Recent developments in the Italian technical rules for dams and barrages

Article type: paper

Manuscript revised on 12/01/2022

RECENT DEVELOPMENTS IN THE ITALIAN TECHNICAL RULES FOR DAMS AND BARRAGES

Fabrizio Barpi

- Associate professor, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Italy
- Email: fabrizio.barpi@polito.it
- ORCID: 0000-0001-8371-5690

Valter Pascucci

- Senior member of Consiglio Superiore dei Lavori Pubblici, Italy
- Email: *valterpascucci@virgilio.it*

Carlo Ricciardi

- Former member of Consiglio Superiore dei Lavori Pubblici, Italy
- Email: carloricciardi.cr@libero.it

Paolo Salandin

- Full professor, Department of Civil, Environmental and Architectural Engineering, Università di Padova, Italy
- Email: paolo.salandin@unipd.it
- ORCID: 0000-0002-4461-7104

Giuseppe Scarpelli

- Full Professor, Department of Materials, Environmental Sciences and Urban Planning, Università Politecnica delle Marche, Italy
- Email: g.scarpelli@univpm.it
- ORCID: 0000-0002-0839-6834

Full contact details of corresponding author. Fabrizio Barpi, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Italy. Email: fabrizio.barpi@polito.it

Abstract

The paper describes the Italian technical regulations for dams and barrages issued in 2014 by the Minister of Infrastructure and Transport, where substantial changes in the existing rules are introduced by suggesting a design approach based on the semi-probabilistic method at limit states. The paper highlights the most innovative aspects as well as the critical issues, suggests some improvements and underlines the need for further updating of the legislation.

Keywords

Barrages, dams, seismic design, structural safety, technical regulation.

1. INTRODUCTION

The paper examines the regulatory situation of dams and barrages following the approval of the Decree of the Minister of Infrastructure and Transport "*Technical standards for the design and construction of dam and barrages*" of June 26, 2014 (hereinafter DM2014) [1]. This decree replaces the previous legislation, dating back to 1982 (DM1982), which had to be updated in relation to the changes in the technical standards for the construction sector, such as the Technical Standards for Construction of January 14, 2008 (NTC2008) recently updated on January 17, 2018 (NTC2018) [2]. This succession of technical standards resulted in the misalignment of the DM1982 with respect to the construction regulations and determined the need for its profound renewal with the current legislation of June 26, 2014. The regulatory framework proposed in the DM2014 substantially embraced the inspiring criteria of the Eurocodes (already accepted in the NTC2008 and NTC2018), superseding the previous legislation, which remained substantially based on the allowable stress design method. However, this update has led to some uncertainties and criticalities which will be described below.

2. DECREE OF JUNE 26, 2014

2.1 General description

The decree introduced, for the first time in Italy, the semi-probabilistic limit state method for dams and established the Monitoring Board (of which the authors were members) for the examination of its first application at the Higher Council of Public Works (*Consiglio Superiore dei Lavori Pubblici,* the technical advisory body of the Ministry of Public Works for projects and issues of urban interest). The DM2014 is particularly advanced since, to the knowledge of the authors, it is one of only three regulations on dams based on the semi-probabilistic method at limit states, although it may be noticed that the other two are the French Recommandations and Chinese standards, which do not have the *mandatory character* of the Italian technical standards. DM2014 is divided in eight main sections described below.

Section '*A. General prescriptions'* states that this legislation applies to all dams and barrages in the Italian territory. For dams whose height does not exceed 10 m or which determine a reservoir volume not exceeding 100,000 m^3, the Administration responsible for security supervision will decide on a case-by-case basis and, in relation to the characteristics of the dam, which rules are to be applied. It also requires that the design and construction of the works and interventions covered by the standard must comply with the (at the time) current Technical Standards for Construction (NTC2008), now updated. An important issue is that the design procedure must be based on investigations and analysis of varying complexity in relation to the level of detail required.

Section '*B. Classification and definition'* lists some definitions and presents a classification scheme used later in the document. Four main dams typology are listed, i.e., concrete dams, embankment dams, barrages and dams built with more than one materials.

The '*C. Common rules'* section defines the external forces (dead load, hydrostatic pressure, temperature effects, uplift pressure, ice thrust, silt effect) and, in particular, seismic forces. The safety of the dam should be analyzed considering the following conditions: 1) normal operation, 2) repairable damage, without uncontrolled release of water, 3) unrepairable damage, without uncontrolled release of water, 4) damage resulting in the uncontrolled release of water, or risk of loss of human life, 5) collapse of the structure. The *Limit State of Immediate Operability* is defined by the exit from condition 1), the *Limit State of Damage* is defined by the transition from condition 2) to condition 3). The *Limit State of Safeguard of Life* is defined by the achievement of condition 4) while the *Limit State of Failure* is defined by the achievement of the condition 5). The first two are considered as Serviceability Limit States while the last two are Ultimate Limit States

Three types are defined: '*Strategic*', the dams whose functionality during and following seismic events is of fundamental importance for the purposes of civil protection; '*Relevant dams*' for the consequences of a possible collapse (all large dams; dams classified in this way according to regional regulations); and '*Dams of normal importance'*, all dams not belonging to the previous types (i.e., small dams). According to this classification, the reference return period for the seismic action is obtained, and, following the Italian seismic hazard mapping, the corresponding actions (i.e, design spectra) to be used for design are defined.

This section also defines the combinations of the different forces, the partial safety factors and combination coefficients that should be taken from the NTC2008 (or NTC2018). Some details are given about the monitoring systems to be installed in the dam body and in the foundation (the projects must include a general plan of the control devices).

Section '*D. Concrete dams'* discusses dams made of concrete and rolled-compacted concrete, and specifies in detail the different limit states and seismic models (pseudo-static and dynamic using spectrum-compatible accelerograms) to be carried out for safety analyses for gravity and vaulted dams. Several stress limits for tension and compression for some Serviceability Limit States are listed. A short part is devoted to vaulted dams. Section '*E. Embankment dams'* states that the non-linear behavior and the interaction phenomena between the different soil phases, as well as the sequence of construction and reservoir operations, must be taken into account in the models and calculations. Particular attention must be paid to the prediction of the settlements evolution, including both hydrodynamic phenomena and the phenomena due to the structural viscosity of the solid skeleton of the soils, and to the evaluation of differential settlements, to evaluate their admissibility during time. Section '*F. Barrages'* proposes a classification and some hints about the water flood to be used in the design procedure, while section 'G., *Mixed dams',* describes dams built using mixed materials (as concrete and earth).

The last part, section '*H. Existing dams'*, is devoted to dams with the structure already completed at the time of the safety assessment or at the the time of interventions. An aspect of particular importance concerns the existing dams that will have to be subjected to safety assessment of the entire structure or parts of it, when the general conditions established by the NTC2008 (now replaced by the NTC2018) are fulfilled. The criteria to define safety are defined together with the different possible interventions to obtain a given level of safety. The following categories of intervention are identified: 1. *restructuring* interventions (aimed at achieving the levels of safety and functionality envisaged by these regulations for new dams); *improvements* aimed at increasing the pre-existing safety, even without necessarily reaching the levels required for new constructions; *repairs* or local interventions affecting isolated elements and which, in any case, lead to an improvement of the pre-existing safety conditions; *downgrading*, with a reduction in the height of the dam and/or the reservoir volume); 2. *decommissioning* interventions to deprive the dam of the hydraulic function, but ensuring the safety of the site and of the downstream territories.

It is mandatory to proceed at least with seismic improvement interventions when the analyses carried out to evaluate the seismic safety show the achievement of an Ultimate Limit State.

For concrete and masonry dams, the mechanical properties of the component materials and their variability within the dam body must be assessed by on-site and laboratory tests on samples taken from the dam body, reconstructing the actual situation; possible filtration phenomena in the foundation must also be identified. Any significant cracks present will be identified; the state of any reinforcements, joints and any sealing devices will also be investigated. It is recommended to experimentally evaluate the local stress level. For embankment dams, the same assessment of the actual condition must be evaluated and the filtration phenomena through the dam body and in the foundation must also be identified.

The seismic actions are defined in the same way for new dams but with the reference return period reduced; for Strategic dams a dynamic analysis is required. An estimate of the maximum seismic action the dam can withstand is also required.

2.2 Critical issues

This section examines the the major criticalities of DM2014. Some of them emerged during the activity of the Monitoring Board that wrote a report on the results of the monitoring activity and a proposed update.

The NTC2008 in §4.1 write: "*with the exception of those works for which there is a specific regulation of a particular nature*" and in §6.8 "*the embankment dams materials are subject to specific legislation*", suggesting that the dams are excluded from these rules. This is perhaps the starting point of the critical issues of the DM2014, which constantly refers to the technical standards of buildings from which, however, the dams seem to be excluded. Eurocode 8 [3] itself writes "*Special structures, such as nuclear power plants, offshore structures and large dams, are excluded from the scope and scope of EN 1998*.". This provision disappears in the revision of the Eurocodes in progress, as it has now been clarified that the Eurocodes can be used for the verification of any engineering work although it will be necessary to use specially prepared supplementary standards for dams, as for other special works.

From the point of view of the application of the DM2014, in particular for existing dams, the main issues concern the use of criteria and coefficients defined for ordinary civil works with partial safety coefficients and combinations parameters with the values defined by the NTC2008 and not instead, as it should be (see the aforementioned French guidelines) tailored *ad hoc*. These coefficients lead to inconsistencies in the design and verification phase. The experience acquired with the application of the NTC2008 gave rise to the need for its substantial revision, which led to the update of 2018.This update makes the application of the DM2014 even more difficult, due to the explicit reference in the part A of a regulation (NTC2008) no longer in force.

The adoption of the verification methodologies provided for civil works is therefore a cause of inconsistencies and uncertainties on the results. An example is the case of existing gravity dams, for which a prominent Italian dam manager produced in 2014 several comparisons between the dimensions of the dam obtained by applying the DM2014 and the previous DM1982. The study shows that not all load combinations and design approaches of DM2014 lead to acceptable results, as the current sizing may be less restrictive and therefore less safe than those obtained with the previous legislation in some conditions.

All this is more evident by the specific examination of DM2104: the substantial differences between the loads in dams and other constructions are neglected (for example the weight of the structures, which for dams assumes a stabilizing character) and great importance is given to the seismic aspect, which is considered more relevant than the hydrological/hydraulic aspect (while the greater vulnerability of dams with respect to hydraulic aspects is known, such as flood events). In fact, it should be noted that the NTCs follow an approach mainly oriented towards buildings, with particular attention to their behavior in seismic conditions.

Furthermore, some of the limit states are not easily distinguishable, for example, the Limit State of Safeguard of Life and the Limit State of Failure, the classification of dams based on the intended use (instead of, for example, the potential consequences of dam failure) is under discussion, the safety margin on the resistance of the soil is expressed through identical partial coefficients for cohesion and the tangent of the friction angle, an aspect that is not found in other regulations, while it would be appropriate to express this margin on the overall resistance, without necessarily binding the standard to the use of a specific criterion of collapse. The seismic combination at the Ultimate Limit State, for small seismic events, is less critical than the fundamental combination at the maximum regulation level. An important novelty is the zero tensile strength for some combinations at the Serviceability Limit State, acceptable for cracking control purposes in reinforced concrete structures with relatively small geometric dimensions, but which leads to excessive structural dimensions in the case of dams.

The standard also lacks indications on the structure (or *behaviour*) factor, an index of the ductility of the structure, which is thus left to the arbitrariness of those who perform the analyses, although in the past, other regulations suggested possible values to be adopted.

The main problematic aspects of DM2014 for gravity dams are, as already mentioned above, related to the use of partial safety coefficients and combinations with the values set by the NTC2008 and the null tensile strength of the material. This limitation leads to an oversizing of the structures with respect to DM1982. Furthermore, the thermal load generally leads to incompatible tensile stresses with the condition of null tensile stresses. It should be noted that the verification for thermal loads was not required by the previous legislation, which increases the difficulty of these verifications for existing dams. Moreover, the verification of the tangential stresses leads to unrealistic results due to the limits imposed on the reference stress and the lack of stress limits in the presence of seismic loads should be corrected. The problem concerning the absence of tensile stresses also concerns vaulted dams, where the stresses due to thermal loads are of particular importance.

Few indications are given for embankment dams, however rather generic, just as generic information is given for rolled concrete and rockfill dams with concrete mantle, two types particularly used in recent years.

Finally, it is therefore clear that the procedure of analysis for dams cannot simply be taken up by the NTCs and Eurocodes and that it is necessary to address the issue of safety from a more systemic perspective in which, in addition to the limit states already envisaged for the dam, a series of other possible critical issues concerning the entire plant are considered, with the hydraulic works, the control and monitoring systems of the work and the upstream and downstream area of the basin, the mechanical devices whose functioning is the critical element for the general safety of the plant. The safety of the reservoir and the dam has to be understood as the safety of a unitary system.

3. POSSIBLE SOLUTIONS

The critical issues highlighted in the previous sections suggest difficulties in the application of the standard, especially in the case of static and seismic analysis of existing dams. However, it should be emphasized that the Italian dams have an average age of about 60 years so even the use of the DM1982 could lead to problematic situations for many plants.

To overcome these difficulties, while awaiting an update of the rules from the Monitoring Board, reference can be made to a series of documents prepared by the various subjects operating in the field of dam research. The Directorate General for dams of the Ministry of Infrastructures and Transport, responsible for the approval of the safety analysis carried out by the dam owners/managers, has prepared the '*Instructions for the application of the Technical Regulations*' [4] which should allow designers to overcome the most difficult aspects in the application of the DM2014. The instructions represent a contribution to the definition of an evaluation procedure designed to avoid possible qualitative and/or subjective evaluation (common for dams, where often an engineering judgment is required).

A similar publication concerns the ancillary works, which in order to consider the dam and ancillary works as a system, must be subjected to verification as well as the dam [5]. On the subject of ancillary works, the ITCOLD report [6] should also be mentioned. The National Institute of Geophysics and Volcanology published in 2017 a guide for the preparation of the seismotectonic study, prescribed to evaluate certain seismic loads [7].

Finally, it should be noted that documentation of particular interest for dams and ancillary works can be consulted on the websites of the International Commission On Large Dams (Bulletin and others) [8], of the Federal Guidelines for Dam Safety [9], of the US Army Corps of Engineers [10] and the US Bureau of Reclamation [11]. Many other countries (European and non-European) have their own legislation on dams that can certainly be useful to consult, together with those just mentioned, to fill the gaps in the Italian one on specific aspects.

4. CONCLUSIONS

The paper described the Italian current regulatory framework for dam, wit some hints on the engineering background that inspired the principles contained therein. The innovative issues and the critical aspects for the verifications were briefly presented in order to allow a conscious application of the standards. Some possible solutions of the most critical aspects suggested in this paper are from the activity of the Monitoring Board in the proposal of update of the DM2014. Among other aspects, an autonomous formulation with respect to the technical standards for constructions, although inspired by the same principles, is required.

REFERENCES

[1] Decreto del Ministero delle Infrastrutture e dei Trasporti. *Norme tecniche per la progettazione e*

la costruzione degli sbarramenti di ritenuta (dighe e traverse). 26/06/2014.

[2] Decreto del Ministero dei Lavori Pubblici. *Norme tecniche per le costruzioni*. 17/01/2018.

[3] EN 1998, *Design of structures for earthquake resistance*, Brussels: Bsi., 2004.

[4] Lanzi A., Paoliani P., *Istruzioni per l'applicazione della Normativa Tecnica di cui al D.M. 26.06.2014 (NTD14) e al D.M. 17.01.2018 (NTC18)*, Divisione VI Strutture e Geotecnica, Ministero delle Infrastrutture e dei Trasporti, 2019.

[5] Ufficio strutture e geotecnica dell'Ufficio tecnico dighe di Napoli. *Verifiche di sicurezza sismica degli scarichi e delle opere accessorie e complementari - Riferimenti per l'istruttoria* (04/04/2016).

[6] Zinetti F. (coordinator), *Opere idrauliche associate alle dighe*. Comitato Nazionale Italiano delle Grandi Dighe, 2012.

[7] Basili R., D'Amico V., Meletti C., Valensise G., *Linee-guida per la redazione e le istruttorie degli studi sismotettonici relativi alle grandi dighe*. Istituto Nazionale di Geofisica e Vulcanologia, 27/09/2017.

[8] International Commission On Large Dams. Link: https://www.icold-cigb.org/

[9] Federal Guidelines for Dam Safety (FEMA). Link: https://www.fema.gov/

[10] U.S. Army Corps of Engineers (USACE). Link: https://www.usace.army.mil/

[11] U.S. Bureau of Reclamation (USBR). Link: https://www.usbr.gov

Addendum. The Italian regulations are published on the "*Gazzetta Ufficiale della Repubblica Italiana*" (https://www.gazzettaufficiale.it), the official source of the regulations in Italy. It is a necessary condition for an ordinary law to be published in the Gazzetta Ufficiale to come into force. For instance, the DM2014 is published on the Gazzetta Ufficiale n. 156 of 08/07/2014.