SEISMIC RESILIENCE OF AN ASPHALT FACING ROCKFILL DAM (AFRD) IN SOUTHERN ITALY[1]

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ITALY

1. FOREWORD

Even if Italy has been affected by periodic important historical earthquakes, the gradual awareness of the widely spread seismic risk in the Italian territory became evident only in the last part of past century, when a large number of dams had already been built.

The Italian Regulatory Codes have then undergone a long series of updates to face the problem according to the increasing knowledges.

Meanwhile some experiences of dams subject to earthquakes have occurred in several Italian regions, giving rise to specific case-histories.

Among those, the limit state of damage has been reached by two embankments, Acciano Dam in Central Italy and Ogliastro Reservoir in Eastern Sicily, while Piana degli Albanesi Dam (masonry massive gravity structure) in Western Sicily has experienced the limit state of life preservation [3].

In the present paper the example of Ogliastro Reservoir, designed and built in the period 1965-1970 outside the riverbed and contained by an asphalt facing rockfill dam (AFRD) is documented. The geographic zone, initially not considered seismic, was interested by an important earthquake in 1990.

After a short description of the works, the characteristics of the occurred seism and its consequences on the structures are presented, associated with the undertaken extraordinary maintenance interventions.

As the geographic zone has been later classified one of the most severe in Italy, finally the results of an updated seismic analysis, developed according to

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[1] *Résilience sismique d'un barrage en enrochement avec masque en asphalte dans le Sud d'Italie*

the Italian Regulatory Codes in force, are illustrated and confirm the safety of the work.

Almost 50 years of regular operation in one area subjected to several increasing seismic reassessments prove the validity of the adopted solutions.

2. EVOLUTION OF THE SEISMIC ITALIAN REGULATORY FRAMEWORK

The Ogliastro Reservoir has been designed and built at the end of ′60s according to the Dam Code in force, in absence of any seismic reference.

Later, on 2nd February 1974 the Law n. 64, which defines typical measures for the constructions with particular prescriptions for the seismic zones, became effective. Meanwhile in 1981 the ministerial decrees of identification of the seismic areas in the various Italian regions classified the Augusta Municipality, where the Ogliastro Reservoir is located, of second category. A few months later, on 24th March 1982, the Ministerial Decree n. 44, “Technical Rules for the design and the construction of the dams”, which replaces the second part of the cited Dam Code giving instructions on the dams seismic analyses, being primarily based on pseudostatic approaches, entered in force.

The review process of that seismic framework required a long time.

In 2003 the Prime Minister Ordinance n. 3274 “First elements about the general criteria for the seismic classification of the national territory and the technical rules concerning the constructions in seismic zones” introduced some new principles based on the progress of the specific knowledge.

In the following years the updating process continued with the Ministerial Decree 14th January 2008 “Technical Rules for the constructions” (briefly NTC08) [4], which entered in force definitively on 1st July 2009, a few months after the L’Aquila earthquake. Such regulations, specifically referred to civil and industrial constructions, bridges and geotechnical constructions, provide the general criteria concerning the safety and the expected performances and introduce the substantial obligation to use the limit state method with specific indications for the design seismic actions to assume.

In particular the primary knowledge element to determine the seismic actions is represented by the ″basis seismic risk″ of the site of construction. That is defined in terms of maximum expected horizontal acceleration a_g in free field on rigid reference site with horizontal topographic surface, as well as of ordinates of the elastic spectrum in acceleration $S_e(T)$ corresponding to it, with reference to prefixed exceedance probabilities P_{VR} in the reference period V_R (F_0 maximum value of the amplification factor and T_C^* initial period of the section at constant velocity of the spectrum in horizontal acceleration). Such values are supplied for all the national territory in an Annex of the NTC08 Rules [4].

In compliance with that concept, on 26th June 2014 the Ministerial Decree "Technical Rules for the design and the construction of the dams" (briefly NTD14) [5] was published in substitution of the 1982 version.

It identifies the operation and ultimate limit states for the various dams types, extending the seismic verifications to the auxiliary works, and establishes a specific approach for the existing dams.

3. OGLIASTRO RESERVOIR FEATURES

The Ogliastro Reservoir has been built between December 1968 and October 1970 in order to provide a 4,450,000 m ^{3} storage (Figure 1) to satisfy the water demand of the Petrochemical Plant located in Priolo, on the East Sicilian coast, in Syracuse Province, Italy [2].

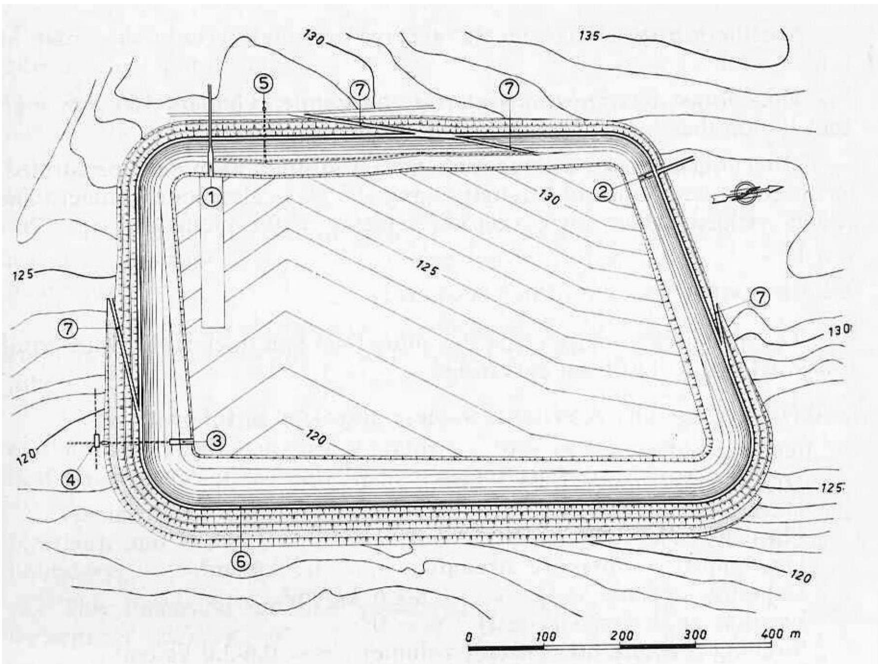


Figure 1
Reservoir plan
Plan du réservoir

1	Delivery structure	*1*	*Ouvrage d'adduction*
2	Spillway	*2*	*Déversoir*
3	Outlet works	*3*	*Vidange de fond*
4	Control house	*4*	*Chambre de la vanne*
5	Inspection galley	*5*	*Tunnel d'accès*
6	Dam crest	*6*	*Couronnement*
7	Access ramps	*7*	*Rampes de raccordement*

Being the reservoir located on a plateau not directly supplied by a catchment area, the water is derived through two dams on adjacent Rio Fiumara and Mulinello Creeks, with a total hydrographic basin of 64.2 km^2.

The pond, with crest elevation at 140 m a.s.l., is delimited by a trapezoidal peripheral rockfill dam, in calcarenite, about 2,350 m long, with height variable between 7.1 and 22.6 m. The water surface elevation may vary between 138.3 and 122 m a.s.l. .

An inlet structure in reinforced concrete is located at the South-West corner.

The bottom outlet and the derivation are in the South side and consist respectively of 1,200 and 600 mm diameter steel pipes inside an accessible 2.5 m x 2.5 m reinforced concrete gallery.

The reinforced concrete spillway, controlled by a 5.0 x 3.0 m gate, with a maximum discharge of 44 m^3 /s, is located in the North side.

Presently the managing authority of the plant is Priolo Servizi S.C.p.A..

3.1 DAM DESIGN CRITERIA

The original stratigraphy of the plateau with a calcarenite level overlying clays all over the reservoir area precluded any leakage through the bottom, but obliged to exclude any rigid type of dam. After an accurate technical and economical comparison it was decided to build an homogeneous embankment of calcarenite with upstream impervious membrane, which was preferred to the more generally used central impervious clay core type.

Slope, height and size of the dam have been chosen on the basis of the underlying geological structure, as well as taking into account the best possible use of the borrow materials available near the reservoir.

3.2 THE EMBANKMENT

The available calcarenite showed a good degree of workability and could be excavated from the borrow area by means of powerful bulldozers.

Maximum dry density, γ_{dry} (Standard Proctor)	Maximum dry density, γ_{dry} (Modified Proctor)	Elastic Modulus, E (Standard Proctor)	Elastic Modulus, E (Modified Proctor)	φ (passing 20 mm sieve)	φ (rock fragments 50÷80 mm size)
t/m^3	t/m^3	Kg/cm^2	Kg/cm^2	°	°
2,0	2,1	250	400	35÷45	38

Table 1
Geotechnical characteristics obtained with laboratory tests on the calcarenite material of the embankment
Caractéristiques géotechniques obtenues avec des essais de laboratoire sur la calcarenite du barrage

Table 1 contains the geotechnical characteristics obtained with laboratory tests.

The embankment typical section (Figure 2) was then formed by:

- a central zone composed of calcarenite blocks up to 0.4 m^3 volume, built disposing 80 cm thick layers, subsequently compacted by six, 13 tons vibrating roller, passes. This roller crushed the weaker blocks whose fragments filled the empty spaces left between larger and stronger blocks, producing an overall earthfill dry density of 1.9 t/m^3 and permeability of 10^{-5} m/s;
- an upstream shell, about 2 m thick, of calcarenite, built by deposition of 40 cm layers, compacted with a 13 t vibrating roller. The final dry density and permeability averaged 1.95 t/m^3 and 10^{-6} m/s, respectively. At the end of compaction the face was leveled, to obtain a regular base for the asphaltic membrane;
- a downstream shell, two metres thick, made of coarse calcarenite with little or no sand and fines.

The downstream face has been covered by a topsoil layer with grass.

The curves connecting the four sides of the reservoir are quite wide, to facilitate the upstream membrane construction operations.

A drainage system, formed by galleries and 400 mm diameter perforated pipes, has been introduced all around the reservoir immediately downstream of the headwall to collect water possibly percolating through the asphaltic membrane.

The pipe is subdivided into several stretches, which discharge outside through 400 mm pipes, provided with flow measuring devices, enabling to locate possible leakage areas.

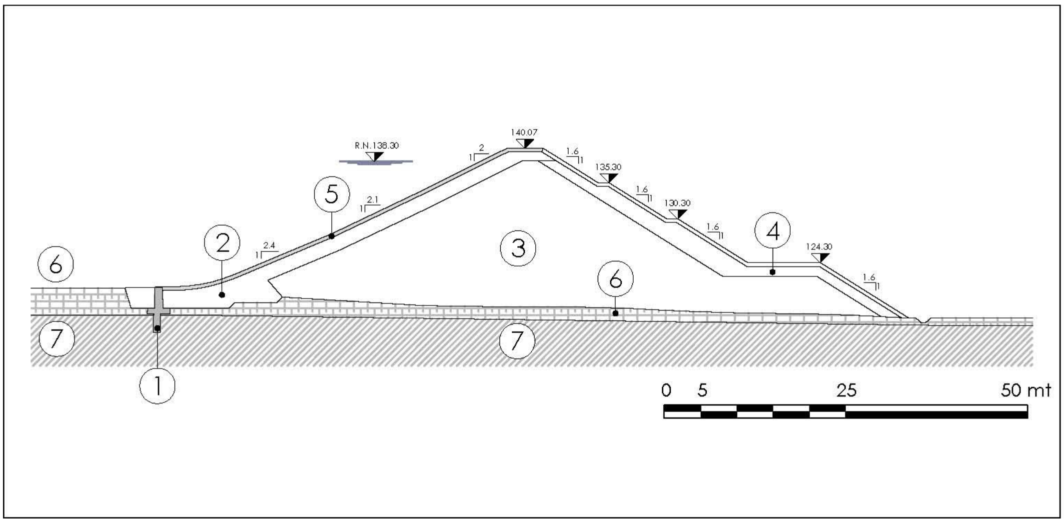


Figure 2
Cross section
Coupe transversale

1	Concrete headwall	*1*	*Parafouille en béton*
2	Type A < 300mm calcarenite	*2*	*Calcarénite, type A < 300 mm*
3	Type B calcarenite (quarry run)	*3*	*Calcarénite, type B (tout-venant)*
4	Type C calcarenite (blocks)	*4*	*Calcarénite, type C (blocks)*
5	Impervious membrane	*5*	*Masque étanche*
6	Calcarenite	*6*	*Calcarenite*
7	Clay	*7*	*Argile*

3.3 THE IMPERVIOUS ASPHALTIC MEMBRANE

The asphaltic concrete has been directly laid on the upstream shell, compacted with a very regular base (maximum allowable roughness 4 cm over 3 m distance) and treated spraying 10% sodium cloride-water solution in the amount of 1 l/m^2, in order to prevent plants growth.

The membrane is formed by the following layers :

- draining asphaltic concrete layer, 8 cm thick, composed of limestone aggregate of 35 mm maximum size; bitumen percentage = 3÷4% of the total weight; permeability K = 10^{-4} m/s; temperature of deposition 140 °C;
- asphaltic concrete binder, 3 cm thick, composed of limestone aggregate of 18 mm maximum size; bitumen percentage = 6÷7% of the total weight; permeability 10^{-6}÷10^{-7} m/s; temperature of deposition 140 °C;
- waterproof asphaltic concrete layer, 6 cm thick, composed of limestone and basaltic aggregate up to 18 mm size; bitumen percentage = 8.5-

9.5% of the total weight; permeability K = 10^{-9}÷10^{-10} m/s; temperature of deposition 180 °C;

- bituminous seal (2 kg/m^2) formed by bitumen, limestone filler, concrete, asbestos and sand, respectively in the following percentages: 41-17-28-5 and 9; temperature of deposition 210 °C.

The asphalt has been obtained using relatively hard (B40/50) bitumen, due to the high temperatures (about latitude 37°) the membrane will be exposed to.

Precautions were taken, in order to avoid melting processes, by spraying the exposed surface of the membrane with 1 l per 10 m^2 lime-vinyl 10% solution.

Complete waterproofing along the deposition joints has been obtained by infrared rays heating and vibrator compacting a 40 cm large band. This treatment gave the membrane a perfect continuity.

Aggregates with size in excess of 2 mm were specified to be basalt because of its lower and more constant porosity; limestone aggregates have been used for smaller sizes.

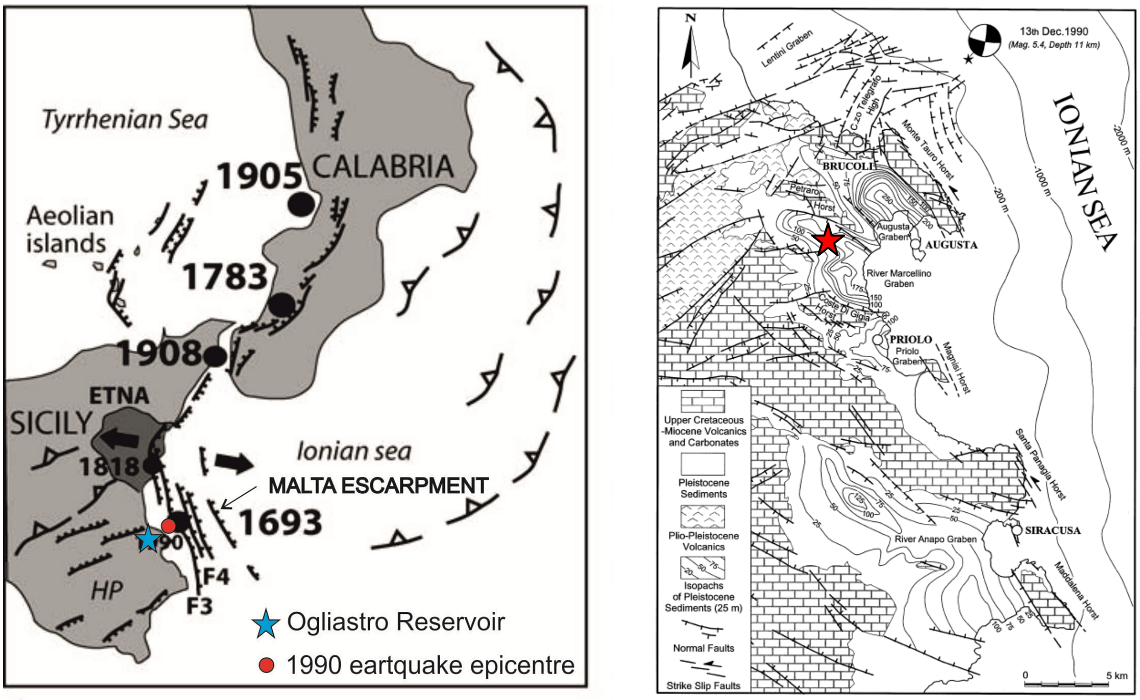
4. SANTA LUCIA EARTHQUAKE

From December 1990 to January 1991, a seismic sequence culminated in a major earthquake (M_w= 5,61±0,1 from database CPTI15) occurred on December 13, 1990 (S. Lucia earthquake), caused very strong shaking in many municipalities of the eastern Sicily, inducing 17 dead, hundreds injured, thousands homeless and serious damages in the whole area.

The hypocentre of the S. Lucia earthquake was estimated at about 10 km and the epicentre was located in the Ionian Sea, at short distance from the city of Augusta (Figure 3/a), about 27 Km from the Ogliastro Reservoir.

The geological origin of the earthquake has been linked to movements occurred along a system of buried structures, oriented NW-SE and NNW-SSE, directly connected to the recent development of the Malta Escarpment, a main lithospheric extensional fault which separates the continental Hyblean Plateau (HP) from the Mesozoic Ionian oceanic basin (Figure 3/a).

Some of these off-shore faults extend also on-shore in the eastern Sicily, originating a series of horst and graben structures recognized between Catania and Siracusa cities (Figure 3/b).



a) b)

Figure 3

Main historical earthquake epicentres occurred in eastern Sicily (a) after [8] modified; b) after [1], the star marks the Ogliastro Reservoir site

Principaux épicentres des séismes historiques produits dans l'Est de la Sicile (a) après [8] modifié; b) après [1]; l'étoile marque le site du Réservoir Ogliastro

The following estimated characteristic parameters of the S. Lucia earthquake at the Ogliastro Reservoir site have been provided by [3]:

- I_{MCS}=6.5,
- PGA =0.241g,
- PGV=0.039 m/s.

5. CONSEQUENCES ON THE OGLIASTRO RESERVOIR

The conditions of the main structural elements, as well as the results of the surveys and control measures carried out immediately following the seismic event, are summarized below.

The reservoir water level was ~132 m a. s. l., more than 6 m under the normal water level, so that the West side was almost completely exposed.

Macroscopic planimetric or altimetric displacements have not been observed either along the crest road on the four sides, or on the external face and on the emerging part of the internal one. Moreover water losses or humidity stains on the external face were not detected.

The only structural element which was mainly affected by the consequences of the event is the asphaltic membrane which waterproofs the interior faces of the reservoir.

In fact it was interested by cracks (Figure 4), mostly observed in the curves of the embankment and in proximity of the auxiliary structures in reinforced concrete (inlet and spillway), or next to the embankment discontinuities. A small part of them, isolated, was observed in the central zone of the West and North sides.

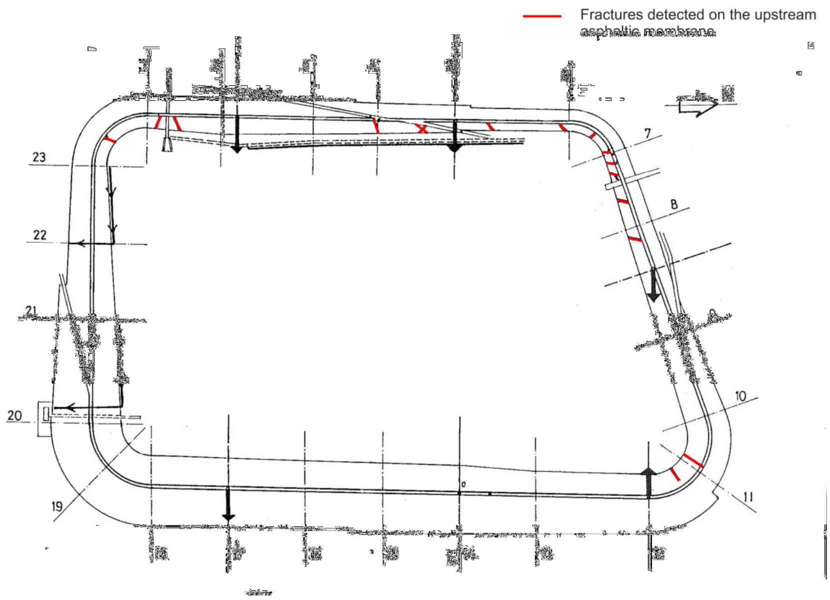


Figure 4

Location of the main cracks of the asphalt facing mapped after the S. Lucia earthquake

Localisation des principales ruptures du masque en asphalte cartographiée après le séisme de S. Lucia

The cracks presented well defined characteristics of continuity (from the crest to the water level and sometimes to the foot of the embankment next to the headwall), orientation (almost all diagonal) and opening (equal or less than 1 mm). Another recurring observed element, which would confirm a failure mechanism for tensile stress, is the absence of differential displacements perpendicular to the surface of the face between the edges of the openings.

Some cracks continued on the crest road pavement, crossing it in all its width, and anyway disappeared on the external face.

The extremity of the impervious asphaltic membrane in contact with the headwall was surveyed on the West side and North-West and South-West corners, where it emerged. Upliftings or tears were not detected, even where the cracks appeared.

In order to verify the depth reached by the fissures, some samples have been taken in correspondence of the cracks.

From the examination of the boreholes and of the extracted cores (Figure 5), it was clearly seen that the ruptures affected the entire thickness of the asphaltic membrane.

Figure 5
Characteristics of the ruptures in the asphaltic membrane as observed on the core drillings

Caractéristiques des ruptures dans la membrane asphaltique observées sur les carottages

Drainages losses have increased a little remaining below 1 l/s, which was considered acceptable.

Anyway it has to be emphasized that the level of the reservoir at the time of the earthquake was low and that it has been kept constant in the following period.

The inspection of the inlet and spillway structures and the results of the related clinometric measures did not detect verticality losses, unexpected deformations or damages, with the exception of a small detachment of concrete at one edge of the counterweight of the spillway gate, probably due to its impact on the piles during the earthquake. Its full operability has been positively verified.

No particular anomaly was observed even in the central, western, and bottom outlet galleries.

6. EXTRAORDINARY MAINTENANCE INTERVENTIONS

The type of detected cracks and the considerable spread of the phenomenon on the asphalt facing, associated with the urgency of coming back to the normal operation of the reservoir, addressed the search towards a technical solution focused to the rapid repair of the cracks.

Evaluated several possible alternatives, in February 1991, in the part of facing above the water level of the reservoir, for a band width of 50 cm across the cracks a graded milling of the entire impervious layer thickness (about 6 cm), was carried out and the restoration of the bituminous conglomerate, with reduced grain-size of the aggregates, was operated.

The following impoundment of the reservoir was characterized by an immediate increase up to 4.5 l/s of the total losses measured at the drainages outlets, probably to be ascribed to a phenomenon of initial adjustment of the embankment.

Later the discharge reached a constant value around 2÷3 l/s, comparable with that before the earthquake.

Anyway, in order to ensure the watertightness of the interior face even at long term, in 1993 Geotecna Progetti was committed to prepare a rehabilitation design of the impervious asphaltic membrane on the West, partly North and South sides, without total emptying of the reservoir due to the necessity to preserve an emergency water storage.

The Concessionary then proceeded with the intervention during the summer 1993.

It consisted in the partial milling of the existing superficial bituminous concrete for a 3 cm thickness (6 cm in correspondence of the cracks) and in the laying of a new impervious layer 8 cm thick, made of modified with termoplastic elastomers bitumen, as well as in the application of a new seal on a total surface of about 30000 m^2. At the same time all the joints have been renovated in the treated zones.

7. SEISMIC REASSESMENT AND OGLIASTRO RESERVOIR ANALYSIS

Following the process of reassessment of the seismic risk on the Italian territory, in the last years the area in which the Ogliastro Reservoir is located has become of particular interest for the Italian Dams Authority, due to the increased expected level of the possible earthquakes.

As a consequence, a seismic analysis has been recently developed in accordance with the presently in force Italian Rules NTD14 [5] and NTC08 [4] (see § 2), based on the limit states.

Within the scope of this verification, a seismotectonic study specific for Ogliastro site has been executed in agreement with NTD14 [5], being the expected maximum horizontal acceleration, normalized with the acceleration of gravity (a_g/g), greater than 0.15 for return periods of 475 years.

The seismotectonic study mainly aimed to:

• assess the seismic potential (maximum expected magnitude, strength parameters, distance from the site) associated with relevant regional seismogenic sources (deterministic evaluation);

• identify the presence on the surface of active tectonic structures around the site.

The main conclusions were the following:

• the values fixed by the NTC08 [4] for the horizontal and vertical acceleration peaks are higher than the deterministic estimates assessed by the study and the horizontal and vertical spectra given by the NTC08 [4] are substantially confirmed by the envelope of the deterministic spectra;

• active tectonic structures around the site are not evident, even if a more detailed local research would be necessary to exclude definitively their presence.

The seismic load definition and the seismic analysis according to NTD14 [5] and NTC08 [4] are presented in the following paragraphs.

7.1 SEISMIC LOAD DEFINITION

In the definition of seismic actions for an existing dam, such as Ogliastro Reservoir embankment, according to the Italian Rules NTD14 [5], a 50 years V_N nominal life is assumed, which, combined with a C_U use coefficient of 1.5 (being the industrial use ″relevant″, but not ″strategic″) becomes V_R 75 years and provides for the return periods to consider in each limit state the values reported in Table 2.

Limit State of	Operation (SLO)	Damage (SLD)	Life safety (SLV)	Collapse (SLC)
P_{VR} (%)	81	63	10	5
T_R (years)	45	75	710	1460

Table 2

Seismic actions return periods vs limit states

Période de retour des actions sismiques par rapport aux états limites

The seismic action to apply to the structure is then extracted by a data base, enclosed to NTC08 [4], depending on longitude (15.12988) and latitude (37.24059) of the site and is defined by the following characteristic parameters, according to the concerned limit state:

T_R = return time;

a_g = maximum horizontal acceleration at the site;

F_0 = maximum value of the amplification factor of the spectrum in horizontal acceleration;

T^*_C = initial period of the section at constant velocity of the spectrum in horizontal acceleration.

In the examined case the related values of such parameters for Ogliastro Reservoir are summarized in Table 2.

Limit State of	T_R [years]	Ag [g]	F_0 [-]	T_C* [s]
Operation (SLO)	45	0.061	2.486	0.267
Damage (SLD)	75	0.083	2.487	0.286
Life safety (SLV)	712	0.315	2.313	0.448
Collapse (SLC)	1462	0.449	2.344	0.503

Table 3

Seismic action parameters
Paramètres de l'action sismique

7.2 SEISMIC ANALYSIS

In case of existing dams NTD14 Rules [5] require to take into account SLD and SLC limit states.

In particular for embankments corresponding to collapse limit states (SLC) the following situations have to be considered:

1. instability of the faces and/or of the foundation grounds and deformations of the dam body and/or of the foundation grounds, able to determine structural damages to the embankment or the overflow;
2. collapse of the embankment for internal erosion or piping;
3. cracking of the asphaltic membrane;
4. liquefaction of the dam body or of the foundation grounds;
5. rupture or damage of the outlets which block the controlled outflow from the reservoir.

In the next paragraphs the results obtained for each situation mentioned by NTD14 Rules [5] are illustrated and discussed.

The analysis confirms the experienced seismic resilience of the Ogliastro Reservoir.

7.2.1 *Instability and deformations of embankment and foundation*

In particular, through the dynamic analysis of the maximum height section interested by the seism associated with the collapse limit state, the possible instability of the faces and/or of the foundation grounds and the deformations of the dam body and/or of the foundation grounds which can determine structural damages to the embankment or its overflow have been examined.

Extracted by the data base enclosed to the NTC08 Rules [4] the seismic actions (see Table 3), seven reference accelerograms have been selected to be used in the calculations (Figure 6).

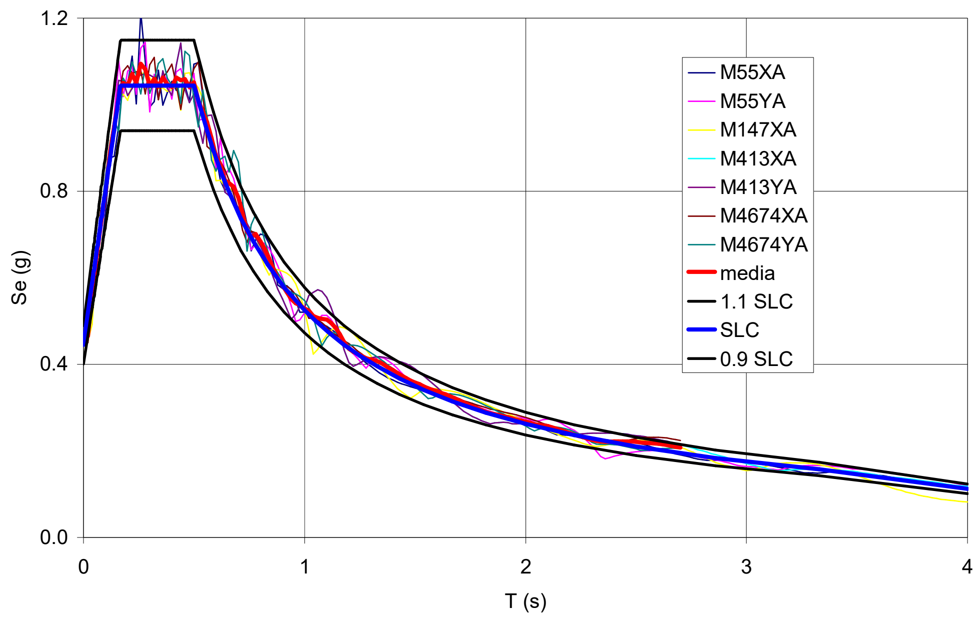


Figure 6
SLC spectrum and scaled accelerograms spectra
Spectre SLC et spectres des accelerograms normalisés

The dynamic geotechnical characteristics of the embankment and of the foundation grounds have been defined on the basis of literature formulations, compared with the results of recent MASW surveys and of previous investigations.

The dynamic analysis has been developed using both a linear equivalent (FLUSH) and a non-linear (FLAC) constitutive law.

The permanent deformations have been evaluated using empirical correlations, with the direct numerical integration of the results of the linear equivalent dynamic analysis and with the non-linear approach.

Also in case of a SLC seism the obtained results confirm the safety of the embankment regarding a possible uncontrolled loss of the water. In fact the risk of overflow for freeboard annulment is avoided and the numerical analysis shows that instability phenomena involving the faces, particularly the upstream one, do not occur and downstream the permanent displacements are concentrated in a cortical zone.

The residual displacements calculated with numerical integration of the linear equivalent dynamic analysis are between 0.5 and 0.85 metres. Such values agree well with those estimated through empirical correlations of literature and which at most reach about 0.9 m.

In particular the non-linear analysis obtains an absolute displacement of 1.18 m (vertical component 0.65 m, downstream). Given the severity of the seism, the ratio between that maximum settlement and the available freeboard (1.70 m) can be considered acceptable.

7.2.2 Collapse for internal erosion

The development of an internal erosion within an embankment in calcarenitic materials and with an impervious asphaltic membrane on the upstream slope could follow a generalized rupture of the membrane and would imply a particular erodibility of the material crossed by the seepage water.

In particular for the Ogliastro Reservoir, seepage analysis and internal erosion risk verification, carried out in the hypothesis of a generalized cracking of the impervious asphaltic membrane, provide satisfactory results regarding the stability of the embankment.

The internal zoning of the embankment is illustrated in the cross section shown in Figure 2; the drainage layer in bituminous conglomerate, underneath the impervious asphaltic membrane, and the calcarenitic blocks which protect the downstream slope of the embankment, are of relevant importance for its functionality in the hypothetical case of a rupture of the impervious facing.

In fact the draining layer prevents the saturation of the dam body by the possible seepage water; the calcarenitic blocks, in addition to improve the stability of the downstream face, tend to contrast the arise of the losses on the same face, in case the upstream draining system fails to intercept all the seepages.

To guarantee the integrity of the embankment also in the hypothetical case of the asphaltic membrane cracking, the stability of the calcarenite with regard to the internal erosion has been verified.

The "self-protection" criterion, usually adopted for the filters, has been successfully applied to an average grain-size, where the bigger fractions have been considered as basis material and the finer ones as filter.

Meantime the embankment in calcarenite can develop the function of provisional hydraulic barrier of the impound.

In fact, using an average permeability coefficient $k=10^{-5}$ m/s for the calcarenite embankment, the seepage discharge on a single sector 100 m long between the emptying pipes towards downstream of the drainages would be about 2.8 l/s.

The transient time necessary to reach a stationary condition of saturation characterized by such discharges can be estimated about 1 - 2 months, starting from the beginning of the seepage, due to the generalized asphaltic membrane cracking.

7.2.3 Cracking of the asphaltic membrane

The cracking of the asphaltic membrane, which is usually limited to some fissures, is hardly predictable with numerical methods, given also the particular trapezoidal form of the Ogliastro Reservoir.

Anyway, it can be assumed that such an event would involve the immediate engagement of the draining system of the embankment, as well as the gradual development of a seepage within the embankment itself.

In addition to the rapidity of the failure detection, in order to manage a possible draw-down operation, the permeability and the self-protection capability of the embankment material, which have been already analysed in the previous paragraph, result very important to face the possible limit state.

The drainage system indeed has been seized to evacuate the seepage water in absence of the impervious asphaltic membrane on the upstream face.

The seepage flow is conveyed through the open layer of bituminous conglomerate located downstream of the sealing layer.

This pervious layer is 8 cm thick and has a coefficient of permeability of about 10^{-4} m/s, higher than the immediately underlying zone. composed of calcarenite with grain size <300 mm, 2 m thick and with a permeability of at least one order lower.

The seepage water, directed towards the inner foot of the embankment, is collected by a 400 mm diameter drainage pipe, located immediately downstream of the headwall, below the face, and which extend along the internal perimeter.

Every 100 m the drainage pipe is interrupted by manholes, from which a transversal pipe conveys the collected water downstream of the embankment, where it is measured.

Any rupture of the impervious asphaltic facing is therefore signalled by an unusual flow of water.

Since the difference in the coefficient of permeability between the draining layer and the underlying calcarenite layer is not big, in case the seepage develops towards the draining pipe located at the foot of the embankment, it starts, even if with lower entity, also towards the central body of the embankment.

7.2.4 Embankment slopes stability

The possible cracking of the impervious asphaltic membrane and the formation of progressively wider saturated zones could result in a marked negative influence on the stability of the slopes of the embankment, due to the formation of pore pressures.

Therefore stability analyses have been carried out on the highest section assuming the most pessimistic conditions, i.e. the integral rupture of the impervious layer and the development of a stationary seepage motion in the dam body.

With regard to the upstream slope, high factors of safety have been obtained when the basin is full.

They become lower considering the downstream slopes, much steeper, even if values over 1.2 persist.

7.2.5 Liquefaction potential of the embankment and the foundation ground

For Ogliastro Reservoir a liquefaction potential analysis of the foundation ground of the embankment is not necessary, since it is predominantly made of fine clayey-silty deposits of Pleistocene age, probably overconsolidated and characterized by high plasticity (IP ratio ≈ 50-60%) and undrained cohesion values higher than 1 Kg / cm^2.

In the foundation subsoil, these clayey deposits are alternated with biocalcarenitic layers some metres thick, with rock consistency and therefore certainly not vulnerable to liquefaction phenomena.

For the granular materials of the embankment, produced crushing the calcarenitic banks present in areas nearby the reservoir, and which are not expected to be saturated due to the presence of the impervious asphaltic membrane on the upstream face, the overall grain-size characteristics ensure the stability to the liquefaction phenomena (Figure 7), despite the high seismicity of the site.

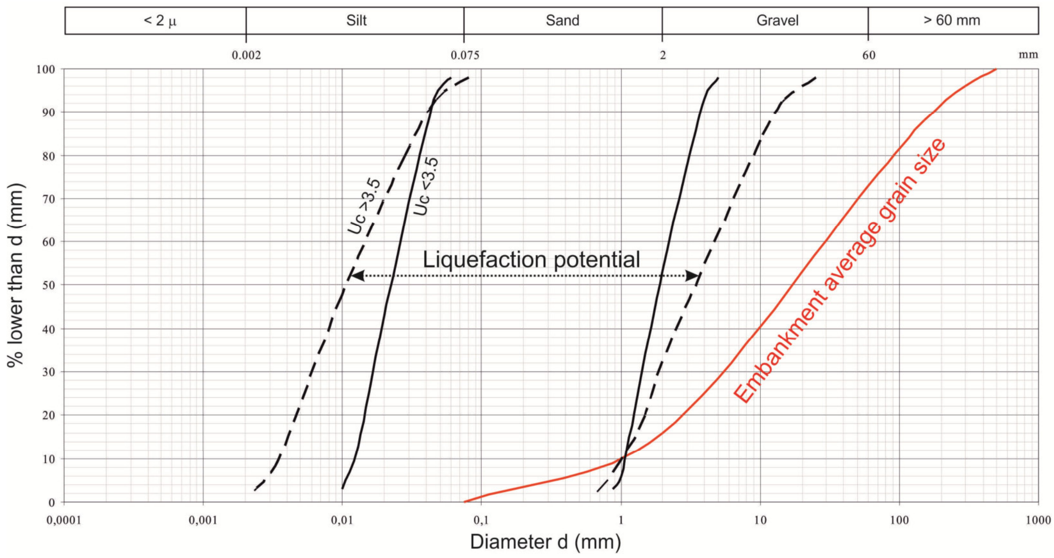


Figure 7

Comparison between the critical grain-size curves for soil liquefaction stability, as fixed by the NTC08 [4], and the average grain-size distribution of the embankment material

Comparaison entre les courbes granulométriques critiques pour la stabilité de la liquéfaction du sol, comme indiquées par le NTC08 [4], et la courbe granulométrique moyenne du matériau du barrage

In fact the average grain-size curve of the calcarenite forming the embankment, corresponding to a sandy gravel with pebbles with Uniformity Coefficient UC (D_{60}/D_{10}) of about 30 (indicative of a very well-graded material), falls substantially outside the critical ranges indicated by NTC08 Rules [4] for materials susceptible to liquefaction.

Moreover the velocities of the seismic shear waves (V_s) attributable to the embankment materials are also quite high, with values close to 300 m / s already starting from the surface and increasing with depth, reaching values above 650 m / s at the base of the embankment.

These velocities are undoubtedly indicative of a state of high density of the material which, in addition to the grain-size characteristics described above, supports a favourable judgment on the stability of the embankment to potential liquefaction phenomena.

7.2.6 Rupture or damage of the spillway and/or of the outlets

As shown in Figure 1, the Ogliastro Reservoir is equipped with an intake structure, a spillway and a bottom outlet.

Anyway it is possible to interrupt the incoming water flow by operating on the gates, locally, remotely through telecontrol or manually.

The reservoir water level control and the drawdown operations are executed through the following devices:

- the spillway, which is equipped with a flap gate, with automatic and manual regulation;
- the bottom outlet and the intake, which are intercepted by two DN1200 and DN600 electrovalves. The operation of the two valves can be controlled locally, remotely via the remote control system, or manually.

The spillway and the outlets have been successfully analysed under the same seismic actions adopted for the embankment analysis.

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ABSTRACT

Even if Italy has been affected by periodic important historical earthquakes, the gradual awareness of the widely spread seismic risk in the Italian territory became evident only in the last part of the past century, when a large number of dams had been already built.

As a consequence the Regulatory Codes have undergone a long series of updates to face the problem according to the increasing knowledges.

Meanwhile some experiences of dams subject to earthquakes have occurred in several Italian regions, giving rise to specific case-histories.

In the present paper the example of Ogliastro Reservoir, designed and built in the period 1965-1970 outside the riverbed and contained by an asphalt facing rockfill dam (AFRD) is documented. The geographic zone, initially not considered seismic, was interested by an important earthquake in 1990 and the structure reached the damage limit state.

After a short description of the works, the characteristics of the seism and its consequences on the structures are presented, associated with the undertaken extraordinary maintenance interventions.

Finally the results of an updated seismic analysis according to the Italian Rules presently in force are illustrated, confirming the experienced seismic resilience of Ogliastro Reservoir.

RESUME

Même si l'Italie a été intéressée par périodiques importants tremblements de terre historiques, la prise de conscience graduelle que le risque sismique est amplement étendu sur le territoire italien est devenue évidente seulement dans la dernière partie du siècle passé, quand un grand nombre de barrages avait déjà été construit.

Par conséquent les Règlements ont subi une longue série de mises à jour pour affronter le problème selon les connaissances croissantes.

Entre temps quelques expériences de barrages sujets aux tremblements de terre se sont produits dans nombreux régions italiennes, en déterminant des exemples spécifiques.

Dans la présente mémoire le cas du Réservoir Ogliastro, projeté et construit dans la période 1965-1970 hors du lit du fleuve et contenu par un barrage en enrochement avec masque en asphalte, est documenté. La zone géographique, initialement non considérée sismique, a été intéressée par un important tremblement de terre en 1990 et la structure a atteint l'état limite de dommage.

Après une brève description des ouvrages, les caractéristiques du séisme et ses conséquences sur les structures sont présentées, associées avec les interventions de maintenance extraordinaire exécutées.

Enfin les résultats d'une analyse séismique mise à jour selon le Règlement italien en vigueur, qui confirment l'expérimentée résilience séismique du Réservoir Ogliastro, sont illustrés .