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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Überströmungssicherer Ausbau von Dämmen

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Berne, 14.03.2018

In cooperation with the CTI

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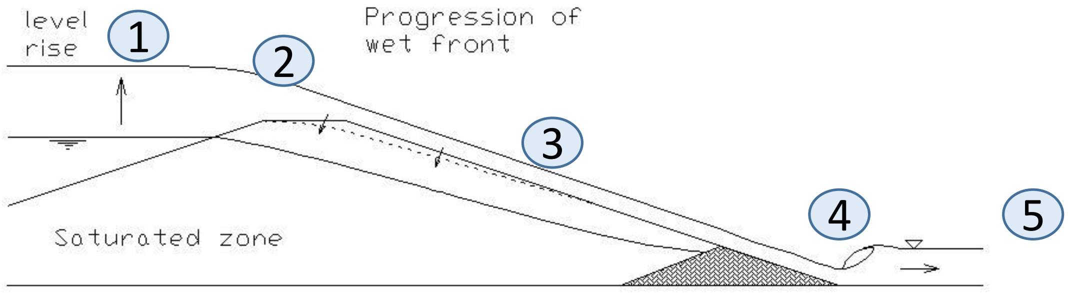
Physikalischer Vorgang der Überflutung

1. Wasserspiegelanstieg im Rückhalteraum (und wasserseitig)
2. Abfluss (Übergang in kritischen Zustand)
3. Beschleunigung (unbelüftet / belüftet) & Infiltration
4. Übergang ins Unterwasser & Energiedissipation (Wassersprung)
5. Feststofftransport der erodierten Dammes und Ablagerung



Beispiel Überflutung mit Bruchversagen

Film

Statistik Dammbrüche

Manso (2002), synthèse du Bulletin CIGB 99, 1995

- *"in absolute terms, most failures involve small dams, which do however make up the greatest proportion of dams in service";*
- *"in earth and rock fill dams, the most common cause of failure is overtopping (31 % as primary cause and 18 % as secondary cause), followed by internal erosion in the body of the dam (15% as primary cause and 13% as secondary cause) and in the foundation (12% as primary cause and 5% as secondary cause)";*
- *"where the appurtenant works were the seat of the failure, the most common cause was inadequate spillway capacity (22 % as primary cause and 39 % as secondary cause)".*

Et aussi synthèse du Bulletin CIGB 109, 1997

- embankment dams are the most widespread type of dam construction around the world; they account for the majority of the overall world total number of dams;
- around 70 per cent of known failures concern Large Dams less than 30 m - Table**;**
- for the estimated existing 100 000 small dams not classified as large dams, failures have been reported, but hardly any statistics are available and it is not certain that the failure rate is any lower or higher than for Large Dams. The majority of these are embankment dams;
- overtopping has been the most frequent cause of embankment dam failures, accounting for more than 50 per cent of the cases, frequently due to an under-estimated flood discharge capacity.

Ruptured dams of over 15 m (1851-1979) (selon Serafim 1981)

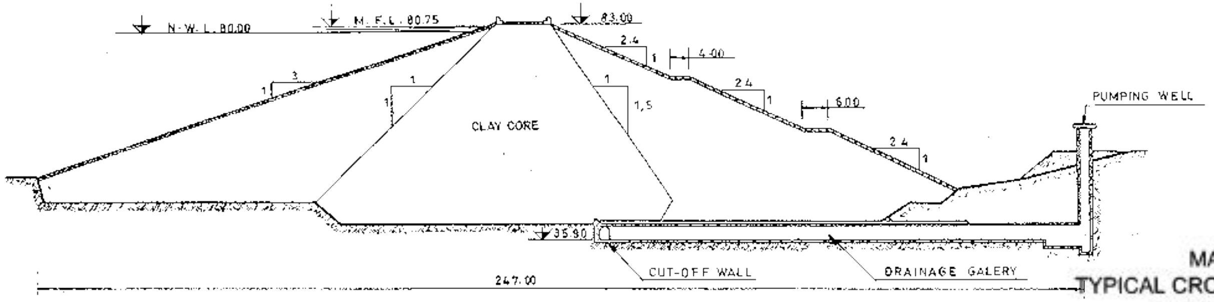
Height	Concrete			Embankment			Other materials			Total
15-20	6	4	3	3	33				1	50
20-25	4	1		1	15	1		1	1	24
25-30	1	1		1	11	1	1			16
30-35	3	2		1	7		1			14
35-40	2			3	5					10
40-45	4				3					7
45-50				1	1	1				3
50-55	1			1	2					4
55-60				1						1
60-65			1	1	2					4
65-70										
70-75										
75-80										
80-85					1					1
85-90										
>90				1	1					2
Total	21	8	4	14	81	3	2	1	2	136

Le rôle des barrages de moins de 30-40 m (≈ Classes 1, 2 et 3 en Suisse)

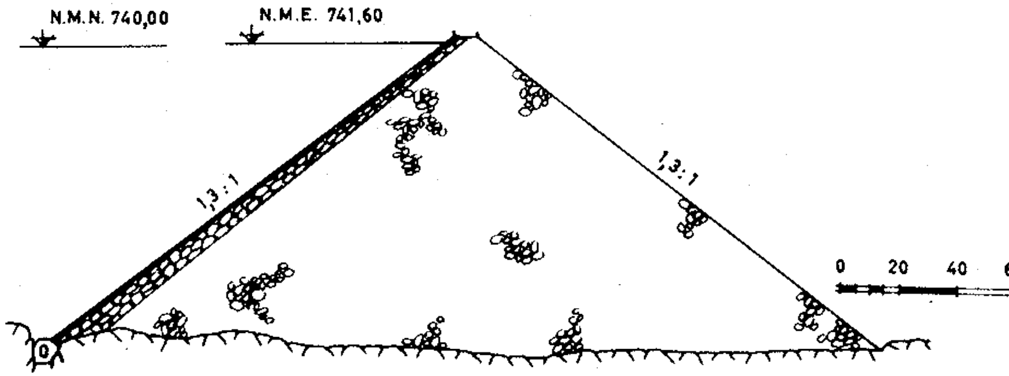
Bulletin 109, ICOLD (1997)

- Rupture de barrages < 30 m a été la cause des 10x plus de victimes que les barrages plus hauts (où il y a moins de digues)
- Dans ce groupe il y a env. 35'000 Grands Barrages, 90% en remblai avec des déversoirs non-contrôlés;
- Il y a environ 1000 barrages de 10-30 m de hauteur avec une retenue ≥ 0.1 hm^3 en construction autour du monde chaque année, desquels seulement 200 à 300 peuvent être nommés Grands Barrages. Leur coût moyen ≤ 1 million USD.
- EVC peut faire 50% CAPEX.

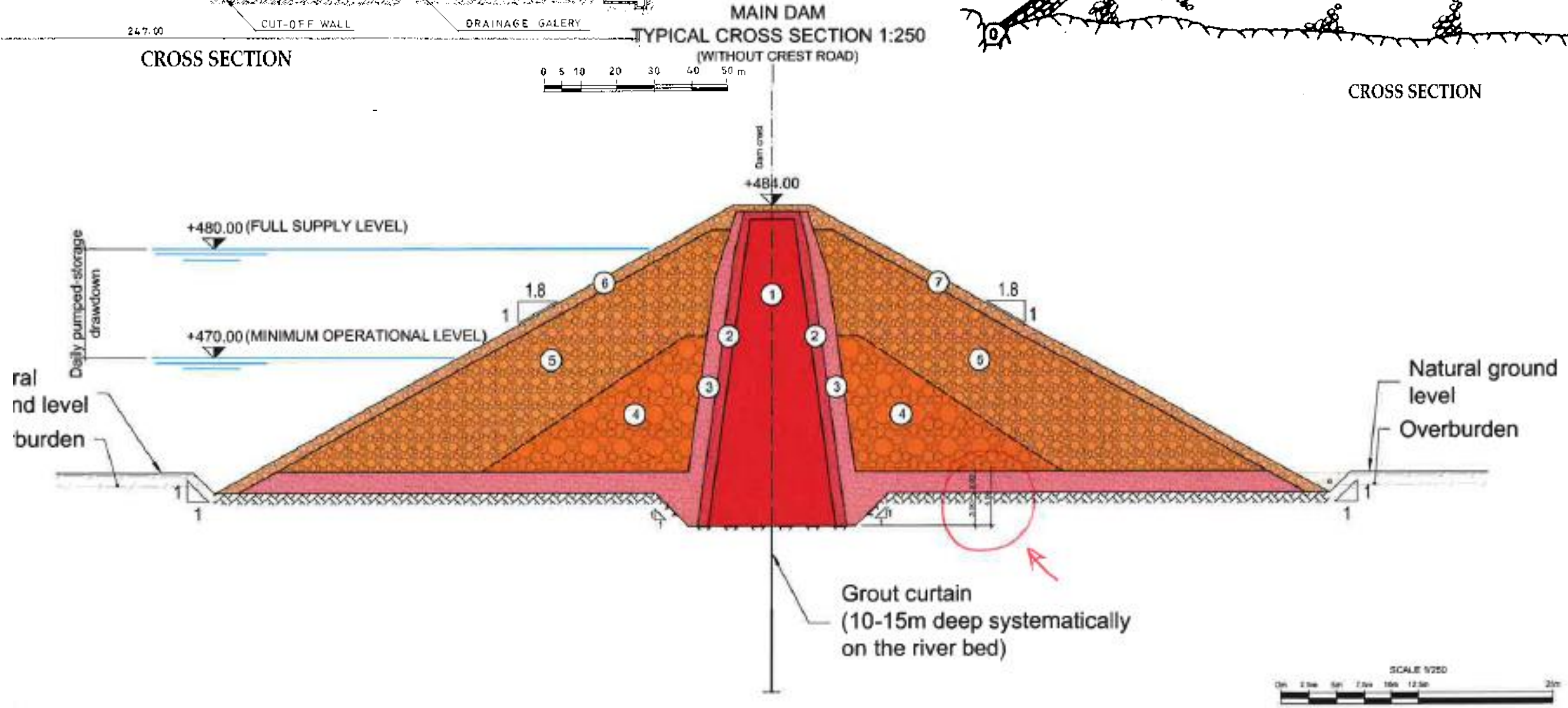
Nombre élevée de typologies de digues



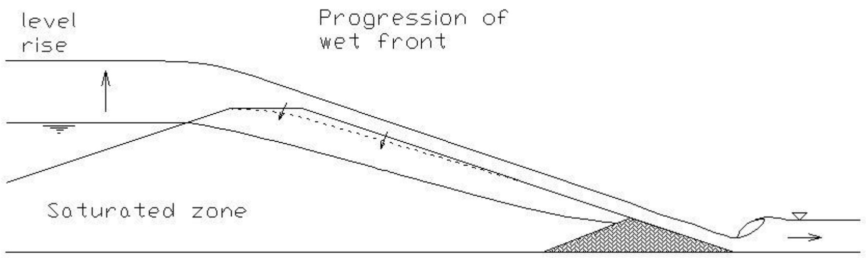
CROSS SECTION

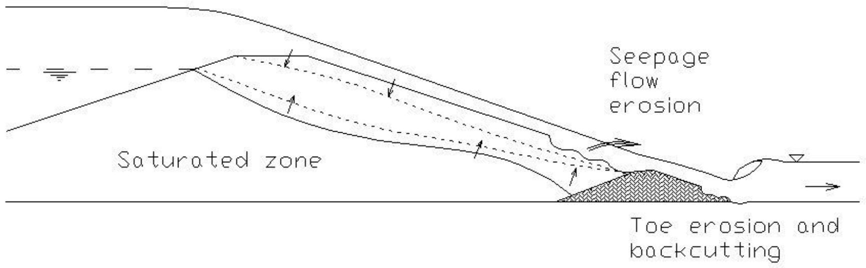


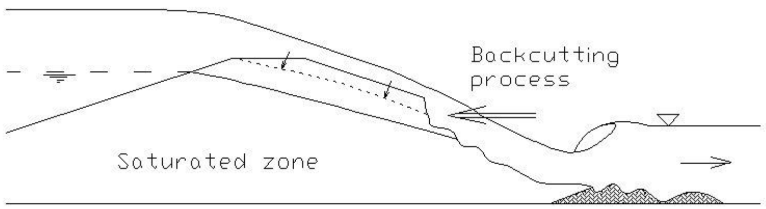
CROSS SECTION



Comment permettre le déversement par-dessus d'un barrage en remblais?







1. Erosion am Dammfuss durch freien Wassersprung
2. Regressive Erosion
3. Progression des gesättigten Bereichs
4. Instabilität der erodierte Böschung
5. Rutschung der instabilen Oberfläche
6. Breschenbildung
7. Progressive oder ruckartige Verbreiterung der Breche

Protection avec blocs en béton qui dissipent l’énergie de l’écoulement !

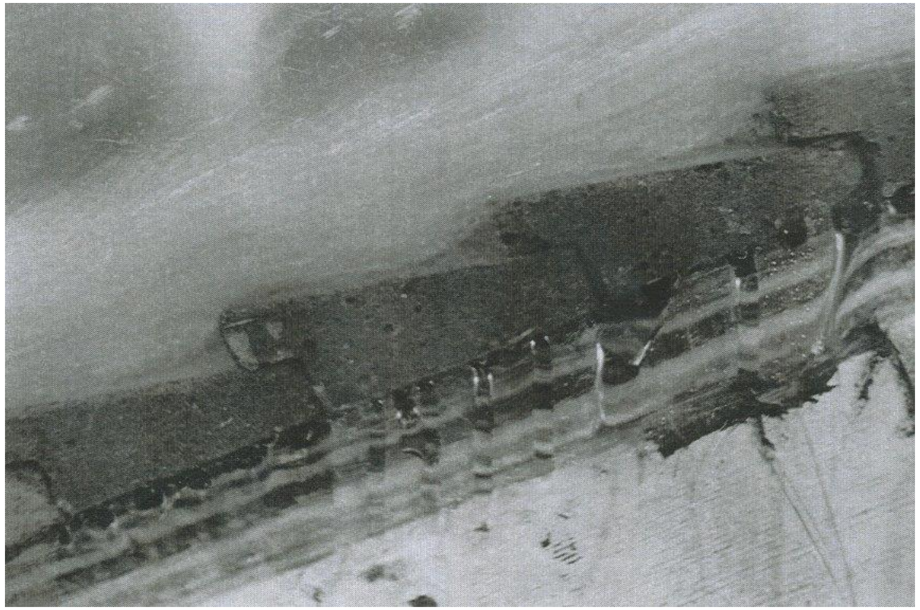
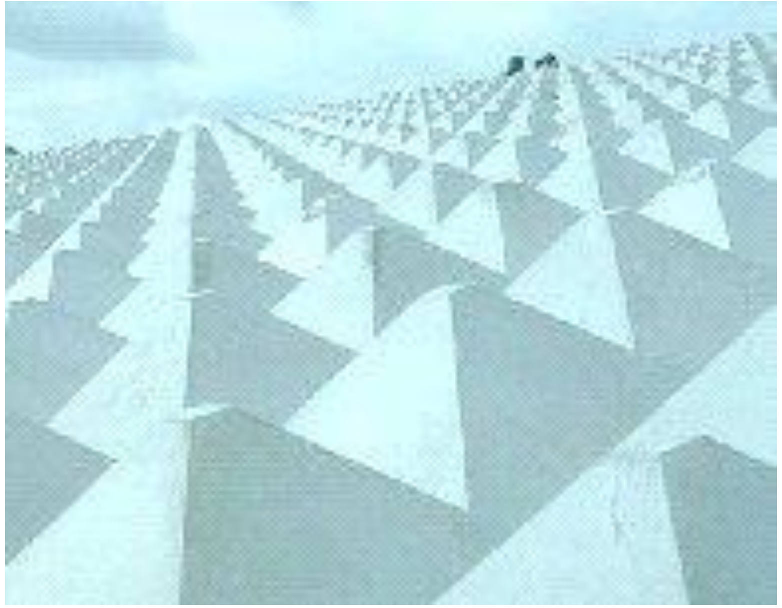


Photo Bulletin CIRIA (1998)



Ouvrage à Leithen, Linz (Autriche)

Différents systèmes selon Manso (2002)

System	Slope	Velocity	Discharge	Overflow depth at crest	Energy dissipation	Built Examples	Features	References
	(V/H)	(m/s)	(m^3/s/m)	(m)				
Grass		3.7	<2				Data from short duration events over cohesive fills	ICOLD (1997)
	1/2.5; 1/20	<1.8 m/s	0.6; 1.85				Prone to vandalism	
Reinforced Rip Rap			66.7			Ust-Khantaysky	Including crest; Observed results	MIKHAILOV et al. (1985)
	1/5		3.7				Grain size: 15-60 cm	FRIZELL et al. (1996)
Geotextile	1/2; ¼	6.7	2.25				With and without cover; failure due to poor anchorage or poor stretching of the material	FRIZELL et al. (1996)
Gabions	½ 1/3	<8	<3		Between 40% and 90%		Laboratorial results	PEYRAT et al. (1991) FRIZELL et al. (1996)
Reinforced concrete			12	3.7		Lebna dam (Tunisia) Dnestrovskaya dam (ex-URSS)	Conventional spillway	SCHOBER (1991); ALBERT et al.(1992) ICOLD (1993) MIKHAILOV et al. (1985)
Reinforced soil (Terre armée)				1.0	Vertical Fall ~100%	Vallon de Bîmes (France)	Dam height = 9 m	ALBERT et al. (1992) ICOLD (1993)
			12			Taylor Draw Dam (USA)	Dam height = 22.5 m	ALBERT et al. (1992) ICOLD (1993)
Soil cement				1.2	Low		Laboratory results USBR; protection against erosion is a function of the thickness ; deterioration problems	POWLEDGE et al. (1989) FRIZELL et al. (1996)
RCC lining			<10					LEMPÉRIÈRE (1993)
			<10	4.3 m during 4-5 days	Between 40% and 90%	Brownwood Country Club Dam (USA)	Dam height = 5.79 m	POWLEDGE et al. (1989)
			<0.5		<90%			ALBERT and GAUTIER (1992)
			8-10		~70%	M'Bali	Dam height = 23,5	ALBERT and GAUTIER (1992)
Concrete blocs and slabs			<50	3– 4		Cabora-Bassa Cofferdams (Mozambique)	During operation. Upstream cofferdam was protected with blocs of 400 kg. Downstream cofferdam had concrete slabs of 7 x 7x 2.5 m, without water-tightness system to prevent up-lift pressures	ICOLD (1984)
Reinforced concrete blocks cast in situ			12			Toktogul (ex-URSS)	Drop of 20 m, observed discharge	MIKHAILOV *et al.* (1985) LAFITTE (1985)
Cable tied concrete blocks		7.9				Jackhouse Dam (UK)	135-160 kg/m^2, under layer of geotextiles, anchored, cohesive subsoil, observed discharge without failure	POWLEDGE *et al.* (1989)
		8.6					With grass cover; anchored; products like ARTIOFLEX, PETRAFLEX, TRI-LOCK with intensive use for river protection	FRIZELL *et al.* (1996)
Pre-cast wedge concrete blocks	1/ 6.5; 1/ 4.5; 1/ 6.5	17-23; -; -	60; 13; 5		-	Dnieper; Dneister cofferdam; Moscow water supply scheme (ex-URSS)	Designed upon ratio block thickness /unit discharge; 3rd example was under 2 m^2/s during one month without damage (dam height=12 m)	PRAVDIVETS and SLISSKY (1981) PRAVDIVETS (1987)
			1.5-2	1			Adequate for earth fill dams with low permeability, $K>10^{-5}$ m/s	BAKER *et al.* (2000)
	½	<13	<2.88		f=0.11 in uniform flow		Better than equivalent smooth surface; cost decrease of about 60% when compared with conventional structures	FRIZELL et al. (1996)
Geomembrane	0.17 (~1/6)	6-8					Observed results; sensible to mechanical damage and deterioration	TIMNLIN Jr. et al. (1988)

Système de blocs superposés en béton

Laboratory

Q	0.325 m^2/s
W	ddddd kg
ho	$\leq$ 0.25 m

Pinheiro A., Relvas A., ASCE J. Hydraul. Eng., 2008, 134(8): 1042-1051.
DOI: 10.1061/(ASCE)0733-9429(2008)134:8(1042)

Protection par blocs en béton. Tests à l'EPFL [Manso, 2002]

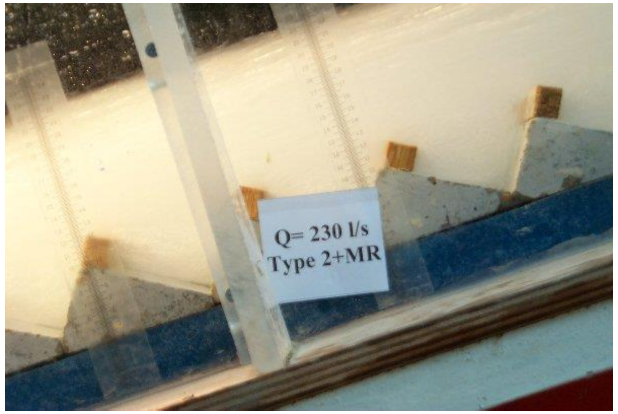
Type 1

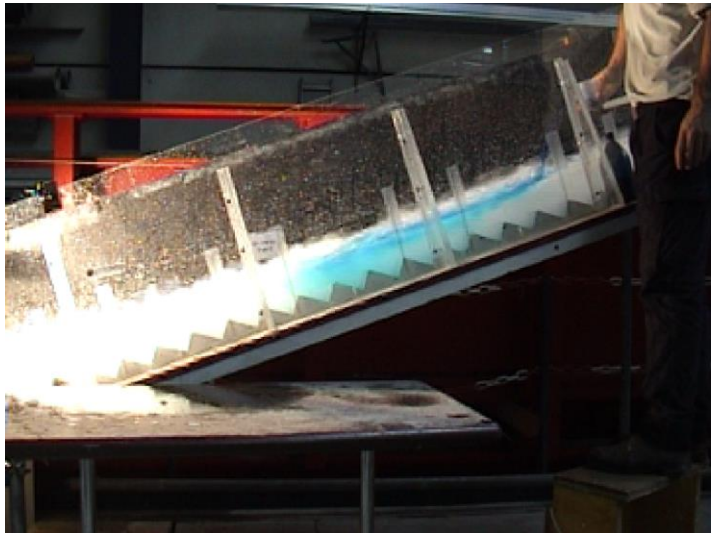
Type 2

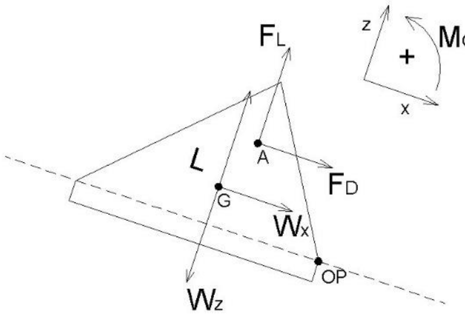
Type 2+ES

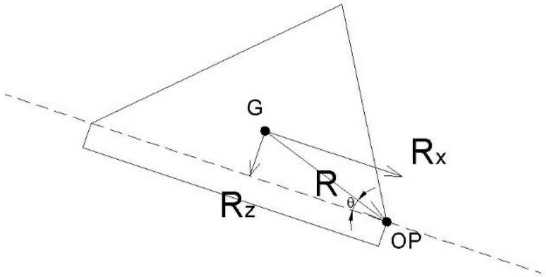
Type 3

Tests à l'EPFL. Modèle de stabilité.

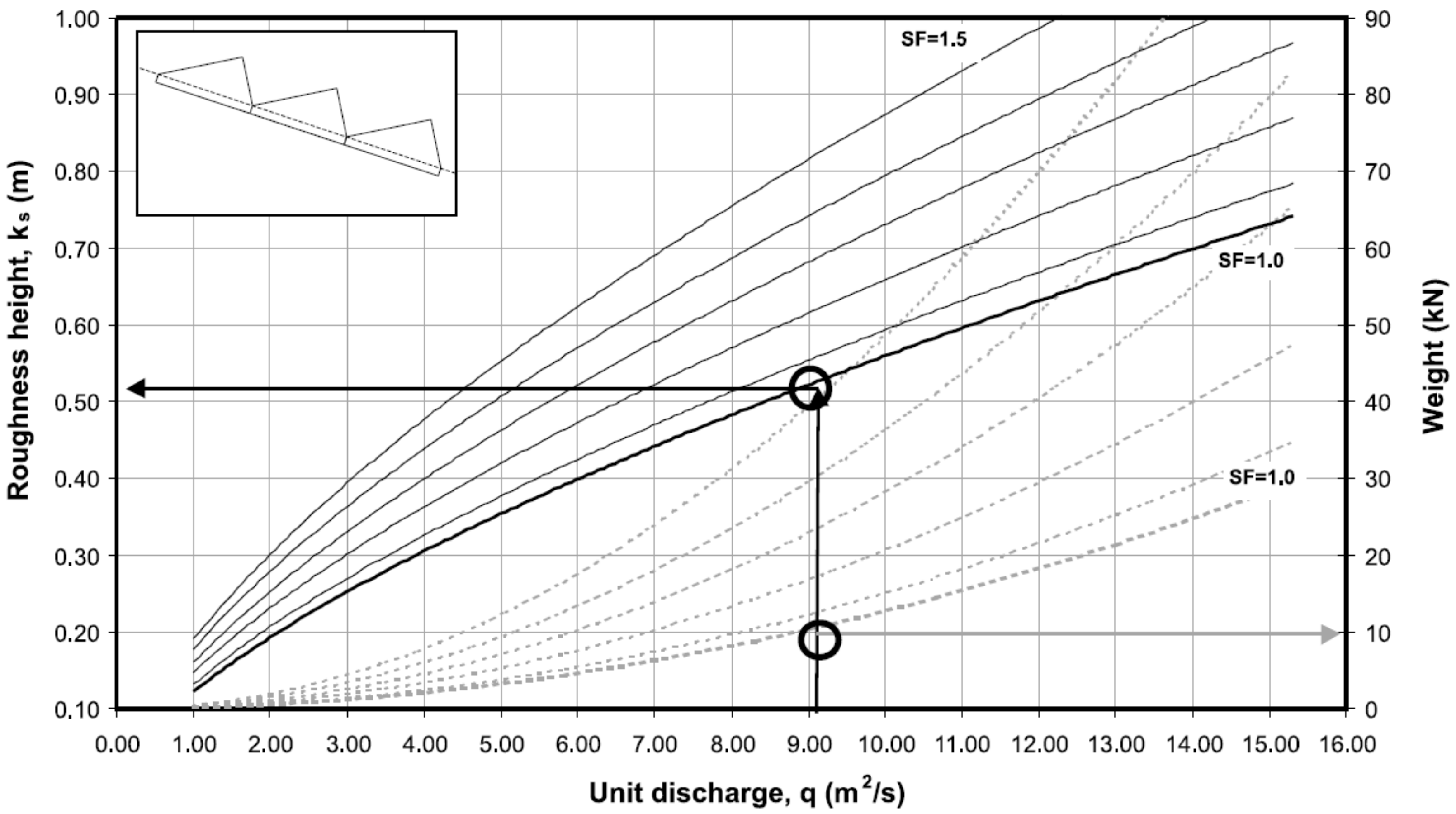




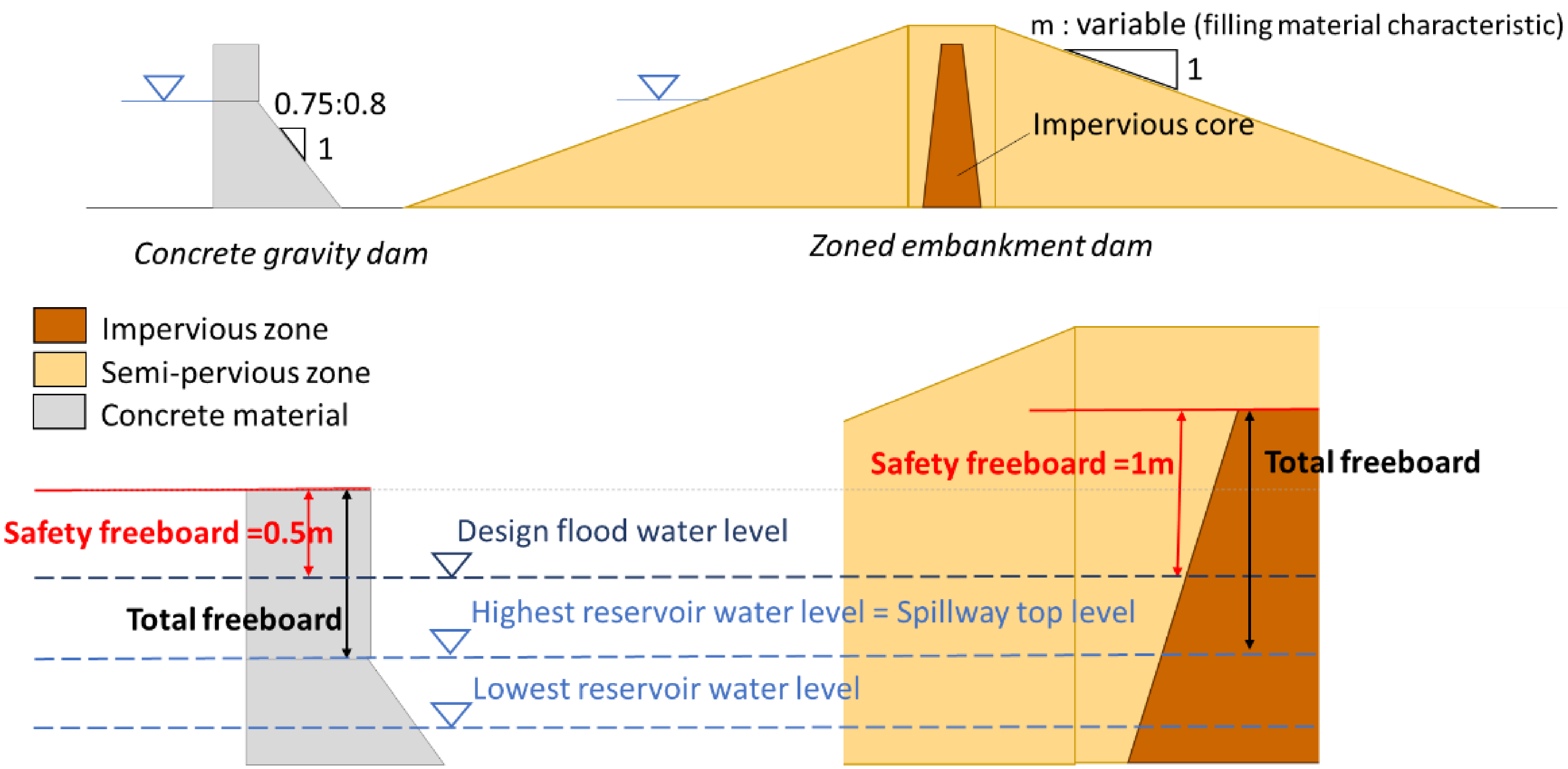




Abaques de dimensionnement

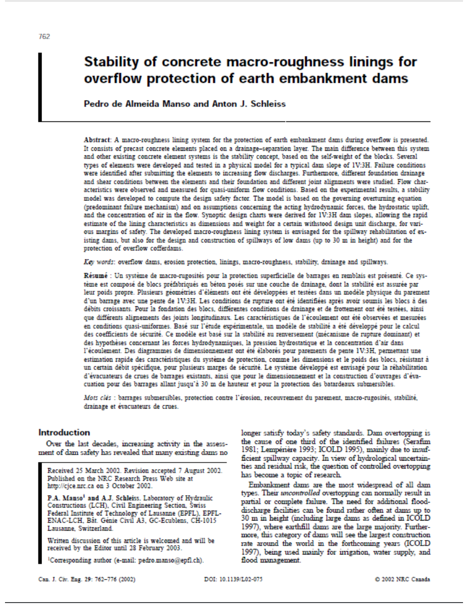


Die Bedeutung des Sicherheitsfreibord



En conclusion

- Submersion est la principale cause de rupture de barrages en remblai
- Plusieurs systèmes de recouvrement sont à disposition. Pas de solution universel.
- Il est important de connaître les limites technologiques de chaque système (régime d’écoulement, q, ho, Vmax).
- Attention aux détails (filtres, transitions, crête, pied de talus, drainage).



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Stability of concrete macro-roughness linings for overflow protection of earth embankment dams

Pedro de Almeida Manso and Anton J. Schleiss

Abstract: A macro-roughness lining system for the protection of earth embankment dams during overflow is presented. It consists of precast concrete elements placed on a drainage–separation layer. The main difference between this system and other existing concrete element systems is the stability concept, based on the self-weight of the blocks. Several types of elements were developed and tested in a physical model for a typical dam slope of 1V:3H. Failure conditions were identified after submitting the elements to increasing flow discharges. Furthermore, different foundation drainage and shear conditions between the elements and their foundation and different joint alignments were studied. Flow characteristics were observed and measured for quasi-uniform flow conditions. Based on the experimental results, a stability model was developed to compute the design safety factor. The model is based on the governing overturning equation (predominant failure mechanism) and on assumptions concerning the acting hydrodynamic forces, the hydrostatic uplift, and the concentration of air in the flow. Synoptic design charts were derived for 1V:3H dam slopes, allowing the rapid estimate of the lining characteristics as dimensions and weight for a certain withstood design unit discharge, for various margins of safety. The developed macro-roughness lining system is envisaged for the spillway rehabilitation of existing dams, but also for the design and construction of spillways of low dams (up to 30 m in height) and for the protection of overflow cofferdams.

Key words: overflow dams, erosion protection, linings, macro-roughness, stability, drainage and spillways.

Résumé : Un système de macro-rugosités pour la protection superficielle de barrages en remblais est présenté. Ce système est composé de blocs préfabriqués en béton posés sur une couche de drainage, dont la stabilité est assurée par leur poids propre. Plusieurs géométries d’éléments ont été développées et testées dans un modèle physique du parement d’un barrage avec une pente de 1V:3H. Les conditions de rupture ont été identifiées après avoir soumis les blocs à des débits croissants. Pour la fondation des blocs, différentes conditions de drainage et de frottement ont été testées, ainsi que différents alignements des joints longitudinaux. Les caractéristiques de l’écoulement ont été observées et mesurées en conditions quasi-uniformes. Basé sur l’étude expérimentale, un modèle de stabilité a été développé pour le calcul des coefficients de sécurité. Ce modèle est basé sur la stabilité au renversement (mécanisme de rupture dominant) et des hypothèses concernant les forces hydrodynamiques, la pression hydrostatique et la concentration d’air dans l’écoulement. Des diagrammes de dimensionnement ont été élaborés pour parements de pente 1V:3H, permettant une estimation rapide des caractéristiques du système de protection, comme les dimensions et le poids des blocs, résistant à un certain débit spécifique, pour plusieurs marges de sécurité. Le système développé est envisagé pour la réhabilitation d’évacuateurs de crues de barrages existants, ainsi que pour le dimensionnement et la construction d’ouvrages d’évacuation pour des barrages allant jusqu’à 30 m de hauteur et pour la protection des batardeaux submersibles.

Mots clés : barrages submersibles, protection contre l’érosion, recouvrement du parement, macro-rugosités, stabilité, drainage et évacuateurs de crues.

Introduction

Over the last decades, increasing activity in the assessment of dam safety has revealed that many existing dams no longer satisfy today’s safety standards. Dam overtopping is the cause of one third of the identified failures (Serafim 1981; Lempérière 1993; ICOLD 1995), mainly due to insufficient spillway capacity. In view of hydrological uncertainties and residual risk, the question of controlled overtopping has become a topic of research.

Embankment dams are the most widespread of all dam types. Their *uncontrolled* overtopping can normally result in partial or complete failure. The need for additional flood-discharge facilities can be found rather often at dams up to 30 m in height (including large dams as defined in ICOLD 1997), where earthfill dams are the large majority. Furthermore, this category of dams will see the largest construction rate around the world in the forthcoming years (ICOLD 1997), being used mainly for irrigation, water supply, and flood management.

Received 25 March 2002. Revision accepted 7 August 2002. Published on the NRC Research Press Web site at http://cjce.nrc.ca on 3 October 2002.

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Written discussion of this article is welcomed and will be received by the Editor until 28 February 2003.

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Can. J. Civ. Eng. 29: 762–776 (2002) DOI: 10.1139/L02-075

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