RECENT ITALIAN REGULATORY GUIDELINES FOR DAM AND BARRAGES

Fabrizio BARPI
Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino (Italy). Email: fabrizio.barpi@polito.it

ABSTRACT

In June 26, 2014 the Minister of Infrastructure and Transport issued a decree with the new technical regulations for dams and barrages. This decree introduced substantial changes in the existing technical rules, by suggesting a design approach according to latest national regulations. A technical board was set up by the same decree to monitor its effects in the first eighteen months following the issue. This paper, written by one member of that board, reports the activities carried out on the evaluation of the new legislation, highlighting the most innovative aspects as well as the critical issues, and underlining 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, which had to be updated in relation to the changes in the technical standards for the construction sector, such as the Ordinance of the President of the Council of Ministers no. 3274 of March 20, 2003 [2], the Technical Standards for Construction of January 14, 2008 (NTC2008) [3] recently updated on January 17, 2018 (NTC2018) [4]. The regulatory framework proposed in the DM2014 substantially embraced the inspiring criteria of the Eurocodes (already accepted in the NTC2008 and NTC2018), overcoming 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.

Historical Evolution of the Italian DAM STANDARDS

This section presents some technical standards of particular interest. More detailed references can be found in the recent report of the ICOLD European Club Report [5] and, in the website maintained by L.A. Ghinami [6] where a very accurate collection of rules and regulations can be found. To these regulations must be added the guidelines issued by the Italian Dams Register (*Registro Italiano Dighe*), currently the Directorate General for Dams (*Direzione Generale Dighe*) of the Ministry of Infrastructures and Transport (see, for example, the recent Instructions for the application of the Technical Regulations) [7] and, possibly, regional laws. More information can be found in [8].

1. Decree of the Ministry of Public Works n. 481 of April 2, 1921: *General rules for the projects and construction of dams for reservoirs and artificial lakes* [9]. It is the first Italian law to regulate the technical provisions on dams. This standard defined the documents necessary for the preparation of the final project and proposed a classification of the works that will also be maintained in the following regulations. Further indications concerned the definition of the stresses, the calculation methods, the safety loads of the materials and some recommendations to be followed during the construction phase.

2. Royal Decree no. 2540 of December 31, 1925: *Regulations for the projects, construction and operation of retaining dams* [10]. This is the standard written by the Technical Commission in charge of analyzing the Italian dams following the failure of the Gleno dam. This standard introduced stricter control of the work in the design phase and accurate control of the quality of materials and construction techniques. It established that, in the testing phase and during the entire period of operation, the dam had to be continuously monitored by personnel residing in the immediate vicinity of the dam itself. It established that the measurements of the deformations of the structure were carried out according to the reservoir levels and the leaks through the dam body. In the static calculation of the dam it required to take into account, in addition to self-weight of the masonry, water pressure and embankments, the possible existence of uplift pressures and, for the dams in the Alpine regions, the pressure exerted by the ice.

3. Royal Decree no. 1370 of October, 1st 1931: *Regulations for the projects, construction and operation of the retaining dams* [11]. It defined the scope of the regulation to dams with a height larger than 10 m, whatever the relative reservoir, or which determined a reservoir greater than 100000 m^3.

For gravity dams, this regulation made some changes to RD n. 2540 with regard to the definition of safety loads for construction materials, introducing more restrictive conditions and prescribing the use of a concrete conglomerate with superior mechanical characteristics of resistance. This provision also provided for the "filtering task" of the Dams Service (*Servizio Dighe*, evolution of the "special department" provided for by the 1921 regulation), interposed between the Civil Engineering Offices (*Ufficio del Genio Civile*) and the Higher Council of Public Works (*Consiglio Superiore dei Lavori Pubblici*). For the examination of the projects and related condition documents; the Dams Service was also entrusted with the examination of the non-substantial variants and construction features proposed in the executive phase and their possible approval, as well as the approval of the particular precautions to be followed in the case of construction in periods of freezing weather, as well as any abbreviation of the terms established in the regulation for partial reservoirs of earth dams.

4. Decree of the President of the Republic n. 1363 of November 1st, 1959: *Regulations for the compilation of projects, construction and operation of the retaining dams (dams and barrages)* [12]. The legislation introduced the seismic load in the calculation of dams. In zones with high seismicity, dams had to be calculated taking into account, in addition to the static loads of weight and water, the corresponding loads in seismic conditions. With regard to gravity dams, the method of calculating the uplift pressures was changed, taking into account the possible presence of drainages in the foundation rock. In case of empty reservoir, the presence of tensile stresses on the edges not exceeding 300 kPa was allowed; with a full reservoir, wherever the stresses on the edges had to be compressive.

5. Decree of the Ministry of Public Works of March 24, 1982: *Technical standards for the design and construction of barrage dams* [13]. It was promulgated according to the Law no. 64 of February 2, 1974 "*Provisions for constructions with special requirements for seismic areas*", which in art. 1 required the issue of specific technical standards for the design, execution and testing of special works, including dams. The law updated the lists of seismic zones and attributed to these areas different values of the degree of seismicity to be taken as a basis for the determination of the corresponding loads. For gravity dams, the safety checks were to be performed for the foundation section at the lowest elevation and for the sections at various elevations in the structure, taking into account self-weight, hydrostatic pressure, uplift pressures and, if applicable, forces due to ice and seismic loads. In general, among the loads to be considered, the constraints of thermal origin and shrinkage were cited, however not taken into account in the calculation of gravity dams but in the calculation for vaulted dams, as already indicated in all the previous regulations. Tensile stresses should not exceed 300 kPa or 500

kPa if the exceeding of 300 kPa was induced solely by seismic loads.

6. Decree of the Ministry of Infrastructure and Transport of June 26, 2014: *Technical standards for the design and construction of restraint barriers (dams and barrages)* [1]. It will be described in detail in the following sections.

The chronological sequence of the Italian rules shows how the DPR 1363 of 1959 represents the last unitary measure referring to procedural regulations and technical standards, to which two distinct parts are dedicated.

From 1982 to today, the national regulatory technical framework has undergone important changes starting with the Ordinance of the President of the Council of Ministers no. 3274 of March 20, 2003 [2] which profoundly innovated the technical standards in the field of construction, adopting solutions consistent with the European regulatory system of Eurocodes (in particular Eurocode 8) and abandoning the purely prescriptive character in favor of a performance-based approach. Since 2008, the technical standards for constructions moved to the semiprobabilistic method and limit states, while the regulations on dams, which were still in 1982, referred to the allowable stress design method no longer in use. These technical standards were updated in January 2018. This succession of technical standards has resulted in the misalignment of the DM1982 with respect to the construction regulations and has determined the need for its profound renewal with the current legislation of June 26, 2014.

DECREE OF JUNE 26, 2014

The decree introduces, for the first time in Italy, the semiprobabilistic limit state method for dams and establishes the Monitoring Board for the exam of its first application at the Higher Council of Public Works. It also introduces the distinction between dams of normal importance and dams of strategic importance, and refers to NTC2008 for what concerns the partial safety, combination and concomitance coefficients.

This legislation applies to all dams and barrages in the national territory. For dams whose height does not exceed 10 m or which determine a reservoir volume not exceeding 100000 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 current Technical Standards for Construction referred to in NTC2008, in compliance with the special provisions indicated below.

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.

Finally, it should be emphasized that the DM2014 is particularly advanced since, to the knowledge of the author, one of the only three regulations on dams based on the semiprobabilistic method at limit states, even if it should be noted that the other two are the French Recommendations [14] and Chinese standards [15], which do not have the mandatory character that characterizes the technical standards in Italy.

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 the buildings from which, however, the dams seem to be excluded. Eurocode 8 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 standard, in particular for existing dams, the main issues concern the use of criteria and coefficients defined for ordinary civil works with partial safety coefficients, combinations and concomitances with the values envisaged 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 direct link between DM2014 and NTC2008, explicitly referred to in the first section (*Generalità*) of the Decree, makes today even more critical the choice of standardizing criteria and partial safety coefficients for the project and verification of the barrier works to those of ordinary constructions as, the recent revision of the NTC (the NTC2018) has introduced substantial changes both to the verification criteria and to the values of the partial factors, following the experiences acquired with the application of the standard.

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 ENEL, 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.

It is therefore clear that the procedure of analysis for dams cannot simply be taken up by the NTCs 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.

All this is more evident by the specific examination of some substantial points: 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). See the work of the ITCOLD (Italian National Committee of Large Dams) Working Group "*Behavior of dams subjected to earthquakes*" [16] for a discussion on the effects of earthquakes on Italian dams. 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 Safeguarding Life (*Stato Limite di Salvaguardia della Vita)* and the Limit State of Collapse (*Stato Limite di Collasso*), the classification of dams based on the intended use 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 Limit State of immediate Operation (*Stato Limite di immediata Operatività*), 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 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 the possible values to be adopted. In this sense, the proposal of the Italian

National Committee of Large Dams [17] allowed to scale the elastic spectrum with a factor of two for concrete works and four for embankment dams.

The main problematic aspects of DM2014 for gravity dams are related to the use of partial safety coefficients, combinations and concomitance with the values set by the NTC2008 (as already mentioned above) and the null tensile strength of the material (the previous legislation allowed values of tensile stresses less than 300 kPa or 500 kPa in case of seismic events). 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.

Finally, 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 traction also concerns vaulted dams, where the stresses due to thermal loads are of particular importance.

Few indications are given for earth 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.

4 MONITORING BOARD

The decree of June 26, 2014 established the Monitoring Board which "... *within 12 months of the entry into force of the technical standards, prepares a report on the results of the monitoring activity and a proposal to update the standards themselves. In the following 6 months, the updating of the aforementioned rules is issued*".

The Monitoring Board for the period of first application of the Technical Standards for the design and construction of the dam works (dams and barrages) referred to in Ministerial Decree of June 26, 2014 was established in accordance with the provisions of the same decree with expert components that they also have an institutional profile in relation to the subjects who have designated them [8]. The members were designated, in addition to the Ministry of Infrastructure, the Ministry of the Interior, the Department for Civil Protection, the Conference of the Regions and the National Association of Italian Municipalities (ANCI). The composition of the Board arose from a precise indication that emerged during the consultation phase and agreement for the issuance of the new rules. It should be remembered that the preparation of the proposal and the subsequent preparatory phase were characterized by a variety of positions that were confronted on multiple occasions and contexts, giving rise to discrepancies of views which were also

a reason for forms of dissent. The innovative nature of the new standard was, especially in the past, a reason for uncertainty about the sharing and acceptance of the proposed rules.

The Board, established by the Minister's Decree in December 2015, operated for approximately 15 months until February 2017, in accordance with the terms set out in the Ministerial Decree 2014 for the issue of the new regulations. In view of the expiry of the terms, the Board proposed a request for an extension of its mandate, to be fixed by law, which was not recognized at the time.

The Board, which met periodically in Rome at the headquarters of the Ministry of Infrastructures, initially consulted the stakeholders involved in the application of the rules, namely the managers, the National Association of Land Reclamation Irrigation Improvements (ANBI), the National Association of Electric Companies (Assoelettrica), the Italian National Committee for Large Dams, consulted the Dams General Management, promoted three meetings with the Universities and proceeded to update the text of the DM2014. In this phase it was intended to carry out an organic recognition of the application experiences of the standards developed by the stakeholders, which also included all the very detailed observations formulated since 2007, when the original text of the proposal to update the technical standards for the barrage works, which remained almost unchanged in the 2014 version. The observations collected were jointly examined by the Board during frequent meetings where the following main conclusions were reached:

- The limit state formulation is confirmed.
- An autonomous formulation with respect to the technical standards for constructions is required although inspired by the same principles. Full autonomy from the NTC is motivated by the specific nature of the dam works, whose structural composition and consequent behavior are different from those of the buildings referred to in the NTC.
- The selection of the limit states should arise from the examination of different scenarios that characterize the element to be analyzed. These scenarios should be identified in order to take into account, in addition to the dam, the ancillary and complementary works, whose functionality and efficiency is also relevant for safety purposes (sealing system, gates, maneuverable mechanical parts, etc.).
- The actual regulations contains widespread, although necessary, numerical references for conducting the checks and developing the calculation models. The engineering, design and construction aspects of the barriers are to be treated in a more explicit and widespread way to balance the formal setting of the regulatory text that appears unbalanced towards numerical and computational aspects.
- The application of the rules will be almost exclusively related to

existing dams, often in operation for decades. These dams are, in a large part, characterized by a well-documented behavior in normal operating conditions and in exceptional conditions, such as for seismic phenomena and hydrological flood events.

The evaluation of the past behavior is an essential prerequisite for the verification of the real condition taking into account the aging of the materials and the re-evaluation of external conditions (earthquakes and floods).

- Like other areas of civil engineering, the levels of knowledge should be codified for each situation considered. According to the levels of knowledge, the partial factors (of uncertainty) that intervene in the numerical checks should be differentiated.
- The stakeholders interviewed reported the need to provide for a differentiation of the formal extension of the verifications according to predefined dimensional classes of the barrier works, in analogy to the provisions of other international regulations.
- The barrages, which present as specificity the prevalence of the mechanical devices that can be maneuvered, are also considered.

During the course of the works, the text of the Ministerial Decree was progressively updated and a series of changes were proposed. The Board has considered and planned the following developments.

- Return consultation with the stakeholders who have formulated the proposed changes, by organizing a special meeting day extended to those who have formulated proposals and observations.
- Comparison with the experiences acquired in relation to the seismic events that, starting from August 2016, have affected the territories on the border between the regions of Abruzzo, Lazio, Umbria and Marche, which include numerous barrage and reservoirs.
- Comparison with the updates of the NTC of the Ministerial Decree of January 17, 2018.

The proposed changes therefore confirmed the limit state approach and the need of a fully independent regulation with respect to NTC2008 (in force at the time). The definitions of the limit states were revised and the need to treat the dam and ancillary works and plants as a single system was highlighted. It is therefore necessary to consider the complementary and ancillary works such as the guard house, the control room, the road system (walkways and bridges), the hydraulic sealing system of the dam body and the drainage system, the electrical equipment (lighting, surveillance, transformers, generators) and mechanical (hydraulic, oleodynamic). The outlet and intake works, penstocks, tunnels and passages, the possible sedimentation affecting the intake works, spillways, energy dissipation tanks and gates must be

checked. The slopes that insist on the banks of the reservoirs and any embankments must be analyzed to verify their stability conditions.

Particular attention was paid to existing dams. A paragraph concerning barrages was then added and the updates of the NTC2008, which became final in 2018, considered in the draft.

Due to the lack of extension of the legal deadlines that established the Monitoring Board, it was not possible to consult back with the subjects who formulated proposals for modification and to compare with the experiences acquired following the damage induced by the seismic sequences of Abruzzo, Lazio, Umbria and Marche. For the same reason it was not possible to carry out an experiment to assess the adequacy of the safety factors, combinations and concomitances necessary to ensure the safety margins and functionality of the plants, as necessary.

6 SOME POSSIBLE SOLUTIONS

The critical issues highlighted in the previous paragraphs 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 [18] 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, 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 has prepared the aforementioned Instructions for the application of the Technical Regulations [7] which should allow designers to overcome the most difficult aspects in the application of the DM2014 and can be compared to the Instructions of the NTC2008 and 2018. 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 [19]. On the subject of ancillary works, the ITCOLD report [20] 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 [21].

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) [22], of the Federal Guidelines for Dam Safety [23], of the US Army Corps of Engineers [24] and the US Bureau of Reclamation [25]. 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 [6].

7 CONCLUSIONS

The previous paragraphs described the current regulatory framework for dams and the regulatory evolution that inspired the principles contained therein. The innovative aspects and the most problematic aspects for the verifications were briefly presented in order to allow a conscious application of the standards, and in order to allow a future commission, possibly in charge of drafting a new version of the standards, to have useful information on the major criticalities that emerged during the activity of the Monitoring Board.

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