Safety by material restoraton of the flood detention basin's weir of the Enza river, Northern Italy.

Francesca Carisi[1], Monica Larocca[2], Annamaria Belardi[3], Andy De Paola[4], E-zio Baldovin[5], Luigi D'Antonio[6], Mirella Vergnani[7]

[1,2,3,7] *AIPo – Agenzia Interregionale per il fiume Po, Parma, Italy*

[4,5,6] *Geotecna Progetti s.r.l., Milan, Italy*

Abstract

The intervention we are presenting relates to the safety of the flood detention basin's weir of the Enza river, a right tributary of the Po River in Northern Italy. The works concern the restoration of concrete and reinforcements of the weir's glacis and downstream stilling basin, seriously damaged due to the continuous exposure to the water action. As flood detention basins are relatively recent works, the related literature is still scarce. The successful intervention showed numerous innovative aspects, e.g., the construction site's management, which is entirely inside the channel, the adaptation of consolidated techniques to the particular structure's shape and the use of materials, tipically employed in different environmental contexts. The amount of collected information makes the intervention an excellent example for the optimization of the qualitative, functional and performance characteristics of future meathods aimed at securing similar hydraulic works.

1 Introduction

This manuscript refers to the works for restoring material and structural conditions of the weir's glacis and downstream stilling basin of a upstream weir, which is part of the Enza river's flood detention basin (Emilia-Romagna Region, Italy). Initially, the project related to a more superficial maintenance, but when the concrete works have been dried and cleaned, their deterioration degree resulted to be much more extensive and deep than expected. Consequently, specific supplementary structural, geological and geotechnical investigation was pursued and, among other analyses, structural assessments of the weir in the transitional phase of the works was performed, in order to test the static feasibility of the proposed interventions. Works have been carried out in two seasons, because of the works' execution times and, after having built suitable provisional works, compatibly with natural hydraulic discharges of the Enza river, therefore during the summer, i.e. the season characterized by the minimum hydraulic flow discharge. The final goal was to restore the work to its original state, re-establishing its initial safety conditions.

2 Intervention area

The Enza river's flood detention basins are a hydraulic work, which occupies an area of about 200 hectares between the municipalities of Montechiarugolo (PR) and Montecchio Emilia (RE) (see Fig. 1a). Its construction was completed in 2006 and actually include two basins, built left outside the channel, with a total water storage capacity of 12 million m^3. These are therefore "diverting" flood detention basins, that is, part of the discharge flowing through the main water course is "diverted" through spillways and temporarily accumulated in two specific neighboring areas, delimited by embankments. This water volume is then slowly released to the main water course through the discharging system (culverts). The interventions described in this article concern the upstream discharge limiting weir (Fig. 1c), consisting of two parts: the main one, in the channel, is made by a concrete structure with five openings, aiming at slowing down the discharge and raising its level, which can thus overflow in the upstream detention basin through the secondary lateral branch of the weir. The works concentrated on the channel's part of the weir (Fig. 1b), which is about 100 m long (5 symmetrical modules of 20 m each) between the right abutment and the central pier of the bridge covering the weir, and affected, specifically, the weir's glacis and the downstream stilling basin.

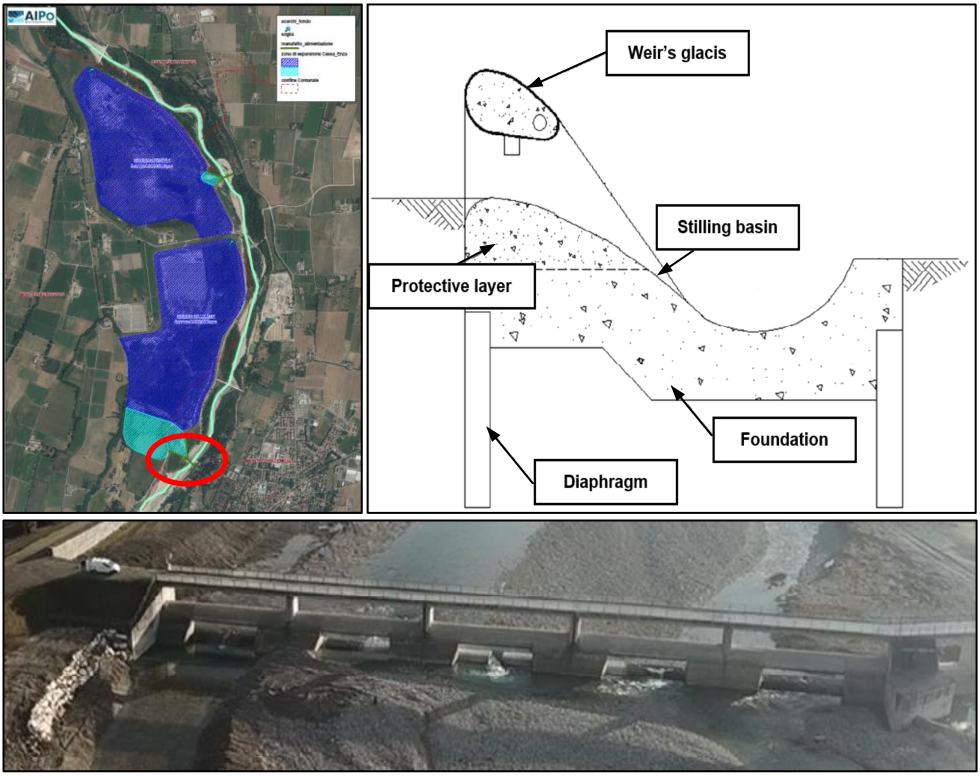

Fig. 1 a) flood detention basins' area and, in red, location of the upstream discharge limiting weir; b) cross section of the structure (without the bridge deck); c) aerial view of the channel's part of the weir.

3 Current situation of the weir

The concrete's strength class of the weir's glacis can be classified as C40/50, while the reinforcements are made of FeB44 k steel; regarding the stilling basin, its foundation is made of class C25/30 concrete and Fe44Bk c.s steel, while the concrete of the protective layer has a strength class of C50/60 and the same reinforcements of the foundation. In this weir branch, additives were used with the concrete, in order to better protect foundations due to the water contact. All materials are compatible with requests by UNI EN 206.

The weir resulted to be considerably abraded and eroded in the downstream glacis and at the bottom of the stilling basin, with an almost constant exposure of the reinforcing bars, which are sometimes not delimited by concrete anymore, instead they are completely external to the theoretical carpentry's profile and sometimes broken (Fig. 2a and 2b). The main causes of deterioration of the structure are:

- carbonation phenomena and freeze-thaw cycles as regards the weir's glacis;
- abrasion/erosion/surface wear regarding the concrete stilling basin.

3.1 Corrosion due to carbonation and degradation of the concrete matrix due to freeze-thaw cycles

Among all cases that may arise in structures concerning the concrete carbonation, in our weir the glacis' concrete cover was intact and carbonated for a thickness that was smaller than the reinforcements' covering: the reinforcements were still "passivated" and therefore sufficiently protected against oxidation; in order to evaluate an adequate intervention in relation to the work's residual life, the time required for the carbonation front to reach the reinforcement was estimated and it resulted to be greater than the residual nominal life of the structure.

In the lower part of the weir's glacis, which is frequently in contact with water due to splashes and nebulization phenomena, the aggressions due to a certain number of freeze-thaw cycles were also evident, which resulted in the complete disintegration of the cortical part of the structure.

3.2 Concrete abrasion/erosion/surface wear

Suspended particles carried by rivers cause an abrasive action on the structures' contact surface. Furthermore, the flowing discharge produces, with its vortices, actions of depression (cavitation) on the stilling basin's concrete, which tend to tear materials' microscopic parts. This type of physical deterioration represents the main damage cause for channel structures. In our specific case, signs of degradation on the concrete cover were evident, which was considerably cracked and/or detached and/or abraded in extensive areas of the structure. In addition, the stilling basin's concrete in some points was also degraded more in depth, with possible aggression of the reinforcement and reduction of the resistant section of structural elements.

Fig. 2 Damaged reinforcement of the weir's glacis (a) and of the stilling basin (b and c).

4 Implemented works

4.1 Weir's glacis

As for the weir's glacis, in which the concrete cover was degraded but the aggression didn't hit the reinforcement yet, the intervention aimed at restoring the concrete cover before the degradation would compromise the structure itself. Specifically, the intervention on the weir's glacis included: milling off the cortical part for a minimum thickness of 40 mm up to a maximum of 60 mm in the areas with greater damages; replacement and/or integration of particularly deteriorated reinforcements with new ones with the same diameter; passivation of all reinforcements, both existing and newly placed, with specific products capable, in addition, to increase their adhesion to the restoration mortar; finally, the restoration of the glacis' cortical layer with a premixed thixotropic fiber-reinforced cement-based mortar, class R4, after cleaning and washing the surfaces to be treated, for a thickness of 40-60 mm. Figure 3a shows the weir's glacis at the end of the intervention.

4.2 Stilling basin (fundation and protective layer)

The purpose of the intervention on this part of the weir was to restore the structure's strength, both in terms of sections and/or thicknesses and durability, bringing it back to the initial design conditions, by means of the following processes: hydrodemolition of the surface layer for a depth of 30 mm; milling around existing reinforcements, check of their state of conservation and replacment as needed; application of bar connectors with improved adherence (to increase the very likely impact and rolling resistance of elements on its surface, when works are in the channel) with two-component epoxy resin anchor; passivation of all reinforcements, as for the glacis; reconstruction of the stilling basin's geometry with the use of premixed thixotropic cement-based mortar, class R4, fiber-reinforced with polypropylene fibers with high adhesion to the support and very high compressive strength, for a thickness of 30 mm, after suitable water saturation of the surfaces to be treated. In addition, high-resistance centimetric joints have been made arranged in the flow's direction with a maximum depth of 2 cm, treated and sealed with high-resistance material, so that the surface of the entire structure resulted uniform and without open joints. For areas with very deep degradation, a next-generation concrete was used, obtained with expansive premixed binders with compensated withdrawal, which guarantees much higher performance than traditional concretes; finally, the usual 3 cm surface finish was carried out with the premixed thixotropic fiber-reinforced cement-based mortar, class R4. The finished intervention on the stilling basin is shown in Figure 3b.

Fig. 3 Weir's glacis (a) and stilling basin (b) after the intervention.

5 Peculiarity of the intervention

Flood detention basins are a quite rare works, typical of the Italian lowland areas (they are not widely used abroad), one very different from the other as regards construction characteristics, in particular those of concrete weirs. Furthermore, they are relatively recent works, so it is quite difficult to find similar restoration interventions to refer to. Being the weirs in the channel, a first difficulty lies in the construction site set up: specific provisional works were necessary, together with particular attention to the surrounding environment (e.g. interventions had to be planned in periods of minimum disturb for bird nesting, or implementing specific measures to avoid the accidental dispersion in water of the materials coming from the processes). Adequate procedures had to be assessed in order to be activated in case of flood: in addition to the installation of hydrometers, alarms, etc., the construction site areas had always been left empty of stored materials and therefore easily to be evacuated in the event of inundation; with the same purpose, motorized work platforms (instead of common scaffolds) were used and trailers were employed for hydrodemolition machines. The choice of materials also proved to be right for the optimization of methods due to the shape of the structure and for timing of the intervention: for example, the used mortar required a spray application, its levelling with a straightedge and then its smoothing with a trowel. This procedure made it possible to avoid formworks for pouring operations in the stilling basins and, consequently, to avoid fixed structures installed in case of flood. The same materials needed both excellent mechanical resistance characteristics, in particular to abrasion, and high adhesion to the support, as well as excellent resistance to cracking, freeze-thaw cycles and aggressive environmental agents. The used mortar, in this regard, did not require the application of a electro-welded metal mesh, which will result in a long lasting intervention given the propensity of the latter to trigger future widespread degradation phenomena.

6 Conclusion

The intervention proved to be particularly satisfactory because, despite being a quite rare work or, in any case, not yet tested in similar conditions, it was possible to find the best way to combine the necessities of the construction site with the characteristics that materials required, due to the structure's geometry and the environmental conditions where the weir is located. The part of the intervention carried out in the first season boasts now more than one year of operation and the analyzes carried out during the last dry period have shown how the restored materials have kept their characteristics practically intact, despite exposure to atmospheric agents and the erosive and abrasive action of water. Further check will be necessary during the weir's service life, but at present this restoration procedure is certainly an example for future maintenance of similar works.

Acknowledgements

Authors wish to thank the Department of Engineering and Architecture of the University of Parma for the precious support in choosing the materials' characteristics and the construction methods. Many thanks also to collegues and companies, who constructively took part to the various phases of the intervention.