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From practical experience to national guidelines for debris-flow mitigation measures in Austria

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Abstract

In the second half of the 19th century a lot of torrential disasters occurred in the Alps causing substantial damage. These catastrophes may be traced back to non-sustainable land-use management with inadequate alpin pasture farming, leading to forests in a poor condition, large denuded areas and steep incised channels. Starting with an analysis of these disasters, political decisions were made to implement mitigations measures, including forestry, agricultural and structural measures. Additional financial regulations were established to facilitate mitigations measures even for poor rural communities. The technological background for the design of structural measures was founded in forestry, because of the experience with construction of log driving. Basic hydraulic models were used for designs, sometimes empirical values were added to consider bedload or the impact of point loads. The structures served to stabilize the channel bed, to deposit bedload upstream of settlements, to restrict sedimentation or inundation on the fan or to redirect the flow to areas of low interest. In the early years of torrent control in the Alps, structures were usually built as dry masonry walls, later cement mortar masonry walls and concrete gravity walls were favoured. New static concepts and the use of reinforced concrete formed the basis of a colloquium in Vienna (1973), where load models and static concepts were discussed. In practice, the multiplier of the static load of the Lichtenhahn-model was used within a broad range, leading to different structural design of check-dams. In the beginning of the 21th century, based on the design concept of EUROCODE, new technical guidelines for barrier design (ONR-Series 248xx) were developed. The load cases include flood and debris-flow and combination of events for all kind of torrential structures. The experience in the application of these guidelines is currently being evaluated and will lead to a new national standard.

Keywords: Mitigation measures; Debris-flow; Design Standards; Torrent control service; Austria;

1. Introduction

There is a long tradition of natural disaster mitigation in Alpine regions. In the 18th century, Joseph Walcher (1719-1830), an Austrian Jesuit, physicist and mathematician, worked on the topic of hydraulic and glacier lakes. In his work "*Nachrichten von den Eisbergen in Tyrol*" (Walcher, 1773), he investigated the Vernagt glacier, Gugler glacier and especially the Rofner glacier lake, which threatened the Ötz valley by repeated glacial lake outburst floods (Fig 1). These outburst floods had catastrophic consequences for the province of Tyrol in the years 1600, 1678, 1680 and at 1845. In the year 1788, an edict promulgated by Wenzel Graf von Sauer, incited working-groups to establish mitigation measures (Graf von Sauer, 1788). Franz Seraphin von Zallinger zum Thurn (1743-1828), priest and physicist, worked on this edict and addressed the issue of inundation in Tyrol in his work "*Abhandlung von den Überschwemmungen in Tyrol*" in the year 1779 (Zallinger zum Thurn, 1778;1779).

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Fig. 1. Glacier lakes illustration of (Walcher, 1773); (a) Rofner glacier lake; (b) Passyer lake

One of the first technical drawings can be found in this publication. Also in France, Jean Antoine Fabre (1748-1834) was involved in the topic of mitigation measures in Alpine regions with his book "*Essai sur la théorie des torrens et des rivéres*" (Fabre, 1797). In the next decades, the topic gained interest, but most work remained theoretical (Aretin, 1808; Streffleur, 1852; Müller, 1857). It was the work of Josef Duile (1776-1863), that started practical implementation of mitigation measures (Duile, 1826). He was an engineer, primarily in the field of hydraulics and road construction with a keen interest in torrent control. Due to his leading role in this field, he was called to Switzerland and applied his knowledge there. He can be considered as father of the European torrent control (Fig 2). In this time, two technical domains characterized the progression of the torrent control: one part was hydraulic engineering and the other part was forest engineering.

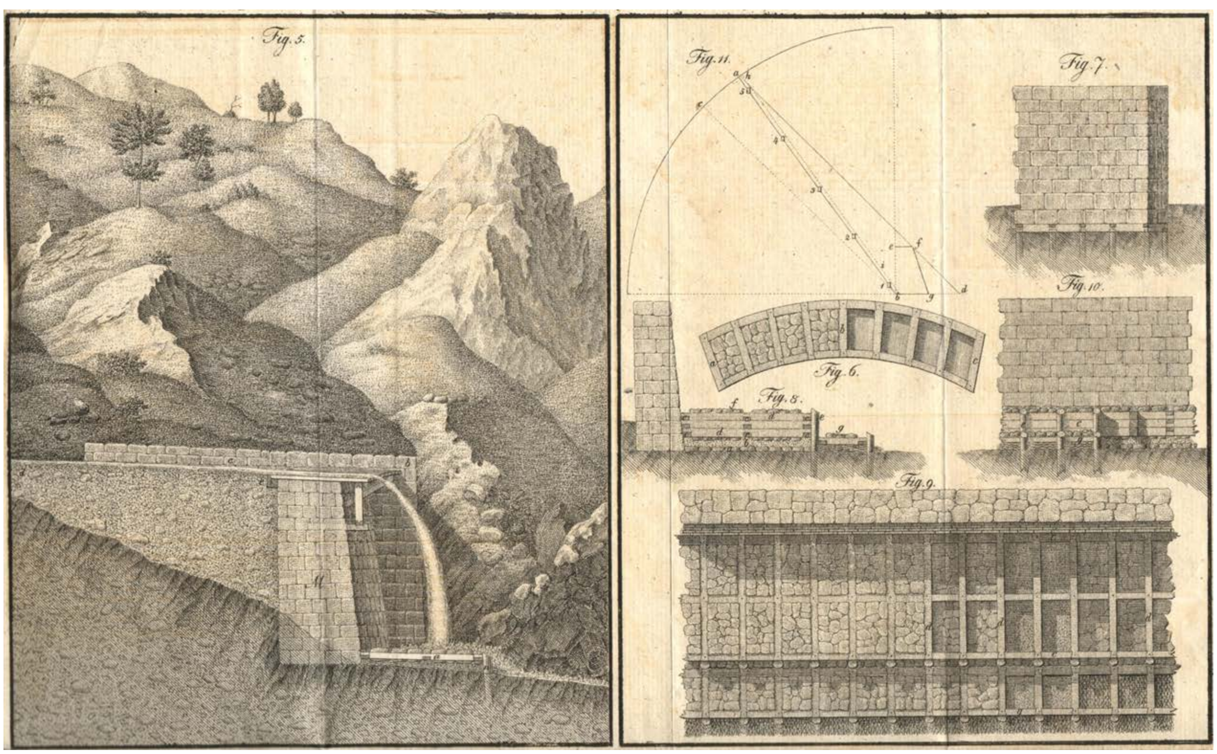

Fig. 2. Technical illustration of mitigation measures; (Duile, 1826)

Hydraulic engineering was mainly applied to the lower part of the torrent while forest engineering addressed the headwaters. The political question who should further be responsible for torrent control works led to a controversy between Arthur Freiherrn von Seckendorff (forest engineering) and Weber von Ebenhof (hydraulic engineering) (Länger, 2003). During this time, Seckendorff started to study the methods developed in France, especially the works of Demontzey, (1880).

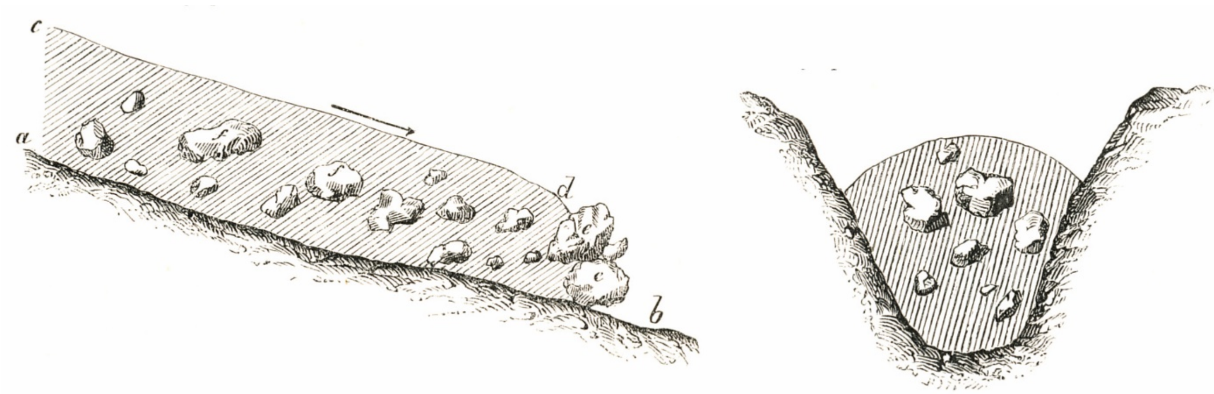

Fig. 3. These drawing originate from a report of an eyewitness (forester) of a debris-flow near Faucon (Barcelonette, France) in (Demontzey, 1880). The longitudinal section shows the accumulation of coarse boulders at the debris-flow front and the right picture displays the debris-flow cross section during the passage of the front.

Owing to the major catastrophes in the years 1846 and 1856 along the rivers Loire and Rhone in France (Fig 3), increasing knowledge developed in this field and public support started and led to a legal foundation of mitigation works in the years 1860 and 1864, especially related to reforestation.

The severe floods in Tyrol and Carinthia in the year 1882 initiated, as in France, a rethinking. Julius Graf Falkenhayn travelled to France in the year 1883 to learn of the methods used, and to implement them in Austria (Wang, 1901). The emperor of Austrian-Hungarian monarchy passed the torrent control act in 1884, stating that torrent control works have to be executed on a national level, with public funding and with a systematic approach. Seckendorff introduced the forest engineering background from France successfully. The government implemented a legal basis for financing and organizing the torrent control service to ensure further development. Educational courses were established at the University of Natural Resources and Life Sciences, Vienna (BOKU) for students and the staff of the new established service.

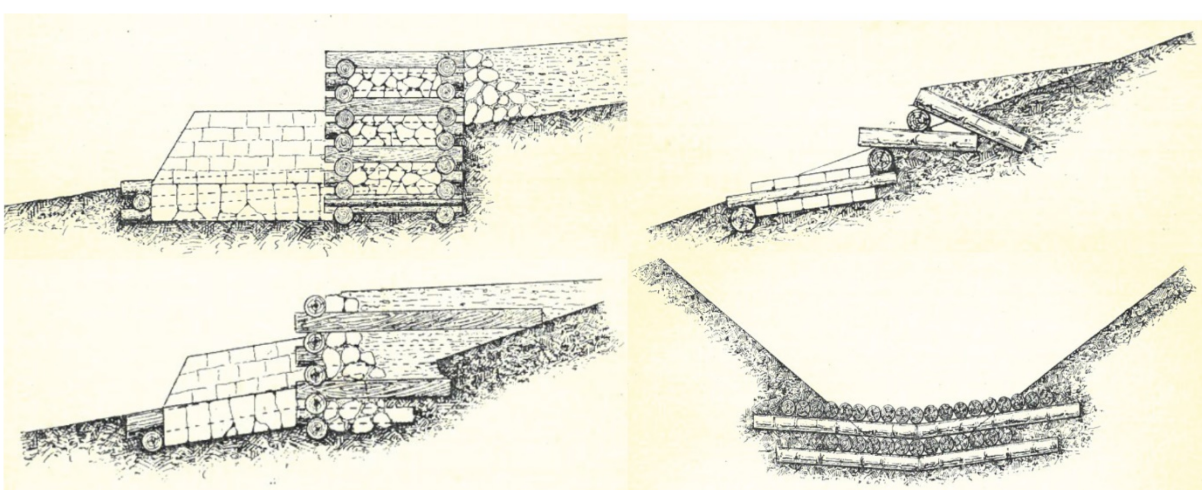

Fig. 4. Example of technical structure of (Wang, 1901)

2. Empirical design approaches

The construction materials used at this period consisted of the locally available construction materials near the torrents, see Fig 4 (Wang, 1901). Wood and dry-stone masonry were used for mitigation measures. Progress was achieved through dissemination of experience and not by research because no research facilities existed at the time. Nonetheless, first innovative experimental structures were raised, for example:

- Barrier with a self-cleaning function (dosing) was installed in the Fischbach, Tyrol (1924-1928) (Fig 5)
- A cement mortar arch dam was built in the years 1951/52 in the Finsingbach, Tyrol, to study the failing conditions of this construction type.
- Prefabricated construction of a barrier of reinforced concrete in the Winklergraben, Upper Austria (1929-1931).

Fig. 5. Barrier with a self-cleaning function (dosing); "Strele-Sperre", Fischbach, Längenfeld, Tyrol (IAN-Archive)

Due to the improvement of materials and mechanization on building sites in the second half of the 20th century, new methods were established in the torrent control service. Increasing usage of heavy machinery in the steep regions enhanced construction efficiency.

Depending on the two main types of structures used, the arch dam and the gravity wall, different formulas were used for design. The focus of the gravity wall was external stability (safety against tilting, sliding and bearing capacity failure) and the dimensions of the bottom width of the structure. Arch dams reduce the construction volumes by using the arching effect for stability. The arch dam designed by Hampel (1960) in the Finsingbach set a trend for the dimension of arch dam with a simple formula based on the ring tension. The formula reads

$$d = \frac{(h+u) \cdot r \cdot \gamma}{\sigma_d} \quad (1)$$

with the thickness of the dam *d*, the height *h*, flow depth *u*, radius of the arch dam *r*, allowable pressure loading of the material σ_d and the density of water γ with 1 metric ton/m³ (Leys, 1968).

The Austrian Centre for Forest Research (BFW) held an international colloquium on check-dams in Vienna in the year 1972. Lichtenhahn presented at this colloquium the often-used load model for design (Lichtenhahn, 1972). He proposed an empirical multiplier k to increase the hydrostatic pressure p_{st} to include load of debris-flow pressure. In practice, this multiplier ranges significantly and led to different structural designs of check-dams.

$$p_{st} = k \cdot \rho \cdot g \cdot h \tag{2}$$

3. Adaptation to EUROCODE concept

Due to this long tradition in torrent control works in the Austrian Alps, numerous different types of protection works were designed in different regions in Austria. The design of technical structures is now based on the EUROCODE concept, that specifies how structural design should be conducted within the European Union (EU). Based on this, the ONR Series 248xx was established, encompassing torrential processes, snow avalanches and rock fall. An interdisciplinary working group (ON-K-256) developed the new standards for the load models, design, construction and life cycle assessment of torrent control works (technical standard series ONR 24800). The following national documents have been developed:

- ONR 24800: 2009 02 15 (Austrian Standards, 2009), Protection works for torrent control - Terms, definitions and classification; Contains the terminology and classifications of torrent control including the terms concerning the design and function of torrential barriers. An important classification is the definition of functional barrier types.
- ONR 24801: 2013 08 15 (Austrian Standards, 2013), Protection works for torrent control - Impacts on structures; stresses on torrential barriers result from water (hydrostatic, dynamic), earth and debris-flow impacts. In special cases effects from avalanches, falling rocks and earthquakes must also be considered.
- ONR 24802: 2011 01 01 (Austrian Standards, 2011), Protection works for torrent control - Design of structures; for the design of torrential barriers, the Ultimate Limit States (ULS) and the Serviceability Limit States (SLS) must be considered. The concept gives specific design rules (e.g. stress combinations) for torrential barriers.
- ONR 24803, 2008 02 01 (Austrian Standards, 2008), Protection works for torrent control - Operation, monitoring, maintenance; a fundamental requirement to guarantee a minimum safety level of the protection works is periodic monitoring of their condition and effectiveness. The monitoring concept, in the *ONR 24803*, is divided in two parts, the inspection and the measurement or intervention part.

By these technical standards, the “traditional” assessment and construction concepts for torrent control structures were adapted to the EUROCODE standards. The documents are based on and interact with EN 1990 (basic of structural design), EN 1992-1-1 (design of concrete structures), EN 1997-7 (geotechnical design) and the related documents for the Austrian national specifications.

Torrential barriers with the functions energy-dissipating, dosing, filtering or deflecting (Hübl, 2018) are subject to extreme dynamic stress that presupposes the application of high safety standards for design, construction and maintenance. The Austrian Standard ONR 248xx provides a standardized model for the design of torrent barriers under debris-flow impact, which was has been developed from comparative calculation of common debris-flow models from engineering practice in torrent control and calibrated by impact measurements of debris-flow events.

The proposed method should enable practitioners to properly design debris-flow countermeasures with the restriction that usually only little data are available. Naturally, simplifications and assumptions are necessary. Therefore, the process “debris-flow” and the interaction with the structure itself are separated. At the interface of the barrier and the debris-flow process the process parameters are transferred to impact parameters that act on a specified load area. The design basis is the load distribution and the force of the stress model (Fig 6).

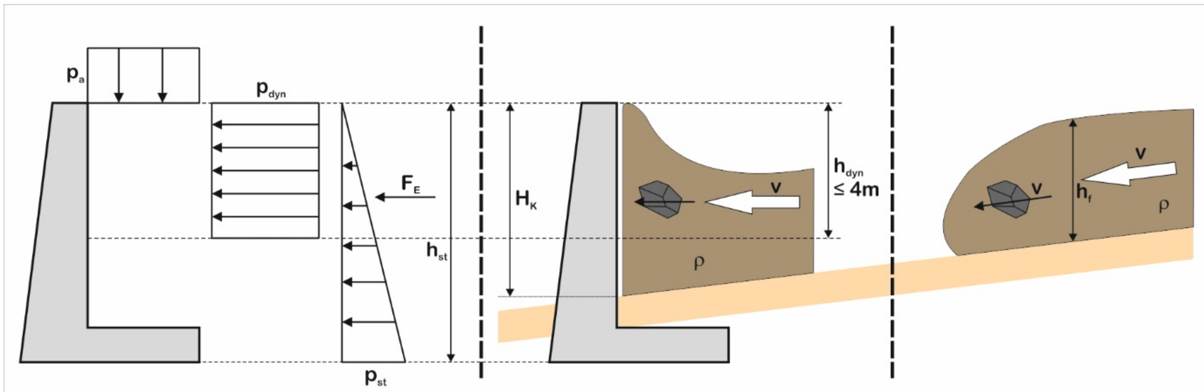

Fig. 6. Schematic illustration of the distinction between load and process model. The standard distinguishes between the process part (right section) the moment of impact (middle section) and the load model for the design (left section), where v is the velocity, h the flow depth, ρ the density, H_k the barrier height, p_{st} the static pressure, p_{dyn} the dynamic pressure, p_a the self-weight of the overtopping material and the impact force of a single element F_E.

For the assessment of impact by channel processes on structures, a process model and a stress model are combined. The process model represents the behavior of a debris-flow process according to its physical properties. At the interface characteristic parameters of the debris-flow process (e.g. energy, density, flow height, flow velocity) are transferred to the impact model, which simulates the interaction of the process with the structure and comprises the representative stress (areal or single load) and the related load distribution. For the design of torrent barriers for engineering purposes, simplifications concerning the model parameters, the stress model and the load distribution are required. A revised version, based on the gained experience with the ONR-Series within the last years, will be published in 2019 as ÖNORM B4800.

4. Conclusion

The challenge in developing national guidelines was to connect the experience of the practitioners with scientific research results and to derive a state of the art, starting with terminology, definitions, construction rules and design procedures. One the one hand the guidelines should provide a standardized method for the design of torrent control structures, on the other hand a degree of freedom must be left to adjust the design according to the peculiarity of the torrent. In Fig.7 is shown a recently completed debris-flow barrier, designed according to the ONR National Guidelines.

Fig. 7. Recently completed debris-flow barrier with the sediment retention basin (Schallerbach, Tyrol), designed according to the ONR National Guidelines.

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