Christian Kutzner

Earth and Rockfill Dams

Principles of Design and Construction

EARTH AND ROCKFILL DAMS
PRINCIPLES OF DESIGN AND CONSTRUCTION

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Principles of design and construction

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A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1997

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Published by
A.A. Balkema, P.O. Box 1675, 3000 BR Rotterdam, Netherlands
Fax: +31.10.4135947; E-mail: balkema@balkema.nl; Internet site: http://www.balkema.nl

A.A. Balkema Publishers, Old Post Road, Brookfield, VT 05036-9704, USA
Fax: 802.276.3837; E-mail: info@ashgate.com

ISBN 90 5410 682 4

©1997 A.A.Balkema, Rotterdam
Printed in the Netherlands

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Notes:
Slopes are figured out '1V : mH' or '1 : m'. '1' always indicates the vertical component.

If there is no other indication, dam sections show the upstream side on the left.

Foreword

In the course of the past hundred years, modern structures of embankment dams for water reservoirs and hydropower plants emerged from a continually evolving fundamental basis consisting of extensive knowledge about soil and rock mechanics, constructional engineering and calculating procedures. This fundamental basis is treated in the literature by means of specialist articles which reach an immense number of publications.

This book was written to consider and treat all specialist fields and peripheral know-how, and its most important goal has been reached, as this knowledge is an indispensable requirement for each engineer specializing in dam design and construction. It offers the necessary technical basis to both the young student engineer and the experienced expert to pursue further undertakings. It may be emphasized that the topics are described in an easy, comprehensible, and extensive way.

In many regions world-wide, the tremendous increase in population requires further construction of dams in order to safeguard basic living conditions with regard to energy and nutrition. Due to restricted habitat space and scarce resources, nowadays it has become imperative that essential provisions, such as sufficient water supply, shall be guaranteed for the following generations. This leads to the conclusion that dam construction has become indispensable. Existing dams need to be kept safe from the operational point of view.

The German Committee on Large Dams (DTK, 'Deutsches Talsperren-Komitee') being a member of the most significant international dam construction forum, the International Commission on Large Dams (ICOLD), has taken up the task of transmitting to experts from all over the world any discovery, experience and know-how gained by professional German dam engineers. They shall even introduce norms, guidelines and recommendations.

This book achieves this aim in a convincing way. Because of the standards requiring the highest technical levels, it is the conviction of DTK that this book makes a German contribution to international evolution in the dam construction field, since the reader is led through all continents of the world by well portrayed examples of dam projects.

The book reflects the many years of experience, diligence and high professionalism of the author. It remains to say that this English edition may meet with as much response as the German first edition.

Professor Dipl.-Ing. Wolfgang Haug
President of the German Committee on Large Dams
January 1997

Preface

In this book an attempt is made to describe methodically the principles of design and construction of earth and rockfill dams. The problems to be solved and the questions to be answered by those involved are presented in the same order as they will come up in the different phases of work. Starting with preliminary works, proceeding first to the design, then to the construction work and finally to the monitoring of the structure. This method of following up the problems was selected to demonstrate the requirement of the permanent presence and cooperation of the geotechnicians involved – from the preliminary works up to the commissioning date and, if appropriate, later as a consultant for the owner. In no way is it advisable that isolated groups, without close contact with each other, should work on the details of design and construction.

The problems discussed herein reflect the experiences which I was able to collect during 20 years of professional activity in the field of earth and rockfill dams. Notably, the basic knowledge of dam engineering and experiences of other experts are presented as I have deemed necessary and helpful to cover the wide range of geotechnical problems in this field – as I hope, for the benefit of the readers. Thankfully, I acknowledge the fruitful advice given to me by well known experts, and the many professional discussions in the course of national and international symposia and congresses.

Whoever has undertaken the task of compiling a book will know that expert knowledge is not all that is required to complete it. In this aspect I recall with great thanks the help and support of my wife who has, over the years, borne with me the burden of excess work and restricted family life. She is also due credit for having the book completed. My thanks to other colleagues, assistants, institutions and companies contributing to the work are expressed in the acknowledgements.

This book is the revised English version of my book *Erd- und Steinschüttdämme für Stauanlagen*, which was published in German by Enke Verlag Stuttgart in 1996. The user will not expect to find comprehensive answers to all questions in this wide field. I have tried to address the main problems and the different approaches to their solution which have developed in different countries. I am confident the large number of references will help to show the way through details which may need further clarification.

It is, finally, my wish that my colleagues will accept the book as an aid in their work. Beginners may draw from it basic knowledge of the geotechnical problems of dam engineering; experienced colleagues may more easily find a suitable approach to questions whenever such an approach is not readily present.

Christian Kutzner
November 1996

Acknowledgements

The author acknowledges with thanks the support and cooperation of experts in the profession, of colleagues, institutions and companies who gave most valuable help in contributing to the text of the book and in giving additional information for the readers.

These are the following personalities:
Prof. Dipl.-Ing. Wolfgang Haug, President of the German Committee on Large Dams, with the Foreword.
Mrs Anka Both from Lahmeyer International, who drafted a part of the diagrams and drawings.
Dr.-Ing. Wolf-Dieter Geiseler, who reviewed the sections on asphaltic concrete and who gave valuable information by verbal and written communication.
Dr.-Ing. Klaus Hönisch with his review of Chapter 8 and related suggestions.
Prof. Dr.-Ing. Theodor Strobl for written communication.

The following institutions and companies submitted photographs, in this way helping to realize the pictorial part of the book:
Bauer Spezialtiefbau GmbH, Schrobenhausen, Germany.
Dynapac Maskin AB, Solna, Sweden.
Glötzl Baumesstechnik, Forchheim-Bahnhof, Germany.
IBF, Institut für Bodenmechanik und Felsmechanik, Universität Karlsruhe, Germany.
Interfels GmbH, Bad Bentheim, Germany.
LI, Lahmeyer International GmbH, Consulting Engineers, Frankfurt am Main, Germany.
Maihak AG, Hamburg, Germany.
Strabag Bau-AG, Köln, Germany.
Trischler & Partner GmbH, Darmstadt, Germany.
Troxler Electronics GmbH, Alling, Germany.

Lahmeyer International and their clients have enabled the author to improve his knowledge of dam engineering, to apply it in practice, and finally to transfer the know-how to others. Their noble assistance in making documents and literature available has been invaluable help.

CHAPTER 1

Introduction

The design and construction of earth and rockfill dams always result in a unique structure. Necessarily, dam engineering – like any other engineering discipline – has to follow basic rules which can be noticed in all structures as design criteria or as constructional peculiarities. Such criteria and peculiarities are discussed in this book. We will notice that the variety of natural construction materials and of potential dam locations demands that designers and builders show extreme scientific and practical effort. It is a challenge for flexibility and innovation.

Such effort can only be successful on the base of proven engineering procedures. Starting design work without respect for known geotechnical rules would lead to extended working time and would involve risks for the safety of the structure.

Nowadays no engineer would like to follow exclusively the methods of 'trial and error' and 'learning by doing'. On the contrary, there is a tendency to put too much confidence in the result of computations, thereby underestimating the imponderabilities of nature. Such imponderabilities exist not only due to the limitation and incompleteness of all investigations, but also due to the facts that the original conditions at the dam location are strongly affected by the weight and the size of the structure and that the hydraulic conditions around the dam are changed to a great extent by impounding the reservoir.

The best way of developing a structure which is safe and functional over its life, will be found between the two extremes 'trial and error' and 'computation only'. This way has its individual character for each project, depending on the complexity of the construction materials and on the special conditions of the location.

Responsible engineers have to follow this way up to the start of operating the project. Design and construction cover the first part of this way. At the end of the design phase the responsibility cannot be passed over to those who have to care for the realization. Other than with structural engineering the construction phase is not mainly a matter of logistics. Instead, we must always ensure that substantial aspects, such as foundation conditions and material properties, still comply with the presuppositions of the design.

As a consequence for advanced dam engineering the following is stated (Fetzer 1988b): 'Uncertainties in the foundation and abutment conditions and in borrow materials have led to the conclusion that the design must continue through construction. Many engineering organizations schedule field trips for their design geologists and engineers at critical stages of construction to determine if field conditions are the same as those assumed during design...'. The author would like to stress that each engineering organization must schedule such field trips for the team of designers not only at critical stages but also periodically to make sure that the field conditions at any stage comply with the design assumptions.

This means in practice that the designer has to supervise the construction. Designer and supervisor in cooperation are called 'the engineer'. The continuous responsibility of this engineer should again and again be stressed, as it is – fortunately – in recent literature (e.g. Leps 1988a). Incomplete continuity in this aspect was discovered during the investigations on the failure of the Teton dam, and it was found to be one of the reasons for failure.

The second part of the way from design to routine operation covers the phases of the first impounding and of the first period of operation. Essential supervision of these phases by the engineer cannot be expected. Responsibility is taken over by the owner who has to be provided by the engineer with a complete documentation of the results of investigations, of the design criteria and of experiences collected during construction.

The first impounding must prove the correctness of earlier made predictions concerning not only the safe function of the structure, but also the effect of the structure on the foundation and the effect of the new hydraulic conditions on the environment. There are two contrasting opinions on the mode of first impounding.

On an international level it is recommended 'the designer should fully consider that the reservoir may fill very quickly, regardless of the generally assumed merit of controlling the filling rate' (Leps 1988a). This recommendation is made 'because of inevitable hydraulic uncertainties, and difficulties in forecasting precisely when critical water control outlets may be completed and serviceable'.

In Germany, the standards request strict control of impounding. According to DIN 19 700 the serviceability of the water control outlets is a precondition for the start of impounding. The rise of the water level is controlled so as to follow stepwise a previously established filling programme. The next step of filling is permitted only when the previous step did not show any critical condition. Such procedure is reasonable under the hydrologic conditions prevailing in Central Europe. It is justified with respect to the safety requirements of a densely populated and highly industrialized country.

Readers of this book or of the table of contents only will find the book compiled according to the common sequence of work: project development under consideration of neighbouring disciplines, investigations of the subsoil and of the construction materials, design and – finally – construction and its supervision. The dam instrumentation with a measuring programme for safety control and the above mentioned complete documentation are the link between the engineer and the owner.

Once the reservoir operation has started and instrument readings are made according to the measuring programme, and once the documentation is completed, the work of the geotechnicians involved is finished. Fortunately, their stock of knowledge will in most cases be greater than before the project had commenced.

CHAPTER 2

History

Building dams is one of the oldest technical activities applied for the benefit of large human groups. Dams made of soil and rock have been known since the 3rd millennium before Christ. Schnitter (1987) nominates not less than 34 dam structures existing at the beginning of our chronology in all civilizations of ancient times. The largest of these was 30 m in height. Even in our day this would be defined as a 'large dam'. At the end of the 16th century the list includes about 300 structures, serving almost exclusively for water storage. Of course, land irrigation, water supply and flood control have been the prevailing functions.

Sadd-el-Kafara near Cairo in Egypt, a 14 m high rockfill dam with earth core, was one of the world's oldest dams, being constructed around 2600 years BC (Fig. 2.1). The dam was designed for flood control. Studies on the history of this structure have been summarized by Garbrecht (1987) as follows (extract):

'...The dam was stable in the sense of recent considerations; it would have been able to resist expected overtoppings. During construction an extreme flood overtopped and destroyed the existing parts of the dam. ...It was a tragedy for the Egyptian engineers to see this unexpected flood leading to a disaster. We owe respect to them for taking on the challenge of starting dam construction given the limited technical potential of their time. They earn our compassion for failing due to an unforeseeable event'.

Another important structure was the earthfill dam Marib, 7 m in height, in North Yemen close to the city of Marib. The dam served for land irrigation. It was constructed in 750 BC. It had been in use over more than 1000 years when it was destroyed in the 2nd half of the 6th century. Its overtopping is mentioned in the 34th Sura of the Koran as a punishment of God to the people who had abjured their faith.

This dam was part of an irrigation system for an area of about 1600 hectares of agricultural land to provide food for about 300,000 people, at this time and in this region of the Queen of Saba (Jenner 1983). A new dam was

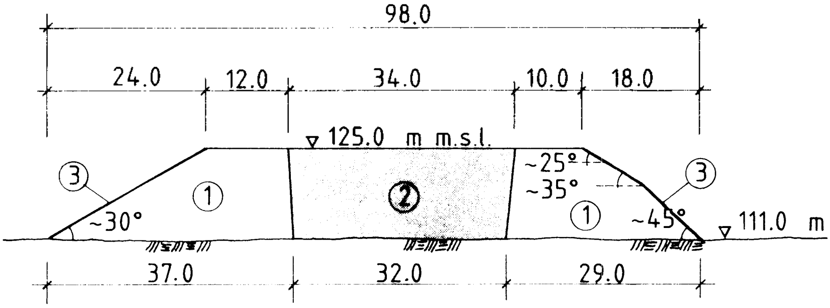

Figure 2.1. Sadd-el-Kafara dam, Egypt, about 2600 BC (adapted from Garbrecht 1987).

1 Rockfill
2 Impervious soil
3 Wave protection, rubble
(Dimensions in m, upstream side is at right)

constructed in our time at the same river some hundred meters upstream to irrigate the area anew.

Activities in dam construction increased rapidly with industrial development. In the Harz-area in Germany 60 embankment dams had been built until the middle of the 17th century in connection with mining industries (Schmidt 1989). An important step in development is applying cohesive soil as an internal sealing member, in contrast to an upstream face sealing (Fig. 2.2). This new method offered the advantages of better protection and less repair work of the sealing after destructive attack by animals and ice. Figure 2.2 demonstrates also the use of transition zones at the interface of sealing and dam shell. Such transition zones served as a protection against erosion, in the same way as in our time.

Up to now the total number of dam structures of all types increased to about 35,000, where the highest dams – Nurek at 300 m and Rogun at 332 m in the former USSR – consist of rock and soil.

In contrast to other fields of technical activity, over the millennia dam construction followed intuition rather than scientific rules. Only around the turn of the last century scientific considerations of soil mechanics and construction techniques resulted in the outstanding performance of modern dam engineering. Substantial credit is due to Wolmar Fellenius (1919) and his development of slide circle calculations and to Karl Terzaghi (1925) and his 'Erdbaumechanik auf bodenphysikalischer Grundlage'. Further development is marked by increasing research on soil mechanical phenomena, summarized by Breth (1972) as follows:

- Soil erosion in relation to its protection by filters,
- water content of cohesive soils in relation to compactability,
- shear strength of cohesive soils in relation to pore-water pressure,

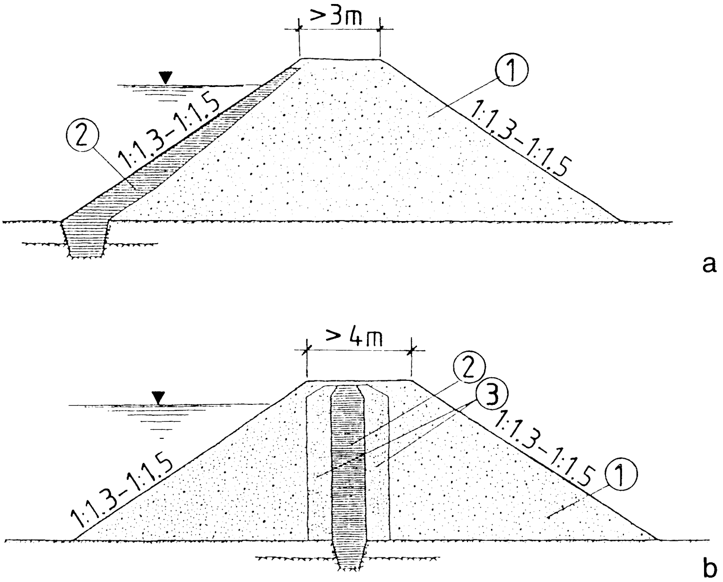

Figure 2.2. Dams of the mining industries, Harz mountains, Germany, 18th century AD (adapted from Schmidt 1989).

a Old method of construction
b New method of construction
1 Embankment material
2 Sealing material, sods
3 Transition zone of fines

– non-linear deformation behaviour of soils in relation to triaxial state of stress and strain.

Scientific research in this respect resulted in increasing confidence of the profession and of the public in dam engineering and its evolution after the 2nd World War. Considerations of geotechnicians are now mainly focused on erosion stability, on dam deformation during construction and reservoir operation and on safety against cracking, in addition to static and dynamic stability.

Stress and strain considerations have been improved essentially by the development of static and dynamic computations based on finite elements, with respect to the non-linear behaviour of earth and rock materials. Static methods cover all conventional load cases, while dynamic methods simulate the effect of earthquake loads. Such computations have been developed mainly in the USA. Comprehensive comments on them are given by Duncan et al. (1980) and Seed (1979). Unfortunately, it is quite expensive to make full use of such methods. In parallel, measuring instruments have been developed to control stresses and strains in existing dams. Today it is common to equip all dam structures with suitable instruments and to evaluate the measured values continuously.

The present state of the art allows us to construct large embankment dams within a reasonable time and at justifiable costs. This is due to the high capacity of all earth moving equipment and of compacting machines giving a maximum of density and hence shear strength to all relevant construction materials. The typical view of a modern dam site is marked by a fleet of self-moving machines being operated by a minimum of people (Fig. 2.3).

Necessarily, all periods of dam engineering had to cope with adverse events. Examples are Sadd-el-Kafara in ancient times and the Oker-dam in Germany in 1714. The dam failed during construction due to an inadequately steep slope of the upstream portion of masonry. At this time Coulomb's theory on earth pressure on retaining walls (1786) had not come to the knowledge of the engineers. As well, our time is not proof against failure. In 1976 the 92 m high Teton earth embankment dam in Idaho, USA failed at the first reservoir impounding. Eleven people died; the damage to property amounted to almost $500 million. According to expert reports (Penman 1977, Londe 1983) failure was caused partly by unreasonable design and construction details ignoring the relevant state of the art. Also human insufficiency came into play.

Apart from such negative experience it may be noted that expert knowledge enables us now to design, to construct and to operate large embank-

Figure 2.3. Kinda dam, Burma 1983 (courtesy of LI).

ment dams and their reservoirs at a high level of safety. This applies to geotechnicians who responsibly apply relevant knowledge and who are cautious where no experience exists. It is prudent to be cautious about designing even higher dams than before, in constructing even more rapidly than before and in realizing the projects at lower costs than before. Progress in these directions is justified, but only small steps should be made.

One institution must be mentioned specifically in view of the high standard of dam engineering. It is the International Committee on Large Dams (ICOLD) with its 78 member countries. The committee calls experts from all over the world to make their relevant experience public in an international congress, held every three years. Each congress is devoted to four selected questions dealing with all types of dams and appurtenant structures. Fifteen questions related to embankment dams have been dealt with in the last six congresses in the period from 1979 to 1994. All contributions and a General Report on them are published in four volumes of proceedings, followed by a fifth volume with the discussions held during the congress.

By this activity the relevant state of the art is constituted permanently on an international base – to the advantage of those geotechnicians involved in dam engineering and to the public in general, which benefits from the operation of dams and reservoirs.

CHAPTER 3

Project development

3.1 OVERVIEW

All projects have to cope with regional and local conditions. For dam construction mainly the following conditions have to be respected:

- Geology,
- morphology and topography,
- hydrology.

At the beginning comprehensive studies and investigations are needed under these headings, which commonly last for several years.

As is known, dam incidents cause human disasters and economic setbacks to a great extent. Statistical investigations of dam failures have been made evaluating the origin of such incidents. A remarkable number of failures was caused by insufficient investigations and by misinterpretation of geological and hydrological conditions. This is confirmed by the last statistics of ICOLD (1974) shown in Table 3.1. Probably, a considerable number of incidents summarized under 'design' is caused also by misinterpretation of geological or soil mechanical investigations. This applies also to projects in karstic areas which failed to function for long time or even permanently.

3.2 GEOLOGY

The geological conditions at a particular site make a project feasible or not: the foundation conditions must be adequate and the major part of the required construction materials should be available within a short distance. Without these preconditions the site may be unfeasible.

All seismic aspects are usually attributed to geology. The seismic conditions have to be studied by region and area (not just locally) to enable the definition of the operational basis earthquake (OBE) and the maximum credible earthquake (MCE) which are appropriate for the site. Respective

Table 3.1. Number of dam incidents (adapted from ICOLD 1974).

Fundamental cause	Earth dams	Rockfill dams	Concrete dams	Miscellaneous	Total
Exploration	49	2	20	1	72
Material	8	–	3	–	11
Layout	17	3	5	–	25
Design	48	3	23	2	76
Construction	32	5	4	–	41
Operation	5	1	–	–	6
Supervision	3	–	2	–	5
Total	162	14	57	3	236
Percentage:					
– Exploration and material	35		40		35
– Design and construction	49		47		50

studies should cover past times, as far as possible, since earthquake events of the past will give valuable information. The seismic conditions may also render a project unfeasible, for instance, if a geological fault of unknown seismic activity constitutes a safety risk for the dam or one of the appurtenant structures. An example is discussed in Section 3.5.

Rock and soils are the main sources of construction materials. Soils are defined according to known classification systems. For rock no unified classification system is available. Many experts have worked on such systems which are used mainly in underground and slope engineering. For dam engineering such a system is dispensable. In practice it proved to be appropriate using weathering grades as a classification, according to Table 3.2 (or equivalent), in combination with drill protocols and the results of field and laboratory tests. Another classification is related to the strength, the prefailure and failure characteristics, the gross homogeneity and the continuity in formation (Thomas 1976).

3.3 MORPHOLOGY AND TOPOGRAPHY

The morphology, i.e. the form and structure of the surface of the earth, is another criterion to select a dam site. For embankment dams the criterion is restricted to finding the most appropriate location among several choices. This is because embankment dams do not demand special conditions of abutment stability or of valley size as, in contrast, arch dams do.

The topography of the dam site and of the reservoir area is a matter of geodetic survey. The survey is made in parallel to the other geotechnical in-

Table 3.2. Rock classification system due to weathering (Geological Society Engineering Group Working Party 1972). Reproduced by permission of the Geological Society, London.

Term	Grade symbol	Diagnostic features
Fresh	W I	Parent rock showing no discolouration, loss of strength or any other weathering effects
Slightly weathered	W II	Rock may be slightly discoloured, particularly adjacent to discontinuities, which may be open and will have slightly discoloured surfaces; the intact rock is not noticeably weaker than the fresh rock.
Moderately weathered	W III	Rock is discoloured; discontinuities may be open and will have discoloured surfaces with alteration starting to penetrate inwards; intact rock is noticeably weaker, as is determined in the field, than the fresh rock. (*The ratio of original rock to weathered rock should be estimated where possible.*)
Highly weathered	W IV	Rock is discoloured; discontinuities may be open and will have discoloured surfaces, and the original fabric of the rock near to the discontinuities may be altered; alteration penetrates deeply inwards, but corestones are still present. (*The ratio of original rock to weathered rock should be estimated where possible.*)
Completely weathered	W V	Rock is discoloured and changed to a soil but original fabric is mainly preserved. There may be occasional small corestones. The properties of the soil depend in part on the nature of the parent rock.
Residual soil	W VI	Rock is discoloured and completely changed to a soil in which original rock fabric is completely destroyed. There is a large change in volume. (*Genesis should be determined where possible.*)

vestigations described in Section 4. The topography of the area in question should be surveyed at the latest when the most appropriate site is to be selected. The topography is the base of the reservoir filling curve.

In developing countries the survey is commonly made by aerial photogrammetry, one to fifty thousand or similar in scale. Under conditions of dense vegetation a tolerance up to 10 m in height has to be taken into account. A more accurate surface survey is often made only at the time when the dam location has been selected. After removal of all vegetation a small change of the previously selected dam location may then be advisable.

Once the reservoir is being impounded the filling curve may prove to be inaccurate, according to the tolerances in height. Then, certain storage levels will be reached later than expected. One has to live with such uncertainties.

Reservoir filling is related also to the saturation of the surrounding rock. This contributes to the inaccuracy of the reservoir filling curve.

3.4 HYDROLOGY

Hydrological aspects are dealt with here only as far as required for better understanding. Hydrology is related to dam construction and reservoir operation by the need to divert rivers during dam construction and by flood control. The forecasting of hydrological events is necessarily based on the available data from previous times. Correct prediction benefits from the length of the period which is covered by accurate and reliable data. In remote areas such periods may be short. This, commonly, results in generous dimensions of the structures for flood control including emergency spillways to exclude dam overtopping.

Common criteria for spillway design are the probable maximum flood (PMF) and the reservoir retention capacity. In some projects PMF is replaced by the 10,000-year flood. For PMF an extreme range of floods to be controlled is existing, e.g. 100 m^3/s at the reservoir Prims and almost 20,000 m^3/s at Atatürk. This demonstrates the importance of correct data and data processing since the size and the construction and operation costs of the spillway depend directly on the hydrological data.

The structures built in diverting rivers are designed according to hydrological data, but not exclusively. Additional criteria are the length of the construction period and the acceptance of a remaining risk of inundating the construction site. Again, there is a wide range of construction flood events to be controlled, e.g. about 20 m^3/s for Prims and 8000 m^3/s for Atatürk. The design will be different for diversion structures than for structures for permanent use.

3.5 SELECTION OF THE DAM LOCATION

The dam location is selected as soon as morphological and topographical studies permit and as soon as geological investigations with respect to bearing capacity, permeability and seismic activity have confirmed the suitability of the prospective site. That means, selection is made in the course of the field investigations described in Section 4.2. The geological, morphological and topographical conditions must be considered. Favourable conditions are:

Geology

- Adequate bearing capacity of the foundation,
- low permeability of the foundation,
- no existing geological faults,

– no risk of seismic activity.

Morphology

– Smooth and symmetrical valley with gentle slopes,

– exposed flanks forming an arch of dam and abutments.

Topography

– High abutments, well above normal pool level,

– high flanks around the reservoir with long seepage path to neighbouring valleys,

– no depressions requiring lateral dams.

Examples of favourable conditions are shown in Figures 3.1 and 3.2. The more the conditions differ from such an 'ideal' state the more costly is project realization.

Figure 3.1. Well shaped valley, almost symmetrical, Lesotho. Topographically ideal conditions for a 200 m high embankment dam.

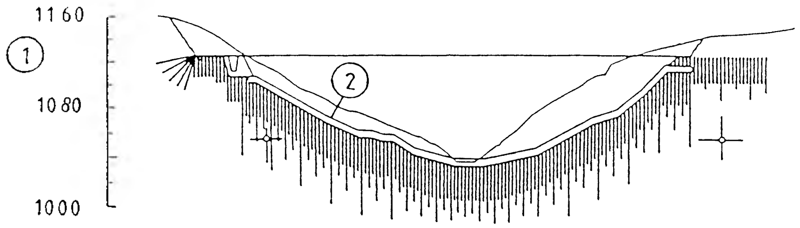

Figure 3.2. Inamura dam, Japan 1982. Well shaped core foundation after deep excavation of soil and weathered rock (adapted from Nakayama et al. 1982).

1 Elevation (m a.s.l.)

2 Inspection gallery, constructed in open trench

As is known, engineers are challenged nowadays to cope with unfavourable conditions since the most favourable sites are occupied by existing dams. Such unfavourable conditions, but still under control, are shown in Figures 3.3 and 3.4:

Geology

– Thick layers of unconsolidated and permeable soil above the bedrock, in many cases requiring deep excavation,

– extremely permeable rock, e.g. karst,

– geological fault in the foundation area (Fig. 3.3). (Faults of seismic activity are excluded.)

Morphology

– Deeply eroded valley with deep excavation (Fig. 3.3) or comprehensive sealing measures (Fig. 3.4),

– irregular contour of the rock surface and extremely steep slopes causing large differential settlements in the dam body (Figs 3.3 and 3.4).

Topography

– Abutment as in Figure 3.3 (right) with lateral extension of the dam (or reduced dam height),

– depressions along the reservoir rim requiring additional dams.

Necessarily, construction costs increase with the length of the structure. In principle, however, there is no limiting length. Large dams have been constructed which are some kilometers in length.

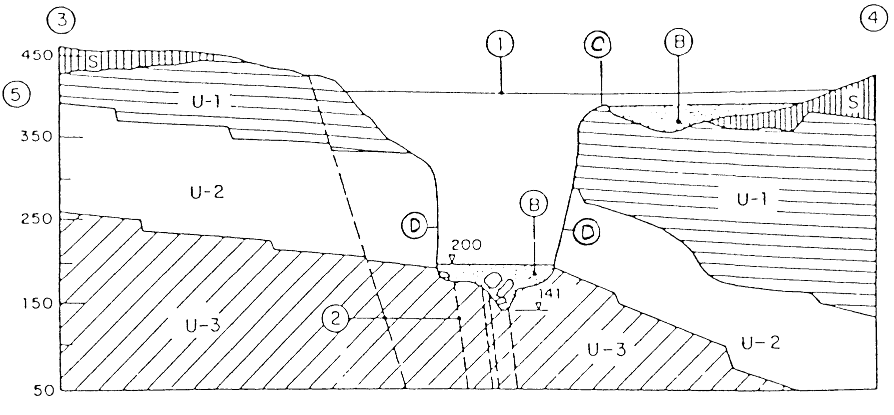

Figure 3.3. Chicoasen dam, valley section (adapted from Moreno & Alberro 1982).

1 Dam crest 402 m a.s.l.
2 Geological faults, parallel to the valley
3 Left abutment
4 Right abutment
5 Elevation (m a.s.l.)
S Clay shales

U-1 Limestone interbedded with clay shales
U-2 Massive limestone
U-3 Limestone interbedded with clay shales
B River deposits with boulders
C Irregular rock surface
D Extremely steep slopes

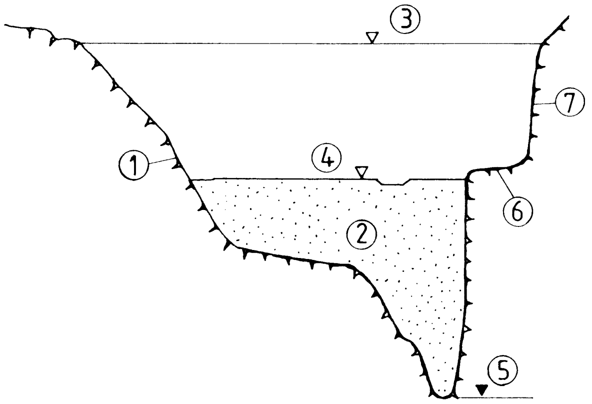

Figure 3.4. Sylvenstein dam, valley section (adapted from Lorenz 1966).

1 Rock: Dolomite
2 Alluvions: Sandy gravel, erratic blocks, mud layers
3 Dam crest 766 m a.s.l., length 175 m
4 Valley bottom 725 m a.s.l.
5 Erosion channel 626.7 m a.s.l.
6 Irregular rock surface
7 Extremely steep slope

Kinda dam is an example of how to select the final dam location. This example demonstrates the required evaluation and quantification of advantages and disadvantages given by the geological, morphological and topographical conditions (Fig. 3.5).

An optimum storage level at 200 m a.s.l. had been identified according to hydrological and topographical conditions. An early study of the project had dam location A in mind, leading to a length of the structure of only about 270 m. At this site the left abutment consists of compact limestone. The right abutment is made of porous Travertin limestone of high and very irregular permeability. A favourable place for the spillway was seen in the depression north-west of the dam. This depression is cut by a geological discontinuity of unidentified seismic activity, named the Kinda-fault.

The area west of the Kinda-fault presents better geological conditions due to the quartzite there. However, a dam at location B would require a length of 630 m to bridge the valley. In the course of studies a connection of the travertine zone with a remote karstic area was discovered by tracer tests resulting in increased risk for impermeabilization of the right abutment at location A. Therefore, it was decided to place the dam at location B with better geological but less favourable topographical conditions. Any effect of the Kinda-fault was deemed to be under control, now running parallel to the center line of the dam at a distance of about 470 m.

Later on the risk of seismic activity of this fault was identified in more detail: the fault was cut 7 m deep by the excavation for the eastern part of the diversion system (no. 6 in Fig. 4.1). The alluvions there did not show any

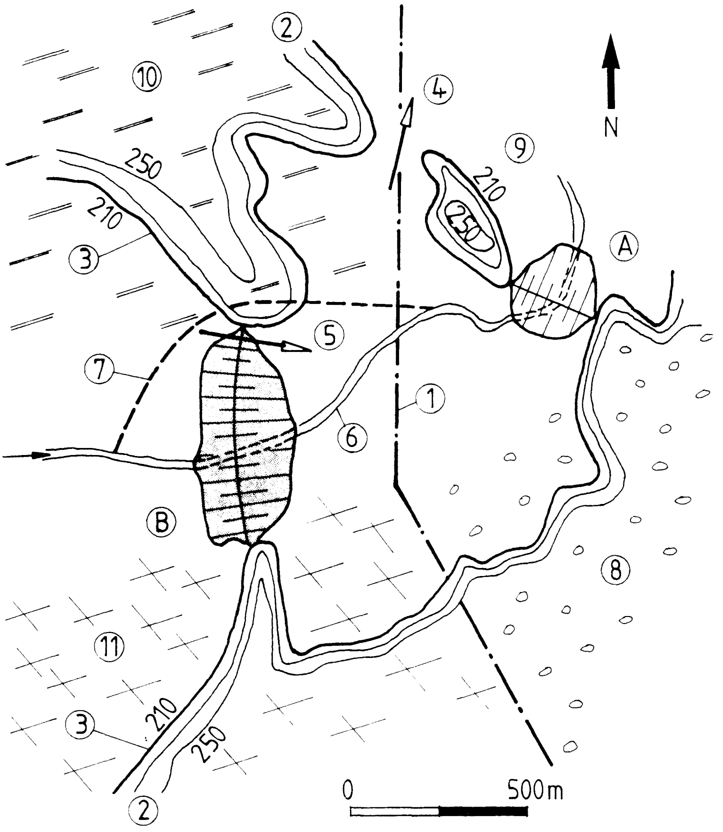

Figure 3.5. Kinda project 1977, selection of dam location.

A Dam location A (previous study)	6 River channel
B Dam location B (final study)	7 River diversion
1 'Kinda' geological fault	8 Karstic limestone (travertine)
2 Contour lines (m a.s.l.)	9 Compact limestone
3 Full supply level 210 m a.s.l.	10 Quartzite, in part slaty
4 Spillway location A	11 Quartzite, slightly jointed
5 Spillway location B	

sign of shear movement. This is considered as an indication that there was no seismic activity in the last 10,000 years.

The main structures are concentrated at the left abutment. An economic design was found using the diversion tunnel later on to conduct water to the turbines for power generation and to the downstream regulating reservoir for irrigation. The two entrances for diversion and power/irrigation can be seen in Figure 4.3 (bottom).

CHAPTER 4

Investigations of the substrata and the natural construction materials

4.1 GENERAL CONSIDERATIONS

After description of the studies needed for the project's development, now those investigations are discussed which are required for the elaboration of a tender design. The first studies cover a large area, while the investigations in question are more concentrated on the area where the structures are located and on the close vicinity where the construction materials should be found. The schedules for studies and investigations may overlap each other.

It is presumed here that the relevant hydrological data have previously been evaluated with respect to river diversion, flood control and dam height. Usually, the selection of the dam location is made in an early phase of the investigations. This was discussed at the end of Chapter 3. What remains now is the task of selecting the type of dam. The selection is made as soon as sufficient information on foundation and material conditions is available. This will be discussed at the end of this chapter. DIN 4020 may serve as a guide for the investigations.

Investigating programmes, prior to the works, are planned and scheduled tentatively. The results of the investigations accumulate with the progress of the works. Progressively emerging results may affect the remaining works. It is, therefore, necessary to keep the programmes flexible and to have enough money budgeted from the beginning. Usually, the costs of substrata and material investigations amount to 2 to 3% of the construction costs.

The main investigatory works are listed in Table 4.1. It is up to the designer to compile the work schedule so as to have the results available in due time. For this goal, the duration of each part of the works must be estimated. In industrialized countries it is common practice to contract tight work schedules. Drilling companies will be flexible enough to adjust their staff and equipment to the high production rate. As an example: the monthly drilling rate of one core drilling rig will be in the order of 300 to 500 drill meters. Such rates can, as a rule, not be expected in remote areas of develop-

Table 4.1. Investigations of the substrata and the natural construction materials.

Type of investigations	Result	Sampling	Field tests
Geological mapping	General overview, identification of material deposits	–	–
Core drilling	Stratification of soils and rock	Rock and soil samples for lab tests	Water pressure tests and test grouting
Penetration tests	Stratification of soils, identification of material deposits	–	–
Test pits and test trenches	Stratification of soils, identification of material deposits	Undisturbed and disturbed soil samples for lab tests	Moisture content, moist unit weight, gradation
Adits and shafts	Rock conditions	Rock samples for lab tests	Rock mechanical tests
Geophysical tests (calibration by core drillings required)	Stratification, thickness of overburden	–	–
Large scale tests, desirable prior to the elaboration of tender documents			Blasting test, compaction tests, grout test

ing countries. The monthly drilling rate of a core drilling rig might not exceed 30 to 50 drill meters, because of idle time waiting for spare parts, drill bits and the like. Also, bureaucratic objections like customs clearance, etc. have to be considered.

Usually, investigating takes 2 to 4 years. Table 4.2 gives an example of an investigating programme for the tender design of a hydropower project in a developing country, consisting of a 100 m high rockfill dam and appurtenant structures. This programme is typical for such a project, with favourable conditions of foundations and construction materials provided. A similar programme was performed for the Kinda hydropower project in Burma (Fig. 4.1). Drillings in the quarry area for rockfill material are not shown.

Note: the curvature of the center line of the dam to be seen in Figure 2.3 was established in a later phase of the design work.

The following should be kept in mind: investigating the substrata and construction materials will not be finished when construction starts. The investigations required for the project development, its design and its con-

Table 4.2. Example of field investigations for a rockfill dam with earth core at favourable geological conditions.

Item	Work to be done	Responsible reporter	Period of performance (months)	
			Beginning	End
1	Site mobilization with two rigs, equipment for borehole tests, workshop, site office, housing, all accessories	Geologist, engineer	Beginning of 1	End of 3
2	Preparation of access to 30 to 35 drill hole locations and 20 to 30 test trench locations	Geologist	Beginning of 4	End of 5
3	Geological mapping	Geologist	Beginning of 5	End of 7
4	Identification of material deposits in close vicinity	Geologist, engineer	Middle of 7	Middle of 9
5	200 m of core drilling in mapped area of quarries, no tests	Geologist, (engineer)	Beginning of 6 Drill rig A	End of 7 100 m per month
6	1400 m of core drilling in 20 to 25 boreholes with complete water pressure testing. The location of boreholes covers the area across the valley and about 300 m d/s and 300 m u/s of the dam	Geologist	Beginning of 6 Drill rig B Beginning of 16 Drill rig A	End of 19 80 m per month End of 19 80 m per month
7	400 m of core drilling in 6 selected boreholes with complete water pressure testing and test grouting	Geologist	Middle of 8 Drill rig A	Middle of 15 60 m per month
8	Excavation of 20 to 30 trenches in mapped borrow areas for core material, filter and concrete aggregates incl. necessary auger drilling and penetration testing	Geologist, engineer	Middle of 8	Middle of 12
9	Soil sampling from all material deposits	Geologist, engineer	Middle of 10	Middle of 13
10	Drafting of complete reports on items 3 through 9	Geologist, engineer	Beginning of 19	End of 20
11	Geodetical survey of all borehole and trench locations	Surveyor	Middle of 19	End of 20
12	Wrapping and shipping of rock and soil samples:	Engineer		
	– to a local laboratory,		Middle of 13	Middle of 14
	– to a laboratory abroad for special testing		Middle of 13	Middle of 16
13	Laboratory testing and reporting:	Engineer		
	– local laboratory,		Beginning of 15	End of 20
	– laboratory abroad		Beginning of 17	End of 20
14	Period to cover delays and unforeseen works		Beginning of 21	End of 24

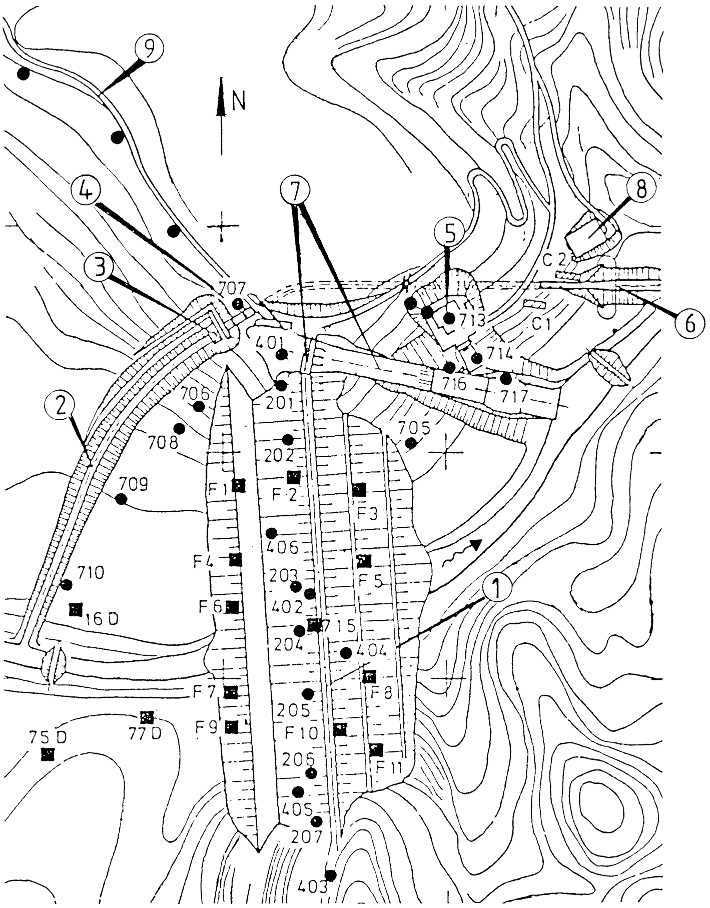

Figure 4.1. Kinda dam. Investigations of the substrata 1977 to 1980.

1 Main dam, early design phase
2 Diversion channel
3 Intake of diversion tunnel
4 Intake of power tunnel
5 Power house
6 End of diversion tunnel and low level outlet, beginning of irrigation channel
7 Spillway
8 Switch yard
9 Access road
Dots: Core drillings
Squares: Test pits and trenches
C1, C2: Adits

struction will in most cases overlap each other. Experienced designers know the unpleasant situation that parameters required for the design work are not available in time. Then, work has to be continued using estimated data. The main reasons for such a situation are:

– Delay in field and laboratory work,

– misleading interpretation or missing special investigations, with the subsequent need to fill the gap of information,