# Standardized stress model for design of torrential barriers under impact by debris flow (according to Austrian Standard Regulation 24801)

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Torrential barriers with energy-dissipating, filtering or deflecting function for debris flows are subject to extreme dynamic stresses that presupposes the application of high safety standards for design, construction and maintenance. The newly issued Austrian Standard ONR 24801 provides a standardized model for the design of torrential barriers under debris flow impact, which 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 model is based on a combined static-dynamic stress approach and also takes into account the impulse by a single object (block, tree trunk). The dynamic part of the debris flow stress is transferred from a characteristic cross-section in the torrent to a vertical impact area of same dimension on the central part of the barrier; additionally static debris flow stress is applied. The standardized model has already been tested successfully at several torrential barriers and is in a good agreement with the common design approaches (experiences) of Austrian Torrent Control Service.

**Key words:** debris flow, torrential barrier, impact stress, standard model

## 1. INTRODUCTION

### 1.1 Debris flow processes and design event

The characteristic displacement processes of torrential events (floods, fluvial solid transport, debris floods, debris flow) are definable by physical parameters like the rheology (newtonian/non-newtonian), the volumetric concentration of solids, the density of the liquid-solid-mixture, the kinematic viscosity, the flow velocity or the relative discharge (ratio of total discharge to water discharge) [*Marco, 2007; Rudolf-Miklau et al., 2012*]. This papers deals with a standardized stress model for assessment of impact by debris flow and debris flood processes acting on torrential barriers which was established within the new Austrian Standard ONR 24801 in 2013. The bases of this model are the characteristic physical properties of debris displacement processes according to ONR 24800 and related standard literature.

**Debris flows** are a wide spread mass wasting process in torrential catchments. This term is used for very rapid to extremely rapid flow of saturated debris in a steep channel. The components of these flows are sediments varying from clay to boulder fraction and water. The volumetric concentration of solids ranges from 20 up to more than 60 percent, leading to bulk densities up to 2.5 t/m³ [*Johnson, 1970; Marco, 2007; ONR 24800:2008; Bergmeister et al., 2009*]. Depending on the water to sediment ratio different types of debris flows can occur. Based on the bulk mechanical behavior of the flowing mixture two types of debris flows in alpine environments occurring in torrential rivers (notwithstanding: debris flow processes on slopes) are distinguished:

**Muddy debris** flow has a wide grain size distribution with a high content of clay-like material. Due to the "relative" low shear resistance, muddy debris flows can propagate over slopes of 5 % minimum. In the field muddy debris flows are recognizable by sharp and well delineated limits of the deposits and randomly distributed boulders and gravel in a finer grained cohesive matrix.

**Granular debris flows** show a wide particle size distribution too, but the content of clay-like material is limited and coarse particles dominate. That is why flow resistance is mainly due to frictional and collisional contacts within the coarse fraction. Energy dissipation is usually much larger than in muddy debris flows, thus granular debris flows require slopes steeper than 15° to flow. In the field deposits of a mass of granular material, from which the fine grained slurry drains easily, and an irregular, chaotic surface give evidence of this type of debris flow.

Another important basis is defined design event based on the frequency and intensity of the torrential processes and their effects on objects. In flood control a design discharge with certain probability of recurrence (e.g. 100-years flood) based on extreme value statistics is applied. For torrent processes the **frequency-intensity-function** shows an emergent behavior [*Schrott & Glade 2008*]. That implies a limited predictability of discharge from extrapolations of hydrological data in case a certain threshold value is exceeded. The event disposition of a torrent catchment, defined as the entirety of all conditions essential for the emergence of hazardous processes, consists of the **basic disposition** comprising all factors immutable over a long range of time (e.g. geology, soils) and the **variable disposition**, which is the sum of all factors subject to a short-term or seasonal change (e.g. precipitation, land use). If the variable disposition of a torrent catchment is altered in the course of an event (e.g. the water storage capacity of soils is exceeded), the debris potential is erratically increasing resulting in a transition of the predominant displacement process (e.g. solid transport is altered to debris flood) and a non-linear increase of discharge. *Hübl (2010)* illustrates this emergent behavior of torrential flows by a multi-stage system status (Fig. 1):

- status I comprises fluvial processes (floods, bedload transport)
- status II includes debris flows and debris floods
- status III represents excessive (extreme) events

The design of debris flow barriers and breakers is related to status II and III.

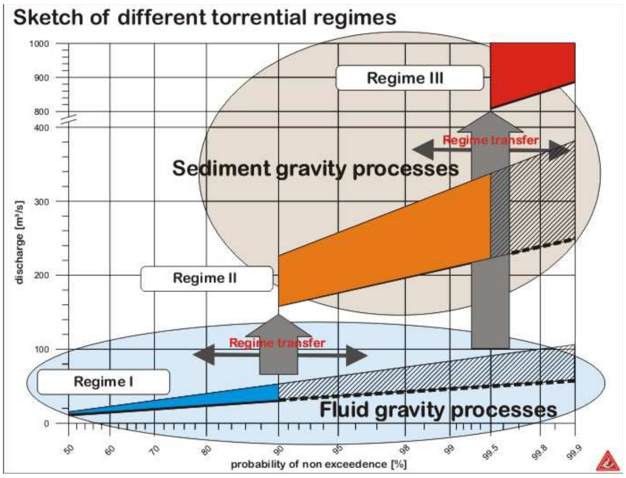

**Fig. 1** System states (I – III) of a torrential catchment as a function of exceedance probability and intensity (discharge)

## 1.2 Torrential barriers under impact of debris flow processes and related function types

As a rule the design of the torrential barriers has to follow its function. According to ONR 24800:2008 the functions of torrential barriers can be divided in the following functional types:

- Stabilization and Consolidation
- Retention
- Dosing and Filtering
- Energy dissipation

Modern protection concepts in torrent control are scenario-oriented and try to optimize different functions in a chain of protections structures (**function chain**). For torrential displacement processes with high concentration of solids (debris floods, debris flow) the following types of structures are applied [*Suda & Rudolf-Miklau, 2010*].

The **dosing** of debris means the temporary retention of coarse bedload during flood peak and the controlled spilling of sediments with descending flood discharge. The intermediate storage of the accumulated material is designed to balance hazard mitigation and a healthy riverine environment.

The **filtering** includes all kind of barriers that serve the selective retention of coarse solid components like boulders or drift wood from the flow process. Filtering structures have to be designed in a way that fine grained bedload can drift through without being retained. The filtering should be limited to those solids that cause the clocking of bridges and narrows in the lower reach. As dosing/filtering barrier large slot grill barriers are used. This type of barriers controls the transport and deposition processes of sediment, boulders and woody debris (Fig. 2).

**Fig. 2** View of a large slot grill barrier for dosing and filtering

Barriers with **energy dissipation** function are designed to reduce debris flow energy of debris flows. By slowing and depositing the surge front of the debris flow, downstream reaches of the stream channel and settlement areas are exposed to considerably lower dynamic impact.

**Fig. 3** Schematic view of a debris flow breaker for energy dissipation

The function of dissipation of debris flow energy can either be reached by retarding the flow process (breaking the surge front) or transforming the displacement process. The purpose is reached either by massive constructions that directly impact the debris flow process ("debris breaker") or by check dams that cause a fall and energy dissipation in the spilling pool ("crash dam").

The function of **debris breaker** (Fig. 3) is reached in combination with a retention basin. The debris flow enters the retention basin and interacts with the dissipation structure. A part of the debris flow is deposited in the basin. Due to the lower inclination of the basins level and the flow resistance of the breaker the kinetic energy of the process will be reduced. Debris flow breakers are built with reinforced concrete and situated as an upper most structure in a function chain. A combination of "debris breaker" with other function at the same barrier should be avoided. If one structure is not sufficient the function may be distributed among several consecutive debris breakers.

**Crash dams** are as a rule situated on the alluvial fan. If the function of process transformation cannot be reached by one dam only, a sequence of dams (cascade) may be carried out.

## 1.3 The new Austrian Standard ONR 24800-series

In the past the technological development of design and construction of torrential barriers was only steered by the experiences of the engineering practice while an institutionalized process of standardization comparable to other engineering branches was not existent. In future all structures have to be designed and dimensioned according to the EUROCODE standards (European norms). This was the reason to establish an interdisciplinary working group (ON-K 256) at the Austrian Standards Institute (ASI), which has managed to developed comprehensive new technical standards for torrent control engineering, including load models, design, dimensioning and life cycle assessment of torrent control works (technical standard ONR 24800-series). The technical standard series consists of the following parts:

- Protection works for torrent control - Terms and their definitions as well as classification, ONR 24800:2009 02 15
- Protection works for torrent control - Static and dynamic actions on structures, ONR 24801:2013 08 15
- Protection works for torrent control - Design of structures, ONR 24802:2011 01 01
- Protection works for torrent control - Operation, monitoring, maintenance, ONR 24803:2008 02 01

These 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.

## 2. DESIGN MODEL FOR CHANNEL PROCESSES RELATED TO DEBRIS FLOW

### 2.1 Principles of debris flow stress models

Torrential barriers with energy-dissipating, dosing, filtering or deflecting function for debris flow are subject to extreme dynamic stress that presupposes the application of high safety standards for design, construction and maintenance. The newly issued Austrian Standard ONR 24801 provides a standardized model for the design of torrential 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 [*Suda et al., 2013*].

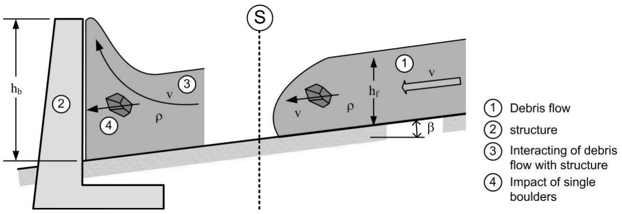

**Fig. 4** Combination of process model and stress model for the design of torrential barriers for the impact of debris flow

For the schematic assessment of impact by channel processes on structures, a process model and a stress model are combined at a characteristic interface. (Fig. 4) The process model simulates 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 torrential barriers for engineering purposes, simplifications concerning the model parameters, the stress model and the load distribution are required.

### 2.2 Properties of the stress model according to ONR 24801

The standardized stress model in ONR 24801 combines the static and dynamic load by debris flow impact on the structure. The flow stress results from the translation of debris material with specific components of water, fine and coarse sediments. For this model it is supposed that the highest impact energy results from the initial contact of the debris flow with the barrier structure. (Fig. 4) Alluvial sediments behind the barrier act depressant on the process and reduce the impact pressure on the structure. The model covers all soil and water pressure resulting from the debris flow.

The design model according to ONR 24801 is based on the following general stress model (Eq. 1). This stress model is combined with a rectangular load figure.

$$p_{\max} = p_{st} + p_{dyn} = C_a \cdot \rho \cdot g \cdot h_b + C_b \cdot \frac{1}{2} \cdot \rho \cdot v^2 \qquad (1)$$

with:

$p_{\max}$ = max. debris pressure; $\rho$ = density of debris material; $h_b$ = flow height at barrier; $v$ = average flow velocity; $C_a$, $C_b$ = resistance coefficients.

The applied design approach in principle is based on the general model which is used for the design to impact by water pressure (cf. EN 1991-1-6, 4.9) and is practically a special case of this model. The stress model is composed of the following components (Fig. 5):

- Dynamic debris flow pressure ($p_{dyn}$)
- Static debris pressure ($p_{st}$)
- Imposed load ($p_a$)
- Equivalent static load for the impact of a single component (eg. Tree trunk, large bolder), ($F_E$)
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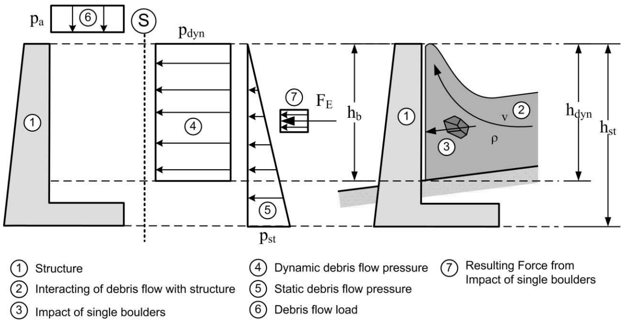

**Fig. 5** Components of the stress model for debris flow impact according to ONR 24801 (displayed in the section axis of the barriers along with the water course axis)

The actions resulting from this model are regarded as characteristic values of action. According to ONR 24802, for the purpose of the following design process the calculated debris flow pressures are taken as variable effect, but combined with a partial safety factor, which corresponds to a permanent effect.

## 2.3 Calculation of acting forces (pressure)

For the purpose of calculation of impact force $F_M$ a combined approach including a static and dynamic load component is used. (Eq. 2) The force by the static component of the debris flow impact is calculated analogously to the water pressure using Eq. 3. The static component is applied as triangular load distribution across the whole area of static impact ($A_{St}$). The force from the dynamic component of the debris flow ($F_{dyn}$) is calculated according to the impulse pressure by Eq. 4 and is applied as uniform load across the whole area of dynamic impact ($A_{Qdyn}$). The according static ($p_{St}$) or dynamic pressure ($p_{dyn}$) is calculated by Eq. 5 and 6. $g$ is the gravitational constant in [m/s²], $v$ is the average flow velocity of the debris flow at the interface, $\rho_M$ is the flow density of debris displacement process in [kg/m³] according to Tab. 1 and $h_{st}$ is the height of impact area of the static component in [m].

$$F_M = F_{St} + F_{dyn} \tag{2}$$

$$F_{St} = 0{,}5 \cdot \rho_M \cdot g \cdot A_{St} \tag{3}$$

$$F_{Dyn} = \rho_M \cdot A_{Qdyn} \cdot v^2 \tag{4}$$

$$p_{dyn} = \frac{F_{D'dyn}}{A_{Qdyn}} \tag{5}$$

$$p_{stat} = \rho_M \cdot g \cdot h_{St} \tag{6}$$

Tab. 1 Characteristic values for parameters of debris flow processes according to ONR 24801

| Channel process[a] | Debris flood (Hyper-concentrated flow) | Debris flow | |
|---|---|---|---|
| | | stony | muddy |
| density $\rho$, in kg/m³ | 1300 to 1700 | 1700 to 2000 | 2000 to 2300 |
| Average flow velocity $v$, in m/s | 3 to 5 | 3 to 6 | 5 to 10 |

[a] These parameters represent a possible bandwidth. The relevant values have to be chosen by an expert on torrent control.

## 2.4 Calculation of impact area

The impact area of the dynamic debris flow component is derived from a characteristic area of discharge ($A_{QM}$) of a debris flow related to the relevant design event. The area of discharge of the design debris flow is determined by the flow depth at a characteristic cross section in the torrent directly upstream of the designed barrier structure (Fig. 6). If no detailed information are available, e.g. from a numerical debris flow model or from "silent witnesses" documented from recent debris flow events, the flow depth in the characteristic cross section can be assessed – as a rough approach for the alpine environment – by 4 m.

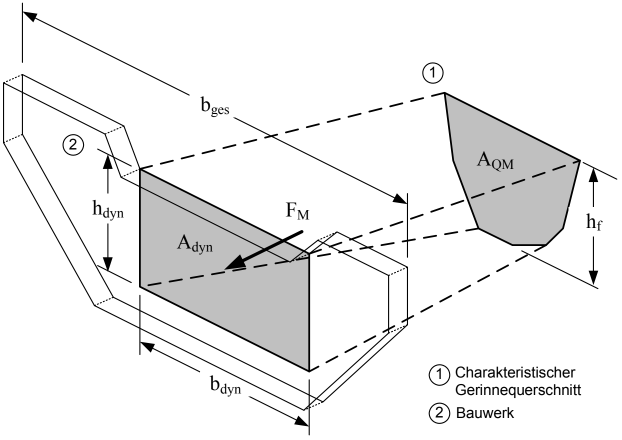

**Fig. 6** Characteristic discharge area of the debris flow and area of stress at the building

The area of impact at the barrier structure is approached by a rectangle with the dimensions $h_{dyn}$ und $b_{dyn}$. The area of impact of the dynamic debris flow component $A_{Qdyn}$ is approached under the conditions of Eq. 7:

$$\begin{array}{ll} A_{Qdyn} = h_{Dyn} \cdot b_{Dyn} & \text{with} \\ 2\ \text{m} \le h_{dyn} \le 4\ \text{m} & A_{Qdyn} = A_{QM} \end{array} \tag{7}$$

The height of the area of impact $h_{dyn}$ at the barrier structure is assessed – depending on the characteristic of the displacement process (muddy debris flow, coarse grained debris flow) – by values between 2 m and 4 m. The process characteristic depends on the density and flow properties (according to Tab. 1) of the debris flow process. The projected area of impact ($A_{Qdyn}$), which is equal in area with $A_{QM}$, has to be positioned directly below the discharge section of the barrier and as a rule in the main axis of the channel. The width of impact $b_{dyn}$ is calculated from the projected area of impact $A_{Qdyn}$ by Eq. 7 ($h_{dyn}$ has to be estimated). If the width of the barrier structure $b_{ges}$ is smaller of equal to the calculated dynamic impact width $b_{dyn}$, the width of the structure is taken equal to the dynamic width. If the width of the barrier structure $b_{ges}$ is larger than 3 times the dynamic impact width $b_{dyn}$, several load cases for variable impact points at the structure have to be assessed.

The impact area of the static debris flow component reaches from the top edge of the dynamic impact area to the bottom edge of the foundation of the barrier structure. It also takes into account in a simplified manner eventually existing sediments or back-fill behind the barrier structure, which generate earth pressure forces. In general the static debris flow component is applied with an impact width $b_{dyn}$. Additional earth pressure (outside of the dynamic impact width $b_{dyn}$) has to be assessed according to the relevant national standards.

## 2.5 Impact by single components

Additionally to the forces by debris flow processes (2.4) also the impact by single components (tree trunks, large boulders) on the barrier structure have to be taken into account, which generate extreme point loads. According to ONR 24801, 10, for the impact force $F_E$ (static equivalent load) related to the impact of a large component in the debris mass, a value of 1000 kN has to be applied. The impact area is taken rectangular with the dimension of 70 cm x 70 cm. This static equivalent force is used for the local proof against punching shear.

## 2.6 Relevant stress combinations

According to ONR 24802:2010 the relevant impacts for the dimensioning of torrent control structures have to be combined according to the predominant displacement process (status I to III). These characteristic combinations of loads are qualified as standardized stress combinations (SC). In SC A (Fig. 7a), the state before backfill, the hydrostatic water pressure from the backwater ($W_{owS}$) is acting on the barrier. The specific gravity of the water, depending on the content of bed load in the pure water, ranging from $\gamma_W$ = 10 to 20 kN/m³. If there is a water flow behind the bottom side of the barriers foundation a reduced hydrostatic water pressure in the soil body can be used. In this stress combination the buoyancy force ($W_A$) is acting on the barriers bottom side. This force reduces the external stability of the barrier. The downstream water pressure ($W_{uw}$) must not be used as a resistance for the barrier.

The highest load on this kind of construction, however, occurs when it is hit by a debris flow.

If there is a possibility for such an event, stress combinations SC G to L (according to ONR 24802) have to be used:

- SC G (Fig. 6) and H – debris flow action on barrier at unfilled storage basin, with/without percolating flow and buoyancy force
- SC I and J – debris flow action on barrier at partly filled storage basin, with/without percolating flow and buoyancy force
- SC K and L – debris flow action on barrier at totally filled storage basin, with/without percolating flow and buoyancy force

Details on the calculation of the specific loads and their load distribution are given in *Bergmeister et al.* (2009) and *Suda & Rudolf-Miklau (2010).*

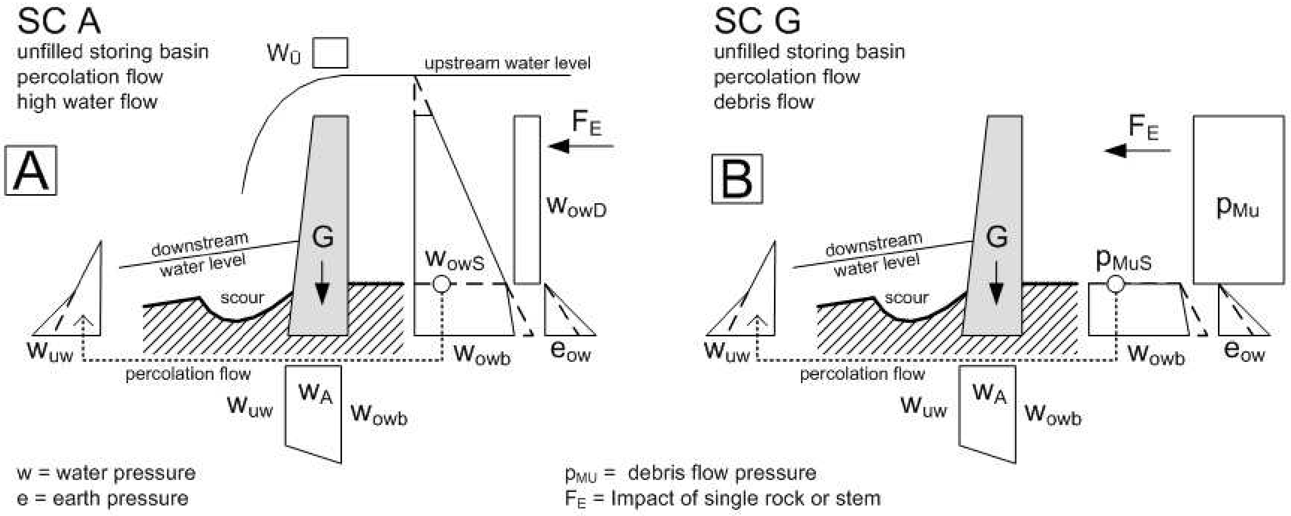

**Fig. 7** Stress combinations (a, left) for retention, dosing and filtering barriers and (b, right) for energy dissipation barriers (debris flow breaker); according to ONR 24802

## 8. CONCLUSIONS

This standardized stress model for debris flow impact on torrential barriers was calibrated with available impact measurements of real debris flow events and is in good agreement with the common design methods of engineering practice in Austria. [*Suda et al., 2013*] The ONR 24801 offers a rather simple model adapted to the requirements of use in engineering practice, which delivers realistic results and seems to be appropriate for safety design of torrential barriers as was already proven by several application examples.

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