ICOLD EUROPEAN CLUB

Working Group on Guidelines

for the Seismic Assessment of Dams

FINAL REPORT

Co-ordinator: N. Reilly (United Kingdom)

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European Working Group on guidelines for the seismic assessment of dams

N.REILLY, Consulting Engineer

SYNOPSIS. Following the publication of the Application Note to An Engineering Guide to Seismic Risk to Dams in the United Kingdom in 1998, a seismic working group was set up by the Euroclub of ICOLD. The purpose of this was to present and compare the approach to seismic appraisal of dams across Europe. To date guidelines for five countries (Austria, Italy, Switzerland, Romania and the United Kingdom) have been made available. The paper presents the key concepts of these and compares them.

INTRODUCTION

The document "An engineering guide to seismic risk to dams in the United Kingdom" (the British seismic guide) was published by the Building Research Establishment in 1991 as part of a large suite of guidance documents for the design and assessment of dams in that country. There are some sixteen similar semi-official guides applicable to dams in the UK but they are not codes of practice and have no formal legal force. Nevertheless they are widely followed, albeit tempered by engineering judgement in specific cases.

The British seismic guide was received as a very useful advance but there were many who thought its provisions were rather severe in terms of the magnitude of risk that dams were to be tested against. As a result a peer review was set up and this resulted in an additional document, the Application Note to the guide, being published by the Institution of Civil Engineers in 1998. This modified the seismic guide as described below.

In the course of the peer review it was suggested that a working group of the Euroclub of ICOLD be formed to prepare a comparison of practice across Europe in relation to the seismic assessment of dams. This was done and copies of guidance documents (codes in some cases) from five countries have been received and reviewed. This paper presents a brief outline of each

and compares them. The key features are summarised in a comparative table (Table 1).

UNITED KINGDOM

In the UK the key document (Charles et al 1991) was published in 1991 and contains in Part A a brief but comprehensive overview of seismic risk and hazard, drawing parallels with flood risk. It presents a summary of the parameters used to describe earthquakes and reviews the historical seismicity of Britain. The guide goes on to propose the standards to be adopted for the safety evaluation of dams in the UK, both existing and new. The **Safety Evaluation Earthquake (SEE)** is defined as the earthquake which will produce the most severe level of ground motion under which the safety of the dam against catastrophic failure should be ensured. The **Operational Basis Earthquake (OBE)** is also defined but the guide does not concern itself with this.

Dams are allocated a hazard category using the method of ICOLD bulletin 72 (ICOLD 1989) which takes into account reservoir capacity, dam height, number of persons at risk and potential downstream damage. This yields a classification number which puts a dam into one of four categories designated I to IV, IV representing the highest hazard. The guide recommends that category IV dams be tested against a 30,000 year return period event. Alternatively the maximum credible earthquake (MCE) estimated by a site specific study could be used. The MCE is defined as the earthquake that would cause the most severe level of ground motion at the site concerned which appears possible for the geological conditions. The other three categories are to be tested against events of return period 10,000, 3,000 and 1,000 years in descending order. For cases where a site specific study of seismicity was not justified, the guide presented a zone map dividing the country into areas A, B and C and tabulated indicative peak ground accelerations for the range of return periods. For zone A (the most seismically active) the recommended peak ground accelerations (PGA) range from 0.375g for 30,000 years return period, 0.25g for 10,000 years, down to 0.1g for 1000 years.

Part B of the guide contains three chapters dealing with embankment dams. The first chapter (Chap 5) outlines the effects of earthquakes on embankment dams and quotes some examples of UK dams which have been subjected to minor events. (This is supplemented in an appendix by a similar review of world wide incidents). The next chapter outlines the methods of analysis available and the final chapter in this part presents recommendations regarding which methods to apply as a function of height and hazard category.

Table 1: Key features of seismic safety assessments

CHARACTERISTIC	UK	AUSTRIA	ITALY	ROMANIA	SWITZERLAND
Status of document	Guide	Guide	Guide	Statutory	Statutory
Hazard designation	ICOLD Bulletin 72	Dam ht, capacity	ICOLD Bulletin 72	Not stated	Dam ht, capacity
Seismic variation	1991: zone map 1998: contour map	Zone map & contour map	Zone map	Zone map	Contour map
Maximum PGA	1991:0.375g 1998: 0.32g	MCE: 0.3g OBE: 0.14g	>0.6g	0.32g	0.03 to 0.16g (for 475 years)
Return periods:					
Cat IV	10,000 yrs/MCE	)Where	>2500 yrs	Top cat: MCE	Not applicable
Cat III	10,000 yrs	)applicable	2500 yrs	or 800 years	(I) 10,000 yrs
Cat II	3000 yrs	)use	1000 yrs		(II) 5,000 years
Cat I	1000 yrs	)MCE	500 yrs		(III) 1000 yrs
OBE	Not stated	200 yrs	Not stated, see text	100 yrs	Not stated
PGA analysis factor*	0.67	Not stated	0.5 to 0.67	Not stated	Not stated
Site specific study	No recommendation	Recommended	Mandatory for cat IV	Recommended	
Seismicity	Very low	Very low	Moderate	High	Very low

*Reduction factor to be applied to PGA for purposes of analysis

Part C deals in the same manner with concrete dams and the quoted appendix reviews worldwide events.

The foreword to the guide stressed that it was provisional in character and would need to be reviewed in the light of experience. As a result of a general view that the risk criteria were unduly severe, a review started almost straightaway, culminating in the Application Note to the guide published in 1998 (ICE 1998). This introduced two main changes. Firstly the zone map was replaced by a contour map giving PGA's for 10,000 year return period events as a result of a nation wide study of seismicity (Musson and Winter 1996). This gives a maximum PGA (in zone A) of 0.32g,which is rather higher than given in the original guide. Secondly the return period for category IV dams was reduced to 10,000 years or MCE.

The Application Note also presents some new information. In the period since the introduction of the seismic guide two large owners of dams had carried out site specific assessments of seismicity for all their damsites. The results of these were summarised and presented. These in general agreed with the Musson and Winter contour map of PGA. The Application Note also presented summary results of a number of seismic assessments of a wide variety of dams, both of concrete and embankment types. It is notable that, to date, despite the great age of many UK dams, no dam has yet had to be strengthened solely for reasons of resistance to earthquake.

AUSTRIA

The Austrian seismic guide is published by the Reservoir Commission of the Federal Ministry of Agriculture and Forestry and is dated 1996. It appears to be part of a broader range of guidelines for dam design. The guide is specifically not a standard but there is provision for its application, procedures and criteria, to be discussed with the authorities. It applies equally to existing and new dams.

The Austrian guide is appreciably shorter than the British guide but it follows similar principles. It follows ICOLD Bulletin 72 in terms of differentiating between OBE and MCE cases but it does not specifically use the bulletin's system of hazard categorisation. Instead it states that for dams >15 m high or capacity >500,000 m^3 then both OBE and MCE should be checked. This would also apply for smaller dams in potentially dangerous circumstances. Otherwise only the OBE case need be considered.

For the OBE a contour map of PGA is presented which has a maximum PGA of 0.14g. The minimum to be considered is 0.06g. For the MCE the guide contains a zone map with PGA varying from 0.11g to 0.3g. However it suggests that in general a site specific study should be carried out.

The guide goes on to give some advice relating to material properties, methods of calculation and factors of safety. It also presents response spectra and time histories for use in analysis and gives guidance on post earthquake inspection.

ITALY

The Italian seismic guide was published by the Dipartimento per I Servizi Tecnici Nazionali of the Presidenza del Consiglio dei Ministri in March 2001 and applies specifically to existing dams. New dams are subject to statutory regulations which since 1959 have included seismic criteria. The seismic guide may be used where it is not possible to apply the current criteria to an existing dam.

In format and philosophy it follows the UK guide quite closely but there are some significant differences which are outlined below.

The system of hazard categorisation follows ICOLD Bulletin 72 but the return period of the events for each category differ markedly. For category IV the return period of the SEE event is specified as not less than 2,500 years or MCE, the definition of the latter being as defined above. For categories III, II and I the return periods are respectively 2500, 1000, and 500 years.

In an appendix, the guide gives some advice on the definitions of high, moderate and low downstream damage. It suggests that high is greater than 1% of gross domestic product (GDP), moderate is 0.1 to 1% and low is 0.01 to 0.1%. Damage less than 0.01% is regarded as none or negligible.

The SEE to be applied is defined by the PGA and there is a legally established map of the country which identifies three seismically active zones and an unclassified zone. For a return period of 2500 years the maximum PGA is given as 0.6g and the minimum (applying in the unclassified zones) is 0.2g. It should be noted that these are the minimum values for category IV dams because of the “not less than 2500 years” criterion mentioned above.

The guide defines the available methods of analysis in a similar way to the UK guide but is more prescriptive in relation to category IV dams which must be subjected to field investigation and dynamic analysis. It also gives more detailed recommendations with regard to material parameters and safety factors and has a section on appurtenant structures.

For the OBE case, the guide recommends using the appropriate zone PGA for category I dams divided by two.

When a dam has been subjected to an earthquake an inspection must be carried out and a report submitted to the authorities. Dams in categories III and IV, as well as those more than 45 m high or retaining more than 10 Mm^3 must be equipped with a seismic monitoring system comprising two strong motion instruments, one at the base and one on the crest.

ROMANIA

The Romanian practice in relation to seismic safety of dams is defined in the "Code for design and seismic safety assessment of dams and hydraulic structures", 3rd edition of March 2002. An English language translation is not available and the following is based on an English precis, hence the level of detail is less than for the other countries' guides. The document comprises a mandatory code plus a detailed advisory guide. It has to be read in conjunction with a code for dams (PE729) first introduced in 1979 by the Ministry of Energy. The latest edition is dated 2001.

Romania differs from the other countries reviewed in that it is seismically very active and a large magnitude event occurred as recently as 1977 (M_L 7.2). The guide contains a useful survey of historical earthquakes in Romania and, despite some very strong events, there has been relatively little damage to hydraulic structures.

The code makes use of two systems of classifying dams which are defined in other documents. The first is "class of importance" (STAS-4273/83) which relates to the economic and social value of the works. There are five classes designated I to V, I being the most important. The other system is "category of importance" (NTHL-021) which relates to the hazard posed by the facility. This grading has four categories, A to D, A being the highest hazard. From the documents available it is not clear how these are derived nor how they are used in combination. However the SEE for categories I/A and II/B appears to be derived by a site specific study with a return period between 475 and 800 years depending on the source of the event. For the lower categories (III, IV, V and C/D) only the OBE case is considered using zone maps giving PGA values for return periods of 100 years. Across the country the PGA varies between 0.08 and 0.32g.

The guide contains detailed recommendations regarding methods of analysis, material parameters and earthquake parameters (response spectra etc). It also addresses appurtenant structures, construction in seismic zones, instrumentation and rehabilitation of dams damaged by earthquakes.

SWITZERLAND

The Swiss seismic guide was published in 2003 as the "Directives relating to the safety assessment of reservoirs subjected to earthquakes" under the authority of the ordinance on the safety of reservoirs (OSOA) dated 1998. It applies equally to new and existing reservoirs.

In format and philosophy it follows the foregoing guides but is appreciably more comprehensive in its treatment of the subject and contains a great deal of theoretical background and bibliography. It also defines in general terms the qualifications and experience required of the engineers who lead the safety evaluation. These are more onerous for the highest hazard category of dam than for the lower hazard ones.

The system of hazard categorisation is based mainly on dam height and, to a lesser extent, reservoir capacity. There are three categories, I (the highest hazard) to III. Categorisation is done by reference to a simple chart of height against capacity. The main determinant is dam height and, broadly, any dam higher than 40 m is in category I and below 10 m is in category III but very large or very small reservoir volumes modify this. For category I the return period of the SEE event is specified as 10,000 years, for category II it is 5,000 years and for category III it is 1,000 years.

The appropriate PGA for the site and return period are given by a series of statutory contour maps for the country and these are supported by response spectra for three types of foundation taken from Eurocode 8. For a return period of 475 years the PGA varies from 0.03 to 0.16g.

The guide defines the available methods of analysis but is generally more prescriptive than the other guides reviewed. Category I dams must be analysed by dynamic methods with material properties obtained by field investigation.

In addition to sections on embankment and concrete/masonry dams the guide has a section on barrages, ie dams containing a preponderance of movable elements. There are also sections on instrumentation and post earthquake inspection. All category I dams are required to have strong motion instruments. Inspections and reports to the authorities are mandatory for all dams following events of specified severity, the threshold event levels being lowest for the highest hazard dams.

CONCLUSIONS

Seismic guidance documents for dams for a range of countries in Europe have been compared. The general approach is similar but there is a divergence on the degree of risk to be accepted for similar categories of

dam. This is particularly true of MCE where, despite accepting the ICOLD definition, some countries use a probabilistic approach with a relatively low return period.

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