollers.	Improvements in compaction techniques. Early dams compacted in relatively thick layers with small rollers. Gradual increase in roller size and reduction in layer thickness reduced the compressibility of the rockfill. Significant increase in dam heights in the mid to late 1970's, up to 250 to 300 m.

CFRD is being recognized as one of the best choices among the dam consultants and engineers for its advantages. A list of several CFRDs which are already completed or still under construction, in the world is tabulated in Table 2.1.

1.3 Identified Problems

Up to date, a common assumption in modeling soil-structure interaction by earlier researchers and particularly, CFRD researchers is that they simulated their program with the foundation as rigid foundation (boundary fixation at the base of the dam), which leads to ignoring differential ground motions and its effects to the dam. This reduces the complexity of the problem (i.e. the number of additional degrees of freedom for accounting for the interaction), and make it possible to present general results. However, this does not present the actual situation, where a dam must rest on the foundations. Therefore, this study will include the effect of foundation (flexible foundation) with infinite elements.

As the actual instrumentation data are difficult to obtain due to certain circumstances, comparison of obtained results with the actual data cannot be done. The results are only been compared based on the results and observations by the previous researchers. The comparison is achieved by comparing different height, dimensions, shape of contours obtained, reasonable values of parameter being studied such as deformation and stresses.

At the initial period of analyzing Bakun Dam, I face difficulties in analyzing proper results for certain parameters. It is because of the Finite element analysis programme (Fotran) used does not considers certain elements, especially face slab elements. However, with some modification by eliminating certain criteria by the experts, it runs successfully. The results obtained are reliable since it shows patterns acquired of analyzing the dam with foundation compared to rigid foundation. Therefore, it is important to be aware of the limitation of the program provided.

1.4 Objectives of Research

1.4.1 General Objective

The main purpose of this research is to study the structural response of Bakun Dam due to static load by simulating finite element principles in linear and non-linear analysis. The type of load is identified, and analysis is done based on the loads specified. This research also compares the analysis of Bakun Dam in two cases i.e. Main Dam with rigid foundation as well as with flexible foundation. The study of structural response of the dam is based on deformation and stresses which is the principal safety evaluation of a structure.

1.4.2 Specific Objectives

The specific objectives of this project are listed as follows:-

a. By using provided 2-D program, the study of structural response of Bakun CFRD is being done. The program has the following features:-

   (i) Simulation of Birth, Dead and Ghost element technique

   (ii) input parameters for the material linear and non-linear

   (iii)contact between any different material represent interface behavior

   (iv) simulation of loading during dam construction and reservoir filling

b. To analyze the relation between dam structure and also soil media (thus known as flexible foundation), then compares with analysis with rigid foundation,

c. To study the safety of the dam from results obtained from static load cases.

d. Study the sequence of construction based on ghost, birth and dead element techniques by using provided finite elements program.

e. Study the sequence of construction with reservoir fillings using the provided finite elements program.

f. To study the face slab response to the dam as this is the most crucial section on CFRD as it always forms leakages and cracks.

1.5 Scope of study

The scope of study under this project is to analyze the behaviour of Bakun Dam in non-linear for both static and dynamic analysis. The study has been carried out within the following scope:

(i) By browsing previous research in journals and books of designing CFRD and their findings of the dam which covers the static linear and non-linear analysis. Then, by considering better results, some justifications are made.

(ii) Modeling and dicretizes of actual dimensions of Bakun CFRD based on finite element principles.

(iii) Verification of program is done based on experimental data available by previous researchers on their published papers.

(iv) Simulation of sequence in construction by using Dead-Birth-Ghost techniques which similar to the actual construction.

(v) Study the structural response of Bakun CFRD and the analysis is presented as follows:-

✓ Displacements (Horizontal and Vertical)

✓ Stresses (Normal stresses, σ_x and σ_y , and shear stress, τ_{xy})

✓ Principal stress (P_{max} and P_{min}) for non-linear analysis

There are 2 cases being investigated for each analysis above:

- Without Foundation (Rigid Foundation)
- With Foundation (Flexible Foundation)

Presentation of analysis will be in form of:-

✓ Graphs

✓ Contours

1.6 Organization of Reports

In this project, the reports are arranged accordingly to give basic understanding in using the finite element programming used to analyze Bakun Dam. There are divided into chapters as follows:-

Chapter 2: Literature Review

This chapter gave basic idea of CFRD dam and illustrates the common CFRD dam section which described each section schematically. The previous investigations prior to this project on CFRD dam analysis for both static and dynamic loading are also described. This is important since we can predict the common behavior of most CFRD.

Chapter 3 to 5 represents the fundamental and principle used in analyzing Bakun Dam by using Fotran finite element programming.

Chapter 3: Fundamental and principal of Finite Element Method.

This chapter described from the basic fundamental in finite element. However, the emphasized to the 2-D strain plane element, by which Bakun Dam are idealized. Dynamic and non-linear approaches to finite element are also described.

Chapter 4: Non Linear Models

For this chapter, since the model used in the analysis of non-linear is "Duncan Model", his model is described in details in this chapter. The equation of non-linear properties which is used in analyzed the dam is also highlighted. Sample of calculation are also given.

Chapter 5: Bakun Dam Analysis

Chapter 5 presents the results of finite element analysis Bakun CFRD models in linear and non-linear analysis with respect to deformation and stresses. The results are discussed in details and comparison is made due to previous findings as well as theory.

Chapter 6: Conclusions and Recommendations

The last chapter which gave the summary of results and overall study. The recommendations for future research are also being proposed here.

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