Sabo check dams – mountain protection systems in Japan

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ABSTRACT
In mountain areas, sabo check dams are commonly used to reduce the impact of debris flows. The dam construction decision process is a very important step in the design, and some experience in Japan is discussed. Past experience suggests that a successful design is closely linked with a global catchment approach, combining hydrology, geomorphology, hydraulic and environmental engineering, and eventually aesthetics. Such a system approach must be combined with long-term planning, excluding short-term political ‘reasoning’.

Keywords: Sabo; check dam; mountain protection; Japanese experience.

Introduction
In mountain areas where debris torrents might have catastrophic and dramatic impacts, “check dams” (also called debris dams or sabo dams) can be used to reduce the impact of debris torrents. Debris dams are common features in Europe, North America and Far East Asia. Illustrations are shown in Nakao (1993), Chanson (2001) and Burridant (2002).

The term “debris dam” is used to describe both consolidation dams and sediment retention structures. The former is generally a wall-type structure (e.g. Fig. 1). It is designed to elevate the torrent bed, to fix and to stabilise the bottom profile. The latter type of structure is commonly an open structure (i.e. grid dam, beam dam and split dam) designed for the trapping of medium- to large-size debris (rocks, boulders, logs) (e.g. Fig. 2). Armanini et al. (1991) described several examples of open structure check dams.

The dam construction decision process is a very important step in the design. The choice of debris dam(s) building and their location must be sound and optimal to prevent debris flow catastrophes. In this note, the writer describes some experience in Japan.

Sabo works in Japan
The Japanese islands are characterised by a steep unstable topography with frequent volcanic activities and earthquakes. Debris flows are frequent and numerous disasters occurred. The original purpose of the sabo structures was to reduce the excess sediment discharge to prevent river degradation further downstream and to enable ship navigation in the downstream streams. More recently the emphasis of Sabo works shifted to the control of debris flows.

In Japanese, the direct translation of Sabo (sa-bo) is “sand protection”. Generally the term “sabo works” refers to mountain protection systems. Early sabo works were undertaken during the 17th and 18th centuries. During the second half of the 19th century and early 20th century, numerous sabo works were constructed under the guidance of foreign engineers and of Japanese engineers educated in Europe. For example, the Austrian engineer Hoffman designed sabo works near the town of Seto, 20 km NE of Nagoya, in 1909. Figure 3 shows an artificial stepped channel (construction: 1916–18) near Matsumoto, Nagano Prefecture which was designed by a Japanese engineer, modelled on Durance catchment works.

Mountain protection systems (sabo works) can range from small, simple structures to large structures involving complex catchment management strategy. For example, a major debris structure is the 63-m high Shiraiwa Sabo dam (also called Siraiva dam). The main dam is equipped with a 12-step overflow spillway (Nakao, 1993) and it is designed to trap up to 1 Mm$^3$ of sediment. Another large sabo structure is the Mount Tokachidake Sabo works in the Furano river catchment. After completion, the sabo system include 72 check dams, 11 sluice dams and 71 consolidation dams. The total cost was 0.8 billion of yen in 1993. Another interesting example of sabo works system is the Kakurajima Volcano Sabo works. The Kakurajima island is 12 km wide by 19 km long. The volcano is active and large scale volcano eruption took place in 1471-1476, 1779–1785, 1914 and 1946. All 18 rivers are equipped with Sabo

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works and debris flow occurred each year. During debris runoff, the velocity of debris flow were observed to reach 40 to 70 km/h (Nakao, 1993).

Sabo check dams

Several types of sabo check dam may be designed as part of mountain protection systems. The most common type is the vertical concrete wall (e.g. Figs 1 and 4). The structure has the initial purpose to trap sediment material and to reduce the slope of the upstream catchment when the reservoir is filled (e.g. Fig. 5). The downstream face of the dam is nearly vertical, followed by a short stilling structure. In steep topography, the downstream channel may be stepped to contribute to further energy dissipation, in a fashion somehow similar to stepped spillways (e.g. Fig. 4 and 6). There is however a major difference in cross-sectional shape. Most stepped spillways are designed with a prismatic rectangular cross-section while stepped waterways may have trapezoidal shapes, sometimes with side floodplains (Fig. 6). Vertical check dam heights range from 3 to 15 m typically (e.g. Fig. 4).

Other types of sabo check dams include permeable check dams, slit dams and overflow stepped weirs. Permeable check dams are designed to trap small to medium size debris. They do not hold water. In forest areas, permeable dam may be made of steel grids. Figure 7 shows a permeable structure near Matsumoto, Nagano prefecture. Others may be made of concrete elements commonly used for coastal protection. Figure 2 shows
a permeable Sabo work off Takatoyo beach, Enshu coast while Figure 8 presents debris material and concrete blocks on the Osaka-gawa, Western slope of Mount Fuji.

Slit check dams are a form of permeable debris dams for medium-size debris. They are designed with one or several vertical opening(s) to allow small to medium flow while large flow will overtop the structure. Figure 9 shows the Inokubo-kawa Kikan Sabo system (Mt Fuji, Japan). The Inokubo stream is located on the Western slope of Mt Fuji, close to Osaka-gawa and Uruiriver. A major debris retention system, called Inokubo-kawa Kikan, was in construction in Nov. 2001. The system includes a flat, wide flood plain area to store large material and a slit check dam downstream. Armanini and Larcher (2001) presented recently a detailed model study of slit check dams (single opening).

Another form of check dams is the series of overflow stepped weirs. Each structure is about 1 to 4 m high. Stepped overflow weirs are designed to reduce the upstream slope while the steps contribute to some energy dissipation of the overflow at small to medium flow rates. For large flows, the weir acts as a large roughness element. Examples include Figs 3, 4 (foreground) and 6. Chanson (2001) illustrated further examples in Europe and South-America.

During the last three decades, a further Sabo dam design was developed: the tubular grid dam (e.g. Fig. 10). Tubular grid Sabo structures are made of large-size steel tubes (diameters between 0.5 to 1 m) anchored in reinforced concrete foundations. They are designed to hold heavy sediment blocks (e.g. boulders, huge rocks) weighting over 10 tons. Figure 10 shows a tubular grid structure that is 9 m high, 60 m long. The steel tubular elements are 7 m high and the tube diameter is 0.7 m.

Such tubular grid structures are porous dams. They do not hold water nor small- to medium-size material. The Japanese experience has shown that such tubular grid dams are efficient to stop large rocks, especially in volcanic areas: e.g., the Sabo works on the Tokashi volcano slopes.

Discussion

Most hydraulic structures, including Sabo check dams, are designed for an optimum use at the most economical cost. The
optimum design must minimise the real total cost; i.e., the cost of construction + maintenance cost + cost of safety. The cost of a failure is not always measurable; damage to properties is assessable, damage to the environment is real and has often a political value, but loss of life is a matter of suffering. In the past, a significant number of hydraulic structures failed including check dams. Figure 5 illustrates an example of failure. The structure was part of a network of check dams designed to protect the Saignon dam (France, 1961). Despite this protection system, the reservoir became fully-silted in less than 2 years! Figure 11 shows a recent photograph of the fully-silted reservoir. Another failure is a series of three Taiwanese debris dams completed in 1994. The structures are straight concrete walls, all located in the same catchment on the Eastern coast of Taiwan. During a typhoon in 1994, the dams failed to control the debris flows and to protect the downstream catchment. All three dams were covered by debris material (muds, rocks) left after torrential floods and debris avalanches in the catchment, less than six months after dam completion. Photographs taken after the flood showed barely the crest of the dams emerging from the newlyformed channel bed. Discussions with experts suggest that the debris control system was ill-designed.

The design of check dam systems must fully-integrated in a long-term strategy of catchment management, associated with adequate maintenance. However, it is felt that more and more failures are caused by political irrational, particularly in developed countries including Australia and Europe. For example, some land developments in debris flow-prone valleys and flood
plains are authorised by local governments lacking engineering expertise and long-term vision. Yet their decisions have long-term implications.

Summary and conclusion

In Japan, mountain protection systems and sabo check dams are very common sights. Different types of check dams were built including vertical walls, permeable dams, slit check dams and tubular grid structures. Past experience suggests that a successful design is closely linked with a global catchment approach, combining hydrology, geomorphology, hydraulic and environmental engineering, and eventually aesthetics. Such a system approach must be combined with long-term planning, excluding short-term, narrow-minded political ‘reasoning’.

It is the writer’s opinion however that further research is much needed into the hydraulics of dense debris and mud flows. Often the interstitial fluid made of clay and water plays a major role in the rheological behaviour of the complete material which behaves like a non-Newtonian fluid. There is a need to explore the interactions between hydrodynamics and fluid rheology (e.g. Coussot, 1997; Chanson et al., 2004).

Website

This note is complemented by the following website:

Figure 10. Tubular grid check dam (H = 9 m, L = 60 m, 5 elements) located upstream of concrete check dam (H = 6 m, L = 53 m) in the Hiakari-gawa catchment, Toyota, Aichi prefecture on 10 Nov, 2001.
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