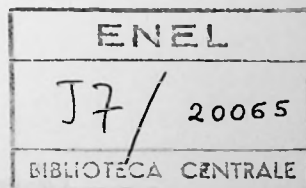


The Engineering of Large Dams

Part II

HENRY H. THOMAS

*Engineering Consultant,
Formerly Deputy Chief Civil Engineer,
The Hydro-Electric Commission, Tasmania,
Australia*



A Wiley — Interscience Publication

JOHN WILEY & SONS

London · New York · Sydney · Toronto

Contents

Foreword	(By Sir William Hudson K.B.E., F.R.S., B.Sc. (Eng.), Hon. F.I.E. Aust.) <i>Formerly Commissioner, The Snowy Mountains Hydro Electric Authority, Australia</i>	ix
Preface	<i>Dam Building—A Challenge to the Engineer—an Art or a Science?</i>	xi
Introduction	xvii
1 Engineering Responsibility		
1.1	The Chief Engineer and the Team	1
1.2	Experience and the Computer	1
1.3	Responsibility in New Concepts	1
1.4	Responsibility—Moral and Legal	2
1.5	Lex Romana and Insurance	2
1.6	The Contract	3
2 Planning		
2.1	Water Resources—National and International	6
2.2	Reservoir Utilization	8
2.3	Life of a Dam	10
2.4	Environmental Implications	13
2.5	Multi-disciplinary Approach	29
2.6	Finance	30
2.7	Contract and Day Labour Construction	31
2.8	Decision Making	32
3 Accidents to Large Dams		
3.1	Consequences of Failure	35
3.2	Statistics	35
3.3	Security v. Failure	36
3.4	Examples	37
4 Loading and Factor of Safety		
4.1	Static Loading	55
4.2	Dynamic Loading	58
4.3	Behaviour of Concrete under Complex Loading	60
4.4	Load-carrying Capacity of Dams	62
4.5	Model Representation	63
4.6	Factor of Safety	64
5 Investigations		
5.1	Preliminary Investigation and Reconnaissance	70
5.2	Time and Money for Investigations	74
5.3	Basic Concepts	74
5.4	Basic Data	75
5.5	Height of Dam	82

5.6	Selection of Type of Dam	83
5.7	Deep Outlets and Controlled Filling	95
5.8	River Diversion	96
6	Hydrology	
6.1	Hydrology and Meteorology	99
6.2	Storage Requirements	117
6.3	Floods	119
6.4	Freeboard	128
7	Geology	
7.1	Regional Geology	139
7.2	Local Geology	141
7.3	Recording and Presentation	156
7.4	Seismic Activity	159
7.5	Valley Wall Stability	163
7.6	Mining	166
7.7	Materials Investigations	166
8	Foundations	
8.1	Properties of Rock	170
8.2	Testing	176
8.3	Sliding	182
8.4	Permeability	190
8.5	Foundation Improvement	199
8.6	Instrumentation	206
9	Concrete	
9.1	Basic Requirements	210
9.2	Constituents	212
9.3	Concrete Mix Design and Grading	227
9.4	Physical Properties of Concrete	228
9.5	Strength of Concrete	232
9.6	Curing	236
9.7	Cracking in Concrete	237
9.8	Special Concretes	240
10	Gravity Dams	
10.1	Evolution	245
10.2	Design Concepts and Criteria	249
10.3	Uplift	252
10.4	Stresses in Gravity Dams	256
10.5	Contraction Joints	260
10.6	Galleries	264
10.7	Appurtenant Structures	268
10.8	Prestressed Gravity Dams	272
10.9	Special Gravity Dams	278
11	Arch Dams	
11.1	History	283
11.2	Design Concepts and Criteria	294
11.3	Valley Shape	301
11.4	Abutments—Stability and Deformability	302
11.5	Shell Geometry	373
11.6	Methods of Analysis	320
11.7	Contraction Joints	333

11.8	Foundation Treatment	339
11.9	Prestressing	340
11.10	Modern Arch Dams	342
12	Buttress Dams	
12.1	Concrete Slab Deck	354
12.2	Massive Head Buttress	355
12.3	Multiple-arch Dam	355
12.4	Buttresses	369
12.5	Uplift and Sliding	372
12.6	Spill-over Buttress Dams	372
12.7	Prestressing	374
13	Embankment Dams	
13.1	Evolution	377
13.2	Types of Embankment Dam	379
13.3	Design	381
13.4	Homogeneous Embankments	393
13.5	Tailings Dams	396
13.6	Earth-Rockfill Dams	399
13.7	Decked Rockfill Dams	417
13.8	Foundation Treatment	440
13.9	Settlement	447
14	Spillways	
14.1	The Handling of Flood Waters	457
14.2	Uncontrolled Spillways	468
14.3	Gated Spillways	484
14.4	Spillway Chutes	500
14.5	Energy Dissipation	508
15	Flow Through and Over Rockfill	
15.1	History	526
15.2	Experience	528
15.3	Research and Development	539
15.4	Conclusions	545
16	Construction—General	
16.1	Economical Construction	548
16.2	Organization	551
16.3	Decision Making	552
16.4	Safety	552
16.5	Specifications	554
16.6	Inspection and Testing	554
16.7	Plant	555
16.8	Cost and its Control	556
16.9	River Diversion	558
17	Construction—Concrete Dams	
17.1	Preparation of Foundations	581
17.2	Aggregate Production	587
17.3	Concrete Production and Handling	592
17.4	Concrete Placing, Consolidation and Curing	597
17.5	Clean-up of Construction Joints	602
17.6	Formwork	603

17.7	Built-in Items	604
17.8	Cooling of Concrete	614
17.9	Economical Construction	615
18	Construction—Embankment Dams	
18.1	General	621
18.2	Foundation Preparation	628
18.3	Materials	637
18.4	Quarry Development and Haul Roads	645
18.5	Material Compaction	646
18.6	Earth-Rockfill Dams	656
18.7	Decked Rockfill Dams	660
19	Models	
19.1	Topography	673
19.2	Site Geology	674
19.3	Structural Models	683
19.4	Hydraulic Models	692
20	Safety and Surveillance	
20.1	Reasons for Surveillance and Legislation	701
20.2	Safety Legislation	702
20.3	Inspection and Monitoring	705
20.4	Observations and Instrumentation	710
21	Repair, Strengthening and Raising	
21.1	Reasons for Modifications	725
21.2	Inadequacy of Spillway	731
21.3	Inadequacy of Structure	731
21.4	Deterioration of Foundation	745
21.5	Raising for Increased Benefits	748
22	The International Commission on Large Dams (ICOLD)	
22.1	The International Commission	763
22.2	National Committees	766
Index	769

Introduction

A large dam has been defined by the International Commission on Large Dams as either:

- A dam above fifteen metres in height, measured from the lowest portion of the general foundation area to the crest, or
- A dam between ten and fifteen metres in height provided it complies with at least one of the following conditions:

- (a) the length of crest of the dam to be not less than 500 metres;
- (b) the capacity of the reservoir formed by the dam to be not less than one million cubic metres;
- (c) the maximum flood discharge dealt with by the dam to be not less than 2000 cubic metres per second;
- (d) the dam has specially difficult foundation problems; or
- (e) the dam is of unusual design.

Although this book has been prepared for application to dams of heights 30 m to 100 m, the text will generally be applicable to smaller dams. On the other hand, any dam exceeding 100 m in height must be considered as unique. Every aspect of its design and construction must be treated as a problem specifically related to that particular site.

At this time in history, when advances in technology are so rapid and when the flow of technical papers is so great, the Engineer should pause and carefully study some of the monumental hydraulic works of the past. He may be surprised how often our forebears adhered to principles now credited to the twentieth century.

A prestige publication was prepared in 1970 by Norman Smith for the Spanish National Committee on Large Dams to mark 'the crossing of the barrier of its 500 completed dams'. Under the title *The Heritage of Spanish Dams*, it presents the history of dam building on the Iberian Peninsula.

It was there that the Romans built some of their finest dams, at least two of which are still performing their useful functions.

The same author covered the world scene with *A History of Dams 1971*.¹ This provides an intriguing story from 'Sadd-el-Kafara' built south from Cairo between 2950 and 2750 B.C. to dams of the twentieth century.

Possibly the first arch dams were those built by the Romans in the first century A.D. in Northern Italy and Southern France. Ponte Alto arch dam¹ was built some 5 metres high from 1611 to 1613. In 1752 it was raised to 17 m curved to a radius of about 15 m, with a thickness of 4 m. In 1824-5 it was raised to 25 m. In 1847-50 further additions were made to bring it to a height of 33 m. The final stage of 3 m was added in 1887 and the dam still stands at a height of 36 m. It appears reasonable to assume that the original builders selected a good foundation!

In the Australian continent dam building is perforce of the modern era. As a developing country considerable ingenuity was displayed to conserve water at minimum cost. Australia is the world's driest continent and it was very soon after settlement that the incidence of droughts threatened the very existence of the early settlers. Naturally the first dams were of earthfill, often consolidated by the feet of sheep driven back and forth across the dam. Possibly the dams that first provoked world interest were the thin arch dams built in New South Wales at the end of the nineteenth century.² Typical of these are Medlow dam (Fig. 1) and Wollongong dam (Fig. 2). These represented a boldness of approach that is still evident in Australian dam building. Restrictions on capital expenditure both then and now have brought forth considerable originality, not unduly influenced by custom.

Although a history of dam building in Australia has not yet been written, an excellent