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6 **RECENT DEVELOPMENTS IN THE ITALIAN TECHNICAL RULES FOR DAMS AND**

7 **BARRAGES**

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37 **Abstract**

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

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44 **Keywords**

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

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50 **1. INTRODUCTION**

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

64 2. DECREE OF JUNE 26, 2014

65 2.1 General description

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

74 Section 'A. *General prescriptions*' states that this legislation applies to all dams and barrages in the
75 Italian territory. For dams whose height does not exceed 10 m or which determine a reservoir volume not
76 exceeding 100,000 m³, the Administration responsible for security supervision will decide on a case-by-case
77 basis and, in relation to the characteristics of the dam, which rules are to be applied. It also requires that the
78 design and construction of the works and interventions covered by the standard must comply with the (at the
79 time) current Technical Standards for Construction (NTC2008), now updated. An important issue is that the
80 design procedure must be based on investigations and analysis of varying complexity in relation to the level
81 of detail required.

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

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

93 condition 5). The first two are considered as Serviceability Limit States while the last two are Ultimate Limit
94 States

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

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

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

117 The last part, section '*H. Existing dams*', is devoted to dams with the structure already completed at the
118 time of the safety assessment or at the the time of interventions. An aspect of particular importance
119 concerns the existing dams that will have to be subjected to safety assessment of the entire structure or
120 parts of it, when the general conditions established by the NTC2008 (now replaced by the NTC2018) are
121 fulfilled. The criteria to define safety are defined together with the different possible interventions to obtain a
122 given level of safety. The following categories of intervention are identified: 1. *restructuring* interventions

123 (aimed at achieving the levels of safety and functionality envisaged by these regulations for new dams);
124 *improvements* aimed at increasing the pre-existing safety, even without necessarily reaching the levels
125 required for new constructions; *repairs* or local interventions affecting isolated elements and which, in any
126 case, lead to an improvement of the pre-existing safety conditions; *downgrading*, with a reduction in the
127 height of the dam and/or the reservoir volume); 2. *decommissioning* interventions to deprive the dam of the
128 hydraulic function, but ensuring the safety of the site and of the downstream territories.

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

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

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

141

142 **2.2 Critical issues**

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

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

153 specially prepared supplementary standards for dams, as for other special works.

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

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

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

175 Furthermore, some of the limit states are not easily distinguishable, for example, the Limit State of
176 Safeguard of Life and the Limit State of Failure, the classification of dams based on the intended use
177 (instead of, for example, the potential consequences of dam failure) is under discussion, the safety margin
178 on the resistance of the soil is expressed through identical partial coefficients for cohesion and the tangent
179 of the friction angle, an aspect that is not found in other regulations, while it would be appropriate to express
180 this margin on the overall resistance, without necessarily binding the standard to the use of a specific
181 criterion of collapse. The seismic combination at the Ultimate Limit State, for small seismic events, is less
182 critical than the fundamental combination at the maximum regulation level. An important novelty is the zero

183 tensile strength for some combinations at the Serviceability Limit State, acceptable for cracking control
184 purposes in reinforced concrete structures with relatively small geometric dimensions, but which leads to
185 excessive structural dimensions in the case of dams.

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

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

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

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

208 **3. POSSIBLE SOLUTIONS**

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

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

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

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

232

233 **4. CONCLUSIONS**

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

240

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262 *Addendum*. The Italian regulations are published on the "*Gazzetta Ufficiale della Repubblica Italiana*"

263 (<https://www.gazzettaufficiale.it>), the official source of the regulations in Italy. It is a necessary condition for

264 an ordinary law to be published in the *Gazzetta Ufficiale* to come into force. For instance, the DM2014 is

265 published on the *Gazzetta Ufficiale* n. 156 of 08/07/2014.

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