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The collapse of the Sella Zerbino gravity dam

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ABSTRACT

When a severe flood wave completely filled the Ortiglieto reservoir on August 13, 1935, the 14 m high "Sella Zerbino" secondary dam failed catastrophically causing >100 casualties. Both of the dams, Sella Zerbino-Zerbino Saddle and Bric Zerbino-Zerbino Peak (Fig. 1) were overtopped but only the Sella Zerbino failed whereas the main barrage did not suffer any damage. The lawsuit that followed this tragic event ended with a full acquittal of the dam's designers since the plaintiff experts succeeded in demonstrating that the collapse was due to an extreme rainfall storm of unpredictable intensity. The case was then officially closed and still today the failure of the Sella Zerbino dam is attributed to the unpredictable hydrological event. Recently, Natale and Petaccia (2013) re-examined the case assessing the capacity of the flood spillways which equipped the Bric Zerbino dam. This paper thoroughly reviews the mechanics of the collapse of the Sella Zerbino dam focusing on the stability of the structure. The water pressure underneath the dam and the poor quality of the foundation rock is believed to have played a major role in the sequence of events that ended in the collapse of the barrage.

1. Introduction

In Italy, the construction of large dams started at the end of XIX Century when the second industrial revolution was just beginning (ANIDEL, 1961). The Gleno disaster, occurred in 1923, is considered as the first dam collapse happened in Italy. It is believed to have been caused by foundation instability combined with changes in the construction methodology. It provoked >400 causalities (Pilotti et al., 2011).

According to ICOLD (1974), the main causes of failure of gravity dams are foundations deficiencies and inadequacy to release flood through spillways and outlet works. Poorly-designed spillways are often causing dams failures (ICOLD, 1991).

The Spanish Puentes dam was a 286 m long and 50 m high concrete dam, laying on wooden pillars inserted in a sandy ground. In 1802 the dam suddenly fell at the first filling of the reservoir and killed 608 people.

The Bouzey dam (France) was a dam 525 m long and 22.7 m high that created a reservoir of 7 million m^3 (Smith, 1994). A 5 m deep cutoff wall was built to improve the rather leaking bedrock. In 1895, at the initial filling of the reservoir, water started to spout out from the bedrock and the dam slipped forward with a maximum displacement of 35 cm. The dam failure killed 85 people.

The St Francis dam (Begnudelli and Sanders, 2007) was a curved concrete gravity dam (California, USA). The dam was 57 m high, 213 m long, and the reservoir stored 47 million m^3. In 1928 when the reservoir was first filled to its crest the dam failed because of the poor quality of the bedrock: the westward abutment was built on a fault while the eastward one was built on mica schist interspersed with talc.

The Sella Zerbino dam in Northern Italy is considered a classical example of poorly designed spillways because the 1935 peak flood discharge was 3 times bigger than the design discharge.

The design of the Bric and Sella Zerbino dams was completed in 1926 under the "Dam Construction Rule No. 1309" emitted by the Ministry of Public Works April 2, 1921, already in force. This Rule required that the water uplift to be considered in the dam stability analysis.

After the Gleno dam failure in 1923, the Italian Government appointed a Technical Commission (December 6, 1923) to carry out a detailed investigation on the safety of existing dams to determine the need for possible retrofitting measures. On December 31, 1925 the Technical Commission submitted to the Government the new Dam Design and Construction Standards which were promptly approved. Only in November 1st 1959, these technical regulations were superseded by the Decree n. 1363; new Construction Standards were issued in March 24, 1982 to update the previous ones. In Italy, the design of new dams and the assessment of existing ones is ruled by the Ministry Decree published on August 7, 2014. The major innovation with respect to the previous technical regulations is the shift from a prescriptive design philosophy to a performance-based design approach. The lessons learned from the catastrophic events occurred over the past 150 years were somehow poured into the new regulations. An important aspect that is now fully recognized is the need to properly recognize from the

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beginning of the design procedure that hydrological, hydraulic, geological, geotechnical and seismic processes are strictly connected.

2. Design history of Sella and Bric Zerbino dams

The Ortiglieto reservoir stored the waters of Orba basin which covers an area of 142 km^2 on the leeward side of the Liguria Apennine in Northern Italy (Fig. 2). The design of the Molare hydropower plant changed several times in the 28 years period from the initial design to the start up of the plant. The first project to exploit a discharge of 0.35 m^3/s from two Orba River tributaries, dates back to 1899 (Zunini, 1899). In the following sections, the design of the main and secondary dams is discussed separately.

2.1. Bric Zerbino main dam

The first project of Bric Zerbino dam, dating 1899, aimed to create a reservoir with storage capacity of 8.1 hm^3. The normal water elevation was 311.00 m above the sea level (a.s.l.); the maximum water elevation was 313.00 m a.s.l. Floods were discharged by a gated lateral spillway. In July 1912 after the permission to exploit the reservoir for hydroelectric purposes was granted, a call to accrue the reservoir volume up to 12.25 hm^3 was put forward. The new project increased the maximum reservoir elevation to 316.00 m a.s.l.

The dam was 40 m high and 50 m long and its flood spilling capacity was 328 m^3/s. This project was approved in 1915.

On April 13, 1921 the construction manager filed for increasing the reservoir capacity to 16.15 hm^3 with 320.00 m a.s.l. maximum water elevation. The 45.5 m high dam was equipped with Heyn siphons and a bottom outlet for an overall discharge of about 660 m^3/s.

In 1923 the Heyn siphons were replaced by 2 groups of 9 broad crested weirs, operating at 322.00 m a.s.l. The discharge released was about 800 m^3/s for a reservoir level of 315.00 m a.s.l.

The May 1924 upgrade increased the reservoir volume to 18 hm^3 and the maximum water elevation to 323.00 m a.s.l. A battery of 12 Heyn siphons released 500 m^3/s (Petaccia and Fenocchi, 2015).

In 1925 the projects of the bottom outlet and the side spillway were presented. The bottom outlet was regulated by a bell valve and could release up to 150 m^3/s. The design discharge of the side spillway, located rightward of the dam, was 110 m^3/s. A high pressure bottom outlet of 55 m^3/s was also present.

The side spillway was then modified in 1926, since a flood event evidenced its insufficiency. The capacity of the modified spillway increased to 160 m^3/s.

Finally, on August 13, 1935, the Bric Zerbino dam was 47 m high, that is 40% higher than the original project, and 191 m long (Fig. 3). The distance between the main and the secondary dam was 500 m.

2.2. Sella Zerbino secondary dam

The 1899 project of the Ortiglieto plant envisaged a straight low sill 78 m long located at Sella Zerbino to evacuate floods. The releasing capacity of this weir, equipped by 24 couples of gates 1.5 m high, was 400 m^3/s.

The 1921 the construction manager proposed to change the weir into an Ambursen non-overflow gravity dam: due to poor quality of the foundation rock spillways were excluded. As the Dam Office of the Ministry rejected this ill-advised proposals, a revised project of a gravity dam was presented on May 21, 1924. No additional geotechnical investigations were accomplished despite the highly deteriorated characteristics of the bedrock. As later discussed, this played a major role in the disaster. The four blocks of the dam were separated by three contraction joints.

On August 13, 1935 the final shape of Sella Zerbino dam was as follows: height 14.5 m, length 109 m, shoulders made as solid walls 3.5 m broad. The slope of the faces of three central blocks of the dam were: 10% upstream and varying from 75% to 55% downstream (Fig. 4). The secondary dam had no spillways.

A soon as the reservoir was filled, water leakages of about 0.06 m^3/s were detected, so that grout injections in the bedrock were called for. The grout curtain did not stop the leakage; in fact the final inspection noticed a considerable water spillage for a reservoir level of 321.80 m a.s.l.: a leakage of 0.017 and 0.005 m^3/s from the right and left abutment of the dam was reported. Table 1 shows the historical evolution of the Ortiglieto project involving the two barrages.

3. The failure of the Sella Zerbino dam

After a long dry period, at 6:15 a.m. of 13th August 1935 an exceptionally severe rainfall storm hit the Orba basin (Natale and Petaccia, 2013). At 7:00 a.m. the rain intensity increased and kept on without interruptions until 3:00 p.m. The rain reached his highest intensity between 7:00 and 8:00 a.m. and between 2:00 p.m. and 3:00 p.m. At

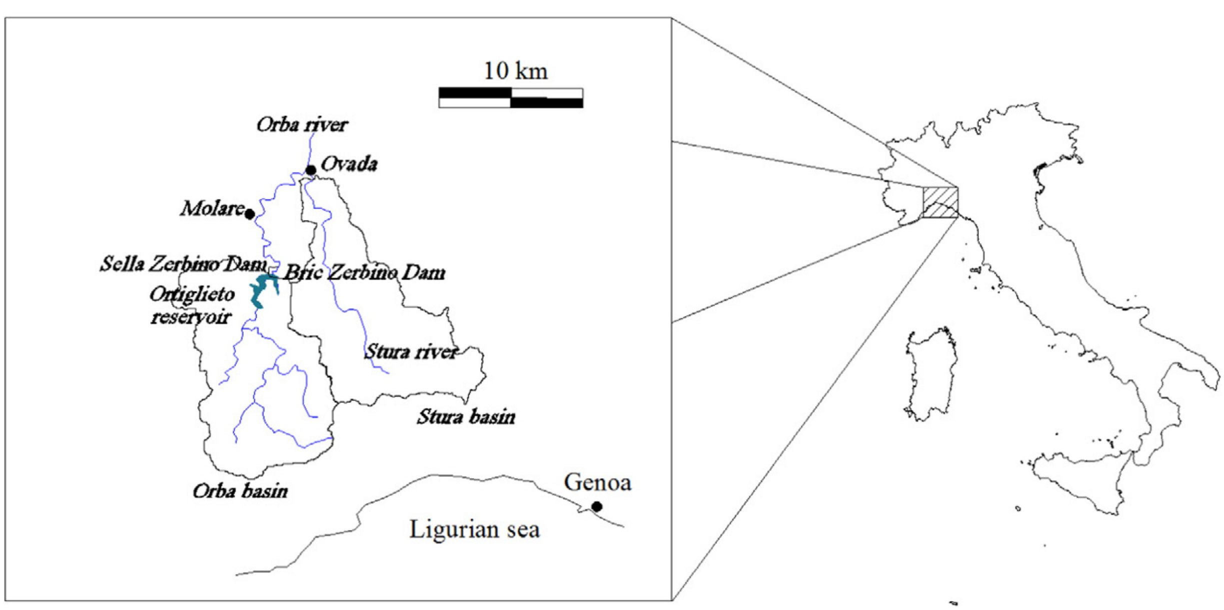

Fig. 1. Location of Ortiglieto reservoir in Northern Italy.