

An engineering guide to seismic risk to dams in the United Kingdom

J A Charles, PhD, DSc(Eng), FICE

C P Abbiss, BSc, MSc, PhD

E M Gosschalk, MA, FICE*

J L Hinks, MA, MSc, MICE*

* Sir William Halcrow and Partners

Building Research Establishment
Garston
Watford
WD2 7JR

Price lists for all available
BRE publications can be
obtained from:
BRE Bookshop
Building Research Establishment
Garston, Watford, WD2 7JR
Telephone: 0923 66444

BR210
ISBN 0 85125 510 8

©Crown copyright 1991
First published 1991

Applications to reproduce extracts
from the text of this publication
should be made to the Publications Manager
at the Building Research Establishment

CONTENTS	Page
Foreword	v
Abbreviations and Notation	vi
Part A General	1
1 Introduction	1
1.1 Background	1
1.2 Scope of this Guide	1
2 Reservoir safety	3
2.1 Hazards	3
2.2 Risk	3
2.3 Risk assessment	3
2.4 Floods	4
2.5 Earthquakes	5
2.6 Scales for earthquake effects	5
2.7 Seismic safety evaluation terminology	6
3 Earthquakes in the United Kingdom	8
3.1 General	8
3.2 Seismic monitoring	8
3.3 Historical record	8
3.4 Reservoir-induced seismicity	8
3.5 Mining-induced seismicity	10
3.6 Dam behaviour during seismic events	10
4 Earthquake resistance standards	12
4.1 General	12
4.2 Risk classification	12
4.3 Prediction of earthquake loading	12
4.4 Performance criteria	13
4.5 Peak ground motion parameters	13
4.6 Duration	16
4.7 Response spectra	16
4.8 Acceleration time histories	16
4.9 Attenuation	17
Part B Embankment dams	19
5 Behaviour under seismic loading	20
5.1 General	20
5.2 Elastic behaviour	20
5.3 Compaction	21
5.4 Liquefaction	21
5.5 Flow slides	22
5.6 Shear deformation	22
5.7 Field performance	22
5.8 Types of damage	23
6 Methods of seismic analysis	25
6.1 General	25
6.2 Pseudostatic analysis	25
6.3 Simplified and empirical deformation relationships	26
6.4 Dynamic analysis	27
6.5 Liquefaction analysis	27

7 Seismic safety evaluation	29
7.1 General	29
7.2 Ancillary works	29
7.3 Earthquake criteria	29
7.4 Performance criteria	29
7.5 Loading criteria	30
7.6 Investigation	30
7.7 Analysis	30
7.8 Surveillance and monitoring	31
7.9 Post-earthquake examination	31
7.10 Conclusions and recommendations	31
Part C Concrete and masonry dams	33
8 Behaviour under seismic loading	34
8.1 General	34
8.2 Load-resisting capacity	34
8.3 Dam-reservoir interaction	35
8.4 Dam-foundation interaction	35
8.5 Field performance	36
8.6 Types of damage	36
9 Methods of seismic analysis	37
9.1 General	37
9.2 Pseudostatic analysis	37
9.3 Standard two-dimensional linear dynamic analysis	37
9.4 Comprehensive two-dimensional linear dynamic analysis	38
9.5 Simplified two-dimensional linear dynamic analysis	38
9.6 Three-dimensional linear dynamic analysis	39
9.7 Non-linear analysis	39
10 Seismic safety evaluation	41
10.1 General	41
10.2 Ancillary works	41
10.3 Earthquake criteria	42
10.4 Performance criteria	42
10.5 Loading criteria	42
10.6 Investigation	42
10.7 Analysis	43
10.8 Surveillance and monitoring	44
10.9 Post-earthquake examination	44
10.10 Conclusions and recommendations	44
Glossary	46
Appendices	
Appendix A List of correspondents and questions raised	50
Appendix B Examples of the behaviour of dams during seismic events worldwide	51
Appendix C Seismic regulations and criteria	55
Acknowledgements	56
References	57

Foreword

This Guide has been prepared by the Building Research Establishment and Sir William Halcrow and Partners Ltd as part of the Department of the Environment's reservoir safety research programme. It is intended to help those responsible for reservoir safety in the United Kingdom to assess seismic loading. It is hoped that it will aid consistency in applying standards and analytical techniques for safety evaluation.

The Guide has been prepared as a result of careful consideration and with reference to representative authorities concerned with the safety of dams. It is not a code of practice, however. It cannot relieve the Engineer appointed under the Reservoirs Act 1975 of his responsibility nor should it restrict his discretion in deciding criteria to be adopted, techniques to be used and standards to be met in the interests of safety.

The objective of the research project, which was essentially in the form of desk studies, was to assess the seriousness of seismic risk and to propose criteria for earthquake safety evaluation of existing dams. The recorded performance of well constructed embankment dams and concrete dams when subjected to earthquakes has been exceptionally good worldwide. Nevertheless, the possibility of severe earthquake loading has not been fully appreciated in the past in the UK and there are small but finite risks that more severe earthquake loading might occur in the future than has generally been perceived.

It is proposed that the seismic safety evaluation of a dam and its ancillary works should be based on a safety evaluation earthquake. The safety of the dam against catastrophic failure (ie breaching) should be ensured under the level of ground motion produced by this earthquake and loss of life should not be expected. Recommended peak ground accelerations for the safety evaluation earthquake are related to 4 dam categories based principally on the downstream hazard posed in the event of failure and 3 zones of seismicity level into which it is suggested that the UK can be divided. The most rational methods practicable should be used in evaluating the safety of dams against realisable combinations of risks of all kinds and this approach should result in the most cost effective practice. A satisfactory balance is required between reducing risk and the expenditure entailed; it is important that seismic hazard and risk should not divert attention from other aspects of dam performance which may be more critical for safety.

Work is progressing in many places on several of the subjects dealt with in this guide (eg UK seismicity, methods of dynamic analysis). While every effort has been made to present the state-of-the-art, the Guide should be regarded as provisional in character and it is recommended that after a reasonable period it should be reviewed and, where necessary, revised.