NNCOLD

DEN NORSKE DAMKOMITÉEN

NYHETSBREV 2022

INNHOLD:

Presidenten har ordet

Vi er glade for å kunne sende deg Den Norske Damkomiteens andre nyhetsbrev. Vi håper dette vil gi deg innsikt i det arbeidet som pågår for sikrere dammer med gode miljømessige løsninger både nasjonalt og internasjonalt. Dammer med formål å sikre tilgjengelig vann for irrigasjon er i flertall på verdensbasis. I Norge er vannkraft hovedformålet for dambygging. ICOLD og NNCOLD arbeider for damsikkerhet uansett hvilket formål dammene er bygget for.

Koronaepidemien har også rammet arbeidet i ICOLD. I år gleder vi oss igjen til å møte kolleger fra hele verden som jobber med damsikkerhet på ICOLDs kongress og årsmøte i Marseille i Frankrike i månedsskiftet mai/juni. Fra Norge bidrar vi med flere gode og relevante artikler som vil bli formidlet på dette møtet. Det viktige arbeidet i de tekniske komiteene kan igjen gjennomføres fysisk som en del av årsmøtet i Marseille. Fra Norge deltar og bidrar våre beste fagfolk i de komiteene som er mest relevante for norske forhold.

I november tar vi opp igjen det Nordiske samarbeidet. Da blir det Nordisk ICOLD-møte der den finske komitéen FINCOLD ønsker oss velkommen til faglige presentasjoner, befaring og sosialt fellesskap i Helsinki. Temaene for dette møtet er aktuelle saker fra hvert av de Nordiske landene, hendelser eller problemer med dammer og gruvedammer. Vi ser fram til gode erfaringsutvekslinger og gode faglige påfyll.

I pandemien har vi i NNCOLD valgt å gi alle våre medlemmer faglig påfyll i form av faglunsjer. Dette ble så godt mottatt at vi har valgt å videreføre dette også i 2022. Her vil du få kjennskap til arbeidet i de tekniske komiteene i ICOLD, få innsikt i aktuelle prosjekt eller problemstillinger. Håper vi sees digitalt i 2022.

God lesning,

Anne Marit Ruud, styreleder
Den norske damkomiteen (NNCOLD)

NNCOLD- styret

Anne Marit Ruud, Energi Norge, President

Leif Lia, NTNU, Visepresident

Goranka Grzanic, NVE, Generalsekretær

Kaare Høeg, NGI, Æresmedlem

Aslak Løvoll, Norconsult, medlem

Fjóla G. Sigtryggsdóttir, NTNU, medlem

Andreas Fløystad, Sweco, medlem

Siri Stokseth, Statkraft, medlem

Vegard Lie, Multiconsult Norge, medlem

Vahid Afsari-Rad, Asphaltcoredams, medlem

Grethe Holm Midttømme, NVE, medlem

Are Eliassen, Skanska Norge, medlem

NNCOLDs faglunsjer og tekniske komitéer

Faglunsjer

Med variert innhold og god oppslutning, ble det arrangert flere nettbaserte faglunsjer i 2021. Blant temaene var presentasjon av utvalgte tekniske komitéer i ICOLD med medlemmer fra Norge. Kjernen av ICOLDs virksomhet foregår i de tekniske komitéene, hvor det blant annet utarbeides tekniske bulletenger om damsikkerhet.

Hilde Marie Kjellesvig (Rådgiver Sweco) er Norges representant i komité C, «Hydraulics for Dams», mens Bård Arntsen (forskningssjef SINTEF Narvik) sitter i komité D, «Concrete Dams». Begge komitéer ble presentert på faglunsjene i 2021.

NNCOLD kommer til å fortsette med faglunsjer i 2022. Første faglunsj ble avholdt 02.03.2022, invitasjon til neste faglunsj kommer på e– post til medlemmer.

Hydraulics for Dams

Det er høy aktivitet i komitéen «Hydraulics for Dams», og det er en svært relevant komité for damsikkerhet i Norge.

Komitéen ledes av prof. Anton Schleiss, og Hilde Marie Kjellesvig er nestleder for komitéen med om lag 28 medlemmer. I inneværende periode arbeides det aktivt med flere bulletenger.

Bulleteng 172 «Technical Advancement in Spillway Design – Progress and Innovations from 1985 to 2015» er i sluttfasen, og preprint på engelsk er tilgjengelig for medlemmer på ICOLDs hjemmesider. Bulletengen tar for seg ulike typer av flomløp, beregningsmetoder og risikovurdering av flomløp.

Det arbeides også med ferdigstillelse av bulleteng 176, «Blockage of reservoir spillways, intakes and bottom outlets by floating debris». Tilstopping av flomløp er en gjentagende problemstilling for damanlegg i Norge, denne bulletengen anbefales til alle som jobber problematikk rundt tilstopping av flomløp. Preprint finnes på engelsk på ICOLDs hjemmesider.

Videre er det igangsatt arbeid med en ny bulleteng med arbeidstittelen «Hydraulic and Structural Design of Chute Spillways and Uprating of Spillways – Recent Developments». I tillegg samarbeider komité C med komité Q, «Dam Surveillance» om ny bulleteng «Need of surveillance and monitoring of spillways».

Concrete Dams

Komité D, «Concrete dams», er også en av komitéene som arbeider med problemstillinger av høy relevans for damanlegg i Norge.

Hovedaktiviteten i denne komitéen er arbeid med ny bulleteng «Aging of concrete dams», hvor Bård er med i arbeidsgruppen som utarbeider Bulletengen.

Bakgrunnen for bulletengen er at alderen på eksisterende betongdammer sakte men sikkert øker, det er derfor viktig å utvikle systemer for å sikre at eldre betongkonstruksjoner også oppfyller krav til damsikkerhet. Kunnskap om effektiv forvaltning av eksisterende eldre betongdammer, har utviklet seg etter flere tiår med drift i mange land. Forskningen og erfaringen innen spesifikke temaer knyttet til aldring av betong har også utviklet seg sterkt de siste tiårene, men det er et potensial i å implementere denne forskningen til fagmiljø innen betongdammer.

Innholdet i bulletengen fokuserer hovedsakelig på betongdammer bygget med tradisjonell vibrert betong (eng: conventially vibrated concrete, CVC) og ikke murdammer, RCC etc. Bulletengen vil blant annet ta for seg tilstandsvurdering av eldre betongkonstruksjoner, hvordan nedbrytning kan unngås og hvordan skader på betongdammer kan repareres. Hovedfokuset i bulletengen vil imidlertid være beskrivelse av typiske nedbrytningsmekanismer for betongdammer og tilhørende konstruksjoner.

Førsteutgaven ble allerede presentert på en workshop i november 2021, og det arbeides videre med å gjøre bulletengen klar for utgivelse.

ICOLD Tekniske komitéer

For tiden har ICOLD 28 tekniske komiteer som tar opp aktuelle tekniske spørsmål knyttet til utvikling og forvaltning av vannressurser. Listingen av ICOLD-komiteene er gitt nedenfor. Mer enn 180 tekniske bulletenger er publisert og er tilgjengelige for kjøp. Disse publikasjonene kan kjøpes direkte på nettstedet vårt www.icold-cigb.org. Medlemmene får gratis tilgang til disse publikasjonene.

Utlysning av nytt medlem til Embankment dams ble publisert på NNCOLD nett side i 2021. NNCOLD har mottatt 3 søknader og foreslått Egil Andreas Vartdal som medlem etter at Vahid Afsari Rad trer av. *Medlemskapet blir avgjort på ICOLD årsmøte i juni.

	Navn på komiteen	Norske medlemmer
A	COMPUTATIONAL ASPECTS OF ANALYSIS AND DESIGN OF DAMS (2020-23)	Ronald Andersen, Eduardo Martins Bretas
B	SEISMIC ASPECTS OF DAM DESIGN (2020-23)	Kaare Høeg, Arnkjell Løkke
C	HYDRAULICS FOR DAMS (2021-25)	Hilde Marie Kjellesvig
D	CONCRETE DAMS (2021-24)	Bård Arntsen
E	EMBANKMENT DAMS (2020-23)	Egil Andreas Vartdal*
F	ENGINEERING ACTIVITIES WITH THE PLANNING PROCESS FOR WATER RESOURCES PROJECTS (2014-22)	Thor Haakon Bakken
G	ENVIRONMENT (2020-22)	
H	DAM SAFETY (2021-24)	Suzanne Lacasse
HWS	HISTORICAL WATER STRUCTURE (Water Heritage) (2021-24)	
I	PUBLIC SAFETY AROUND DAMS (2016-22)	Anne Marit Ruud
J	SEDIMENTATION OF RESERVOIRS (2020-23)	Tom Jakobsen
K	INTEGRATED OPERATION OF HYDROPOWER STATIONS AND RESERVOIRS (2015-23)	
L	TAILINGS DAMS & WASTE LAGOONS (2020-23)	Øyvind Torgersrud
LE	LEVEES (2018-24)	Priska Hiller, Martin Jespersen
M	OPERATION, MAINTENANCE AND REHABILITATION OF DAMS (2020-23)	Thomas Konow
N	PUBLIC AWARENESS AND EDUCATION (2021-24)	
O	WORLD REGISTER OF DAMS AND DOCUMENTATION (2021-24)	Kontaktperson Kristoffer M. Skogseid
P	CEMENTED MATERIAL DAMS (2020-25)	
Q	DAM SURVEILLANCE (2017-22)	Goranka Grzanic
RE	RESETTLEMENT DUE TO RESERVOIRS (2021-24)	
S	FLOOD EVALUATION AND DAM SAFETY (2020-24)	Trond Rinde, Seija Stenius
T	PROSPECTIVE AND NEW CHALLENGES FOR DAMS AND RESERVOIRS IN THE 21st CENTURY (2000-23) (AD HOC Committee)	
TRS	TROPICAL RESIDUAL SOILS (2020-23)	
U	DAMS AND RIVER BASIN MANAGEMENT (2021-24)	
V	HYDROMECHANICAL EQUIPMENT (2016-22)	
X	FINANCIAL AND ADVISORY (AD HOC Committee)	
Y	CLIMATE CHANGE (2021-23)	Ingjerd Haddeland, Deborah Lawrence
Z	CAPACITY BUILDING AND DAMS (2021-24) (AD HOC Committee)	
ZZ4	REGIONAL CLUB EUROPE	Anne Marit Ruud og Goranka Grzanic
ZX2	YOUNG ENGINEERS	
ZX3	ICOLD BOARD	

Damkrona 2021

Damkrona deles ut av NNCOLD, og er en hederspris til anlegg som fremmer landskapsmessige, miljømessige og teknisk gode løsninger ved vassdragsanlegg i regulerte vassdrag. Det benyttes store ressurser til å få gode løsninger i forbindelse med nybygging og fornying av dammer og andre vassdragsanlegg. Et viktig formål med prisen er å synliggjøre dette arbeidet. Både nye og eldre anlegg kan fremmes som kandidater til prisen.

Tidligere prisvinnere er:

- Dam Stolsvatn (2010)
- Telemarkskanalen (2011)
- Kraftverksanlegg i Jørpelandsvassdraget (2012)
- Bjørndalsdammene (2013)
- Grorudparken (2014)
- Dam Sønstevatn (2015)
- Dam Svartavatnet (2016)
- Dam Elgsjø (2017)
- Dammer Skjerkevatn (2018)
- Dam Finnflot (2019)
- Songa og Trolldalen dammer (2020)

VINNER 2021: DAM FISKEVATNET

Prisutdeling for Damkrona 2021 ble delt ut av Den Norske Damkomiteen (NNCOLD) på VTF Dagene 12. januar 2022.

NNCOLD– styret gratulerer!

Om vinneren sier tildelingskomitéen av prisen følgende:

«Dammen har tilsnitt av å være ei innovativ ingeniørmessig løysing gjennom si utradisjonelle oppbygging i forhold til dagens tradisjonelle byggemetode. Dette har gjeve miljømessige fordelar gjennom redusert CO_2 utslipp ettersom betongvolumet er redusert. Steinforblendinga er flott utført, liknar den originale steinforblendinga og bidrar til en bestandig overflate mot luftsida. Metoden er og verdt å vurdere andre stadar, eksempelvis der ein eller fleir av følgande kriteria gjeld:

- Estetikk spelar ei vesentleg rolle
- Det er ønskeleg med eit lite visuelt framtredande anlegg
- Anlegg i tilknyting til kulturhistoriske miljø

Løsningen kan også være økonomisk og miljømessig fordelaktig på grunn av redusert betongvolum og mindre sementforbruk. Vi ser potensiale for at løsningen med bruk av sparestein i massive betongkonstruksjoner kan videreutvikles og raffineres. Forblending med stein vil også kunne redusere behov for en bestandig betong og dermed redusere sementforbruket. Dette er for øvrig en kjent teknikk benyttet ved eldre betongdammer, men byggemetoden er ikke vanlig i dag.

Metoden er et eksempel til etterfølgelse, og kan være egnet både i nye og eksisterende konstruksjoner. Når løsningen benyttes ved eksisterende dammer, er det imidlertid viktig at den opprinnelige dammen har en god tilstand, både med hensyn til lekkasjer og betongkvalitet.»

Vinner Damkrona 2021:
Dam Fiskevatnet

Om anlegget

Fiskevatnet er inntaksmagasin for Frøland kraftverk i Samnanger kommune, Vestland fylke. Dammen ved Fiskevatnet ble bygget i samband med byggingen av Frøland kraftverk i 1909 – 1912, men rehabilitert i 2001 før den ble forsterket på nytt i 2021. Dammen er en massivdam i betong med sparestein, der luftsiden er forblendet med mur.

Revurdering

Dammen ble forsterket med fjellanker og ny damkrone i 2001. Revurderingen 2015-2017 avdekket imidlertid at dammen likevel ikke hadde tilstrekkelig stabilitet for velting og glidning i bruddgrensetilstand, og heller ikke tilstrekkelig stabilitet mot velting i ved ulykkeslast.

Nøkkelinfo

Eier:	Eviny
Damtype:	Massiv betongdam
Byggeår:	1911
Fornying:	2001/ 2021
Konsekvensklasse:	2
Kronelengde:	52,3 m
Høyde:	13,5 m
HRV/LRV:	178,3 / 172,7
Magasinvolum:	0,3 Mm^3
Rådgiver:	Multiconsult
Entreprenør:	GBS AS, Øystese

Foto fra byggetiden 27.07.2011

Damkrona vinner 2021 - Dam Fiskevatnet

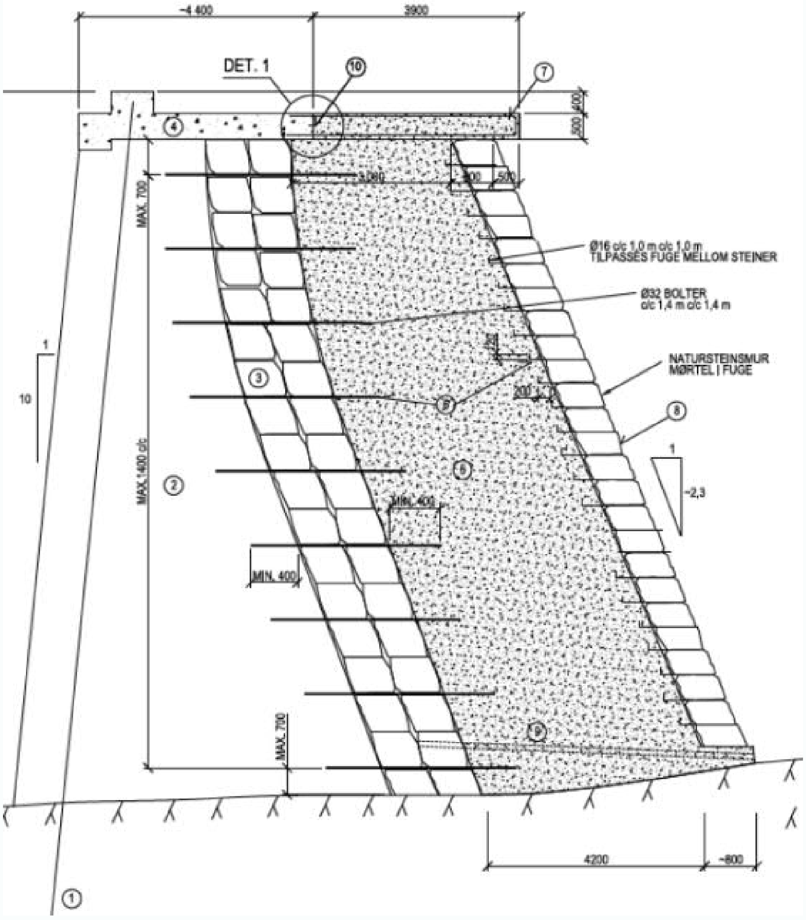
Løsning

For å kunne drifte kraftverket gjennom hele byggeperioden (sommeren 2021) ble det valgt en løsning med nedstrøms påbygging. Det uvanlige er at det ble benytta ei uarmert betongforsterkning av lavkarbo-betong med sparstein, kombinert med en murforblending med stein fra steinbrudd. Murforblendingen ble samtidig benyttet som nedstrøms forskaling ved utlegging av lagene med betong.

Samtidig ble det bygget inn et nytt tappeløp med fjernstyrt tappeventil som skal slippe minstevannføring. Målepunktet for konsesjonspålagt minstevannføring ligger 1 km nedstrøms dammen, og målepunktet skal fjernstyre tappeventilen i dammen (denne styringen bygges vinteren 2022).

Påstøpen er i utgangspunktet uarmert, noe som er en utradisjonell løsning. Dette gav muligheten for å benytte sparestein under støpeprosessen. Bruk av stor murstein og sparestein har redusert betongforbruket med om lag 25% Det ble også valgt lavkarbobetong i de massive støpene.

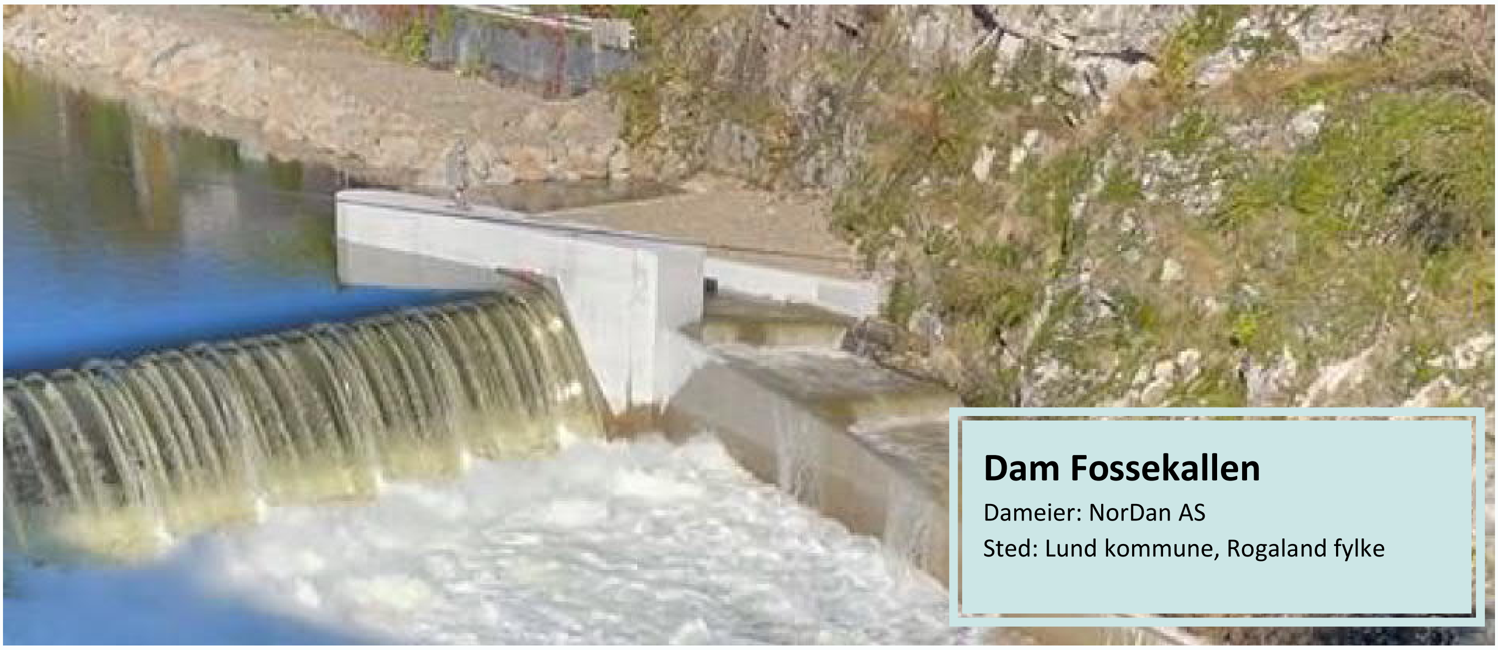
Ny nedstrøms forblending benyttes som «forskaling» under utstøpingen.



Øvrige kandidater for damkrona 2021

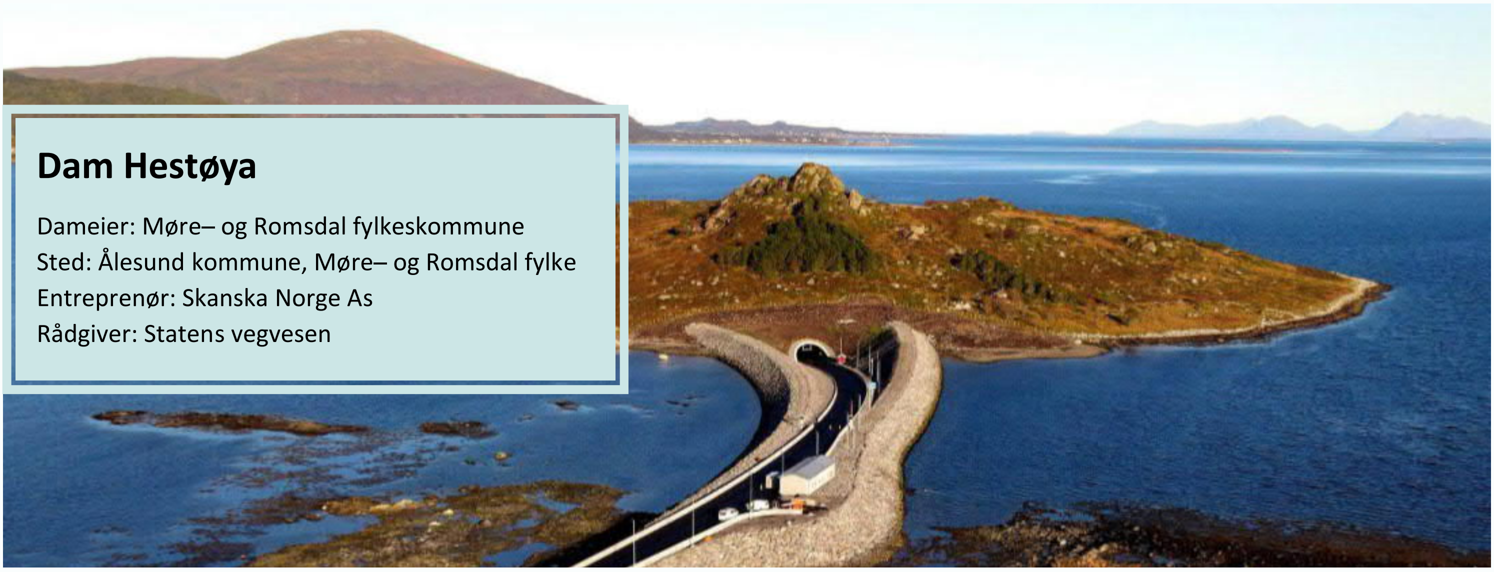
Dam Øvre Jegersbergvatn

Dameier: Kristiansand kommune
Sted: Kristiansand kommune, Agder fylke
Entreprenør: Kristiansand Ingeniørvesen
Rådgiver: Multiconsult



Dam Fossekallen

Dameier: NorDan AS
Sted: Lund kommune, Rogaland fylke



Dam Hestøya

Dameier: Møre– og Romsdal fylkeskommune
Sted: Ålesund kommune, Møre– og Romsdal fylke
Entreprenør: Skanska Norge As
Rådgiver: Statens vegvesen

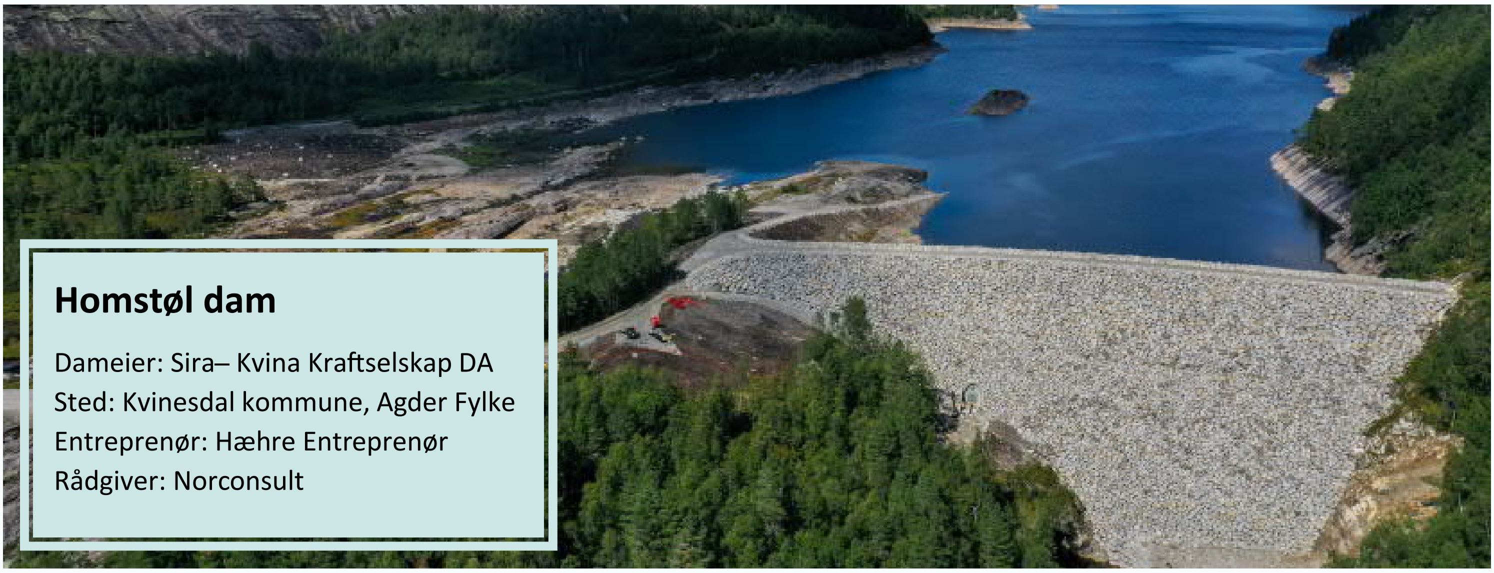
Øvrige kandidater for damkrona 2021

Dam Krokavatn

Dameier: Sunnhordaland Kraftlag AS (SKL)
Sted: Etne kommune, Vestland fylke
Entreprenør: Røynstrand Entreprenør
Rådgiver: Norconsult

Dam Lyngsvatn

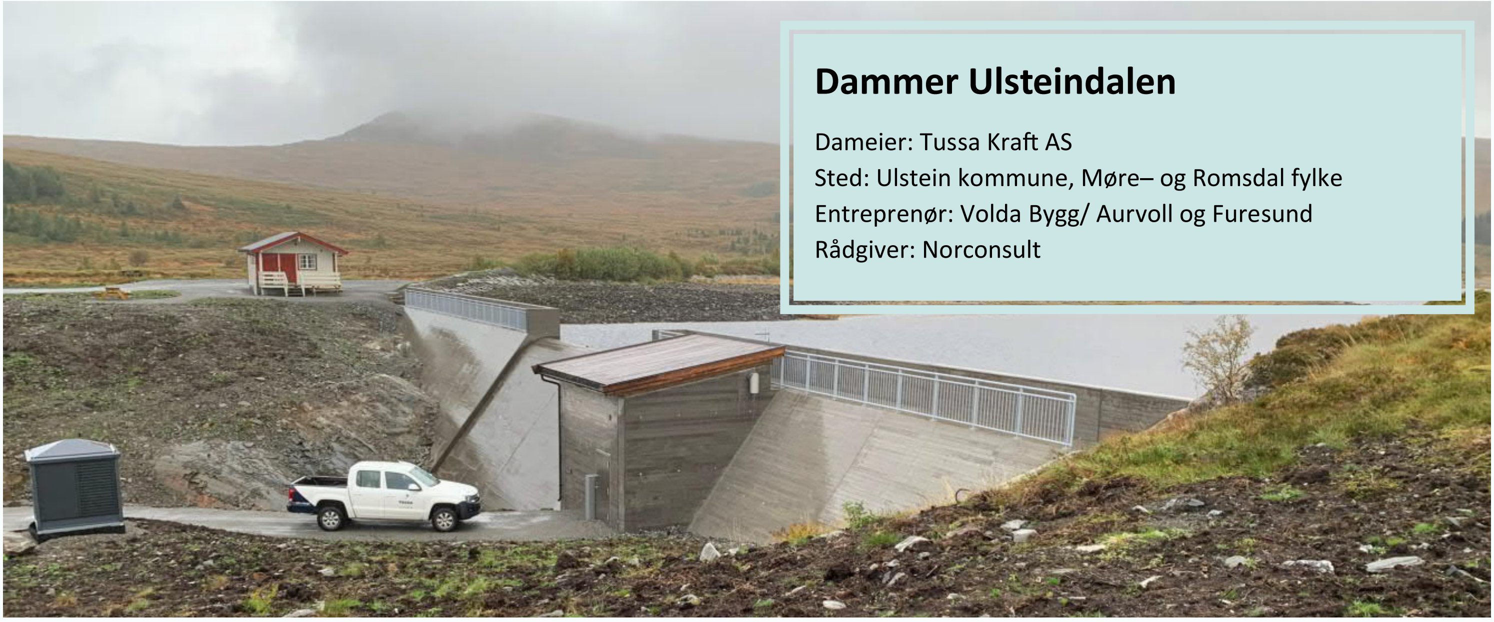
Dameier: Hydro Energi/ Lyse Kraft
Sted: Hjelmeland, Rogaland fylke
Entreprenør: Stangeland Maskin AS
Rådgiver: Norconsult



Homstøl dam

Dameier: Sira– Kvina Kraftselskap DA
Sted: Kvinesdal kommune, Agder Fylke
Entreprenør: Hæhre Entreprenør
Rådgiver: Norconsult

Øvrige kandidater for damkrona 2021



Dammer Ulsteindalen

Dameier: Tussa Kraft AS
Sted: Ulstein kommune, Møre– og Romsdal fylke
Entreprenør: Volda Bygg/ Aurvoll og Furesund
Rådgiver: Norconsult

Dam Mjåvatn

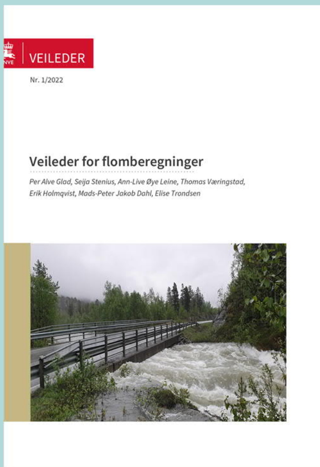
Dameier: Hafslund Eco
Sted: Ål kommune, Viken fylke
Entreprenør: YIT Norge
Rådgiver: Norconsult

Dam Langevatn

Dameier: Agder Energi AS
Sted: Åseral kommune, Agder Fylke
Entreprenør: Risa & Implenia
Rådgiver: Sweco

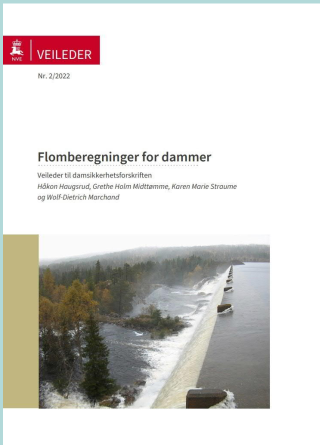
NVE - Nyheter 2022

***Damsikkerheit - informasjonsskriv 2022* blir publisert etter påske og vil inneholde blant annet informasjon om:**



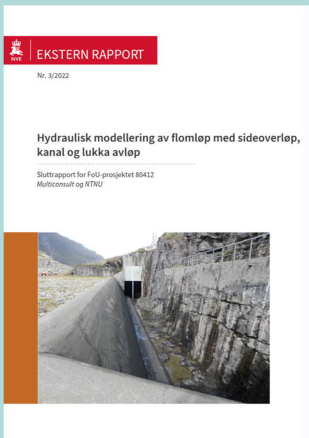
Denne veilederen gir anbefalinger innen flomberegninger i Norge. Målet er å gi et rammeverk som sikrer konsistente og robuste estimater av flomvannføringer for ulike formål. Veilederen vil bidra til å sikre at flomestimatene er tilpasset formålet og mest mulig uavhengig av den som utfører beregningen. Anbefalingene og metodene er oppdatert i henhold til resultater fra relevant FoU-arbeid de siste årene. Målgruppen for veilederen er først og fremst fagkyndige personer med erfaring innen flomberegninger. Veilederen egner seg også som en innføring i praktisk gjennomføring av en flomberegning.

♦



Veilederen *Flomberegninger for dammer* utdyper bestemmelser gitt i forskrift om sikkerhet ved vassdragsanlegg (damsikkerhetsforskriften) § 5-7 og hvilke øvrige krav damsikkerhetsforskriften stiller til flomberegninger for dammer. I tillegg gir den råd og anbefalinger der damsikkerhetsforskriften ikke angir krav.

♦



Rapporten sammenstiller tilgjengelig kunnskap om forskjellige beregningsmetoder og modeller som kan benyttes for å finne kapasiteten til lukka flomløp med sideoverløp og samlekanal. Dette innbefatter metoder som handberegninger, numeriske modeller og fysiske modellforsøk. Det er utarbeida tabeller der forskjellige metoder er vurdert for ulike komponenter i et flomløp og ved varierende betingelser. Tabellene forutsetter korrekt bruk av de presenterte metodene.

Følg med på:

https://www.nve.no/energi/tilsyn/damsikkerhet/nytt-om-damsikkerhet/rapporter-og-informasjonsskriv-damsikkerhet/

NVE - damsikkerhet - forskning 2022

Nedstrøms plastring og damtå

Ved NTNU skal det opprettes et postdoktorprosjekt som skal ta utgangspunkt i det som allerede foreligger av studier på hvor stor betydning tilstedeværelse og utforming av nedstrøms plastring og damtå har for sikkerheten av tradisjonelle norske steinfyllingsdammer. NTNU skal kjøre videre forsøk for å få et bedre kunnskapsgrunnlag om sammenhengen mellom nedstrøms plastring og damtå. Prosjektet skal også støtte pågående PhD prosjekt i HydroCen om bruddforløp i fyllingsdammer. I vårt FoU prosjektet "Miljølaster på fyllingsdammer ved høyfjellsmagasiner" er det anbefalt å studere videre på forhold knyttet til dimensjonering av plastring på oppstrøms skråning på fyllingsdammer. Dette kan også bli en det av dette postdoktorprosjektet.

Individuell fastsettelse av termisk istrykk mot dammer

Termisk istrykk er i forbindelse med stabilitets- og kapasitetsberegninger den dominerende lasten mot betong- og murdammer med høyde mindre enn ca. 10 m. Likevel har det på verdensbasis ikke vært registrert reelle dambrudd med ukontrollert tømming av magasin som følge av istrykk. Ifølge NVEs damdatabase er det i Norge 2457 klassifiserte dammer i den nevnte kategorien. Frem til nå har istrykket i NVEs regelverk vært angitt som en linjelast med normverdi på 100-150 kN/m. I praksis har en «sjablongverdi» på 100 kN/m blitt anvendt i de fleste tilfeller. Det gjennomføres i dag omfattende tiltak på eksisterende dammer i Norge for å ivareta sikkerheten i forhold til istrykk. En mer presis og individuell fastsettelse av istrykket vil bidra til at behovet for forsterkning og oppgradering av eksisterende dammer kan angis mer presist. Dette gir i neste omgang riktig bruk av ressurser.

I perioden 2011-2014 deltok NVE i et prosjekt sammen med flere kraftselskaper, NORUT Narvik (nå SINTEF Narvik) og Luleå Tekniske Universitet for å øke kunnskapsnivået om istrykk og for å etablere bedre empirisk grunnlag for å fastsette islast ved å gjøre feltmålinger over tid. Feltmålingene har vært videreført i regi av SINTEF Narvik frem til i dag. Parallelt med dette har man utviklet en algoritme og numerisk modell for individuell fastsetting av istrykk basert på klimadata (SeNorge) fra 1958 og frem til i dag. Dette er testet ut på 1700 lokaliteter i Norge og resultatene er delvis verifiserte mot feltmålinger av istrykk og rapporterte målinger av istykkelser (RegObs). En «bieffekt» av forskningen er at man har statistisk signifikant grunnlag for å si at klimaendringer har gitt reduserte istrykk. Samtidig registrerer vi at forventet frostmengde med 100 års gjentaksintervall i flere kommuner nærmer seg 0.

NVE (v/TBD) ser at ovennevnte prosjekter gir grunnlag for å kunne differensiere kravene til laststørrelser på dammer ut fra klimadata. Målet med dette prosjektet er å videreutvikle modellen til å hensynta snødekke på isen (identifisert behov) og å fremskaffe en overbevisende verifikasjon av modellen. Videre skal modellen implementeres i NVEs regelverk slik at den vanlige fagansvarlige ingeniør skal kunne anvende den i forbindelse med vurdering av damsikkerhet (veiledere for betongdammer og for laster på dammer skal fornyes).

EXPERIMENTAL STUDY ON BREACHING OF ROCKFILL EMBANKMENT DAMS WITH DOWNSTREAM EROSION PROTECTION

Nisal Deelaka Halaba A. Senarathna

Project Description

Embankment dams in general and more specifically rockfill embankment dams as discussed here are subjected to destructive breakout floods as a result of overtopping due to their pervious and erodible characteristics. Use of ripraps on the crest and downstream face are on of the solutions employed to overcome this problem. Norway in particular has gone far in implementing placed riprap on the upstream and downstream slope and at the crest. Models are required to evaluate the breach development in order to determine the consequences of a dam breach. Even though many parametric models exist, there is a lot of uncertainty with regards to aspects such as varying material properties, and also the effects of erosion protection. Thus, it is of interest to examine the breach mechanism of rockfill dams with erosion protection on the downstream slope in order to establish a more reliable and well-founded consequence classification as well as downstream flood inundation areas in case of breaching.

The focus of the master thesis can be broken down into three stages. The first stage includes carrying out a literature review on embankment dams and identifying research gaps. Secondly, to carry out physical tests on the breaching of rockfill dams with a central core and investigate the effects of erosion protection on the downstream slope. The final stage consists of a quantitative and qualitative analysis of the breaching process and comparison of data with and without erosion protection including concluding remarks and suggestions for future studies. The study has been funded by the Norwegian Research Centre for Hydropower Technology (HydroCen) under WP 1.2, pertaining to dam construction and safety. The study was supervised by Associate Professor Fjóla Gudrun Sigtryggsdóttir and co-supervised by PhD candidate Geir Helge Kiplesund.

Physical Model

The physical models were carried out in a flume that is 25 m long, 1 m wide and 2 m deep. The discharge is produced by two inflow pipes with a combined maximum discharge of 0.5 m^3/s (500 l/s). The pore pressure development across the dam section was measured using 10 metal pipes connected to pressure sensor outside the flume. The structure was built in layers of 10 cm which were compacted before building the next layer, a rubber membrane was used to mimic the core of the rockfill dam. After all the supporting fill has been added a pilot channel was constructed at the crest of the dam so as to isolate the breach so that it can be well observed and documented. A filter layer was then added, on top of which the riprap material was placed. The riprap stones were then individually placed by hand in an interlocking manner. The stones at the toe were placed horizontally and the stones at the crest were placed vertically while the remaining stones on the side slopes were placed with the longest axis at an angle of 60°. Figure 1 below depicts the overall sectional view of the dam that was constructed.

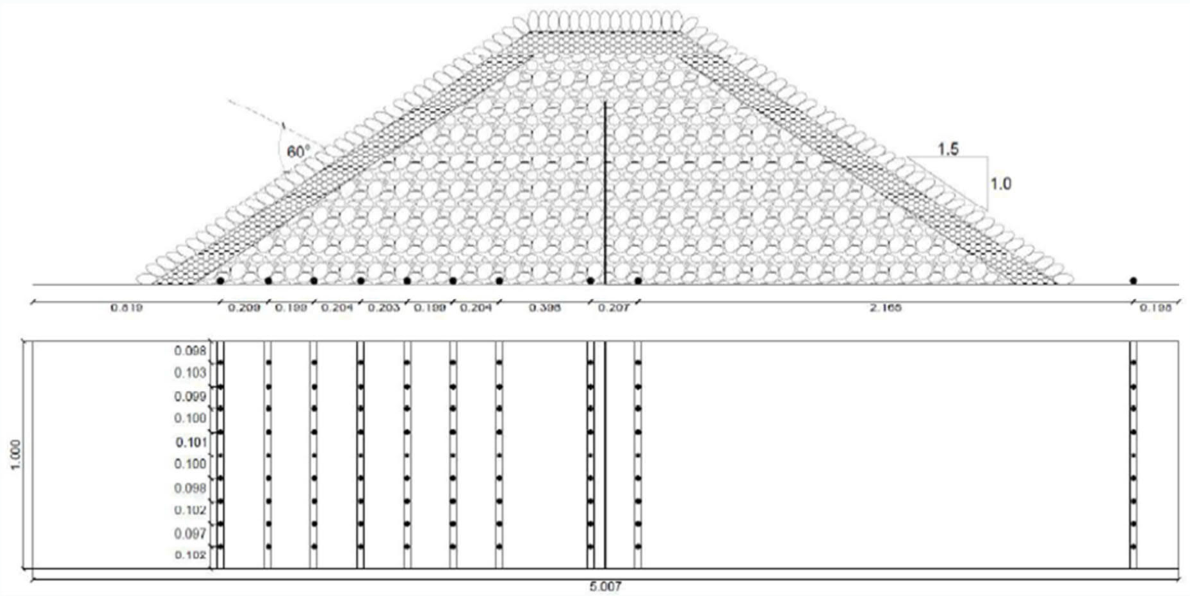


Figure 1: (Top) Sectional view of the dam set up and pressor sensors with the riprap and filter layer; (Bottom) Planar view of the pressure sensor configuration.

Results

The study did reveal that the structural stability of the dam considerably increases with the additional protection. However, when the dams with protection do fail as a result of the riprap sliding the resulting failure discharge is much greater. Furthermore, though placed riprap provides significant increase in stability against overtopping it is very time, labor and cost intensive. Hence, a more interdisciplinary approach is necessary in order to establish the most optimized socio-economic riprap design for rockfill embankment dams with downstream riprap protection. Nonetheless, this study is a step forward in defining breach parameters for a conventional Norwegian rockfill dam.

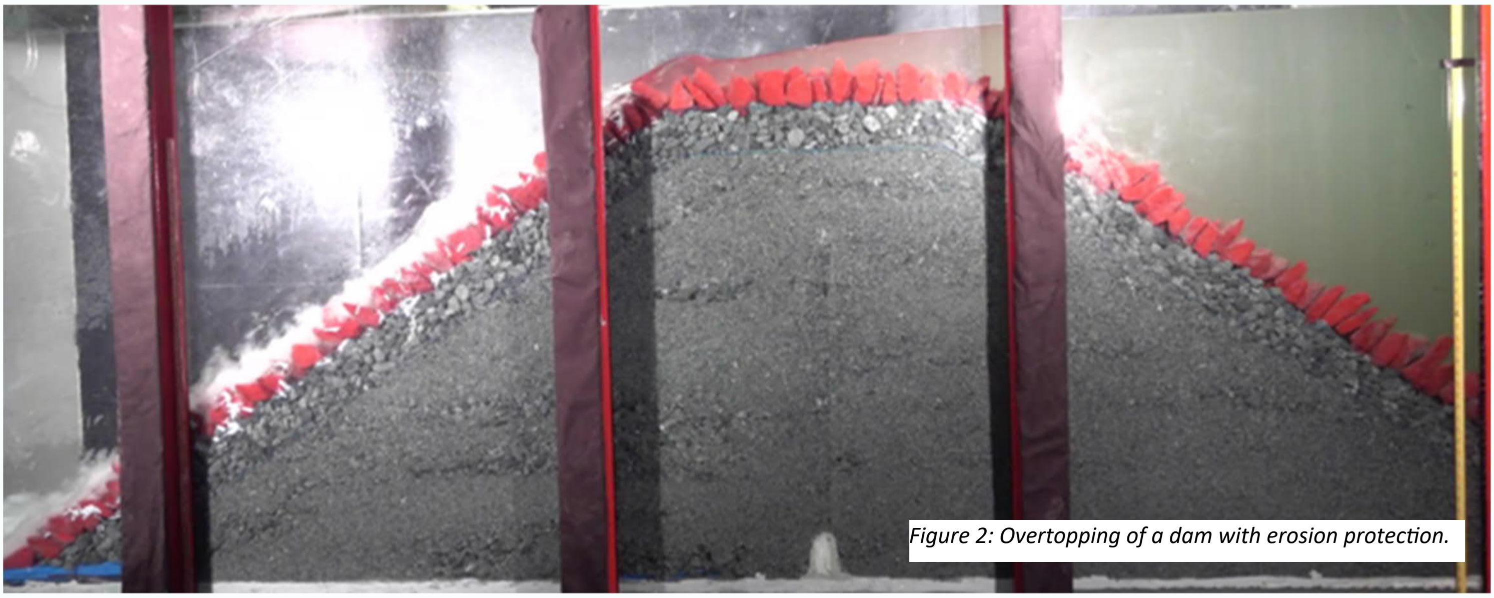


Figure 2: Overtopping of a dam with erosion protection.

ROCKFILL DAM BREACHING EXPERIMENTS WITH THE APPLICATION OF PHOTOGRAMMETRY TECHNIQUES

Ghaith E. Alkholossi

Norway is one of the leading countries in producing sustainable energy from hydropower. Hydropower dams include embankment dams. There are over 185 large embankment dams in Norway. Most of these dams are rockfill dams with a central core of moraine or asphalt. Damaging outbursts of flooding triggered by embankment failures must be evaluated in order to prepare emergency action plans. This requires estimate of the dam breaching process and breach opening. Traditionally, parametric models based on historic dam collapses are used to evaluate the breaching of embankment dams. However, these base mostly on earthfill dam failures. Thus, further research is needed into the breaching of rockfill dams.

The master thesis focused on investigating rockfill dam breaching through experimental research involving rockfill dam models subjected to overtopping. The study was conducted under the HydroCen project WP1.2 on dam construction and safety. Supervisors for the work were Fjóla G. Sigtryggsdóttir and Geir Helge Kiplesund. The main challenge in modelling a rockfill dam in the available test settings related to the watertight membrane in the dam.

Two different core materials were tested as a part of the master study, styrofoam and rubber plastic. Furthermore, an important part of the study was to investigate the use of photogrammetric techniques for the analysis of the breach process.

The experiments were carried out in a rectangular horizontal flume (channel) in the hydraulic laboratory at NTNU (Figure 1). Four physical simulations were performed. Instrumentation of the model included pore pressure sensors and video recording from multiple angles. The video is used to extract images at intervals throughout the breaching process, and 3D models of the breach opening of selected tests created using “Structure from motion” and “Multi-View Stereo” processing techniques.

The structure from motion technology (SFM), is based on photogrammetric range imaging that defines a three-dimensional (3D) model from two-dimensional images. For more accurate model, it needs to be covered from every possible angle. The program used for building the 3D model is Agisoft Metashape which is a stand-alone software. Agisoft Metashape performs a photogrammetric study of the visual images, which may be aerial, close-range imaging, as well as satellite imagery, which produces 3D spatial data.

After the photos were uploaded, the Agisoft Metashape software constructs the model, at first aligning of the images was made to create a dense cloud with absolutely no details of the actual dam, then creating a texture to the mesh as it will provide a detailed 3D model of the dam. This 3D model allowed a significant compression ability, and with further technology, the more accurate 67 prediction would be allowed off the breach formation depending on the data calibrated from model varieties. Example figures from this study are provided in Figure 2 and 3.

The outcome of the study supports further use of “Structure from motion” and “Multi-View Stereo” processing techniques in the analysis of the breach process of embankment dams, however more cameras are recommended than the four used in this study. Construction of the core was challenging and of the two materials tested the rubber plastic was a better choice. The aim was to model a realistic breaching of the rockfill material. The rubber plastic core resulted in realistic modelling of the phreatic line in the downstream rockfill shell section, with reasonable leakage before the overtopping starts.

Figure 2: Front elevation plan and a section of the dam and breach stages.

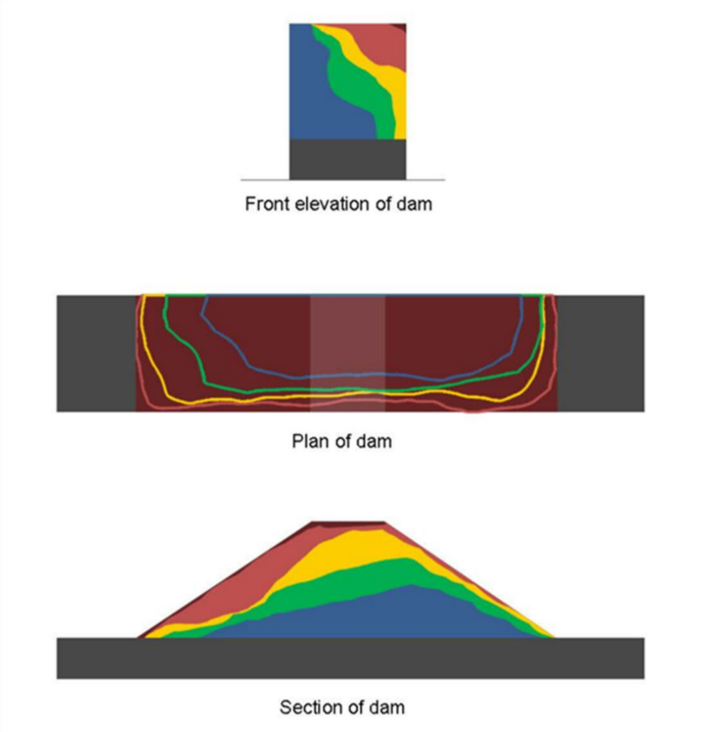


Figure 1: Model setup in the flume.

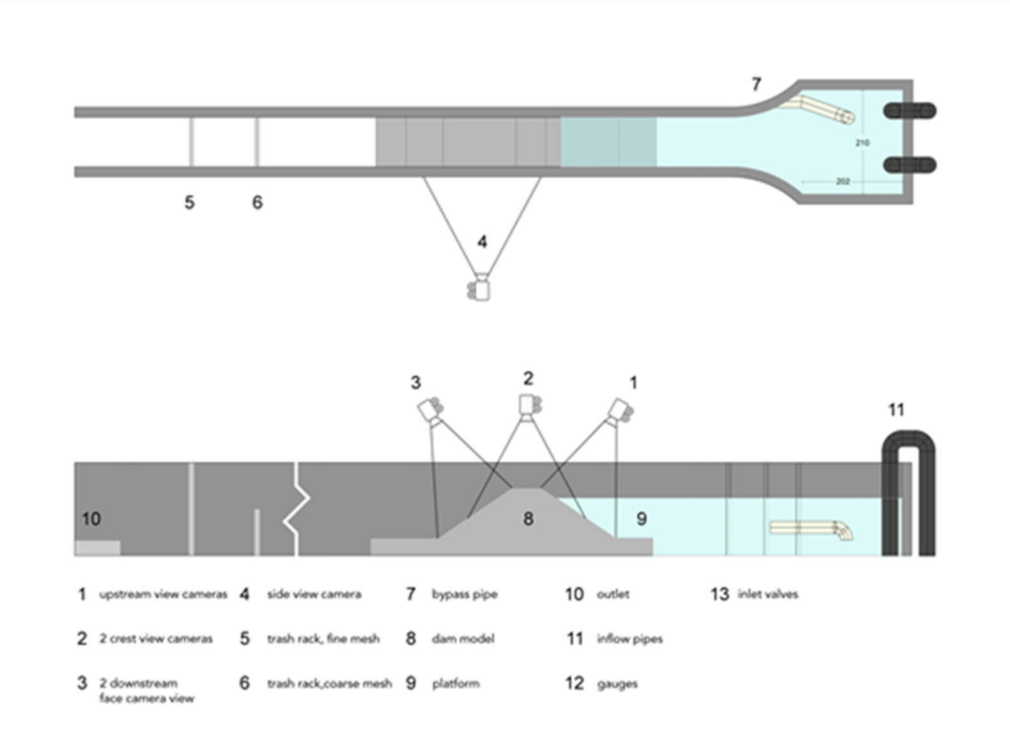
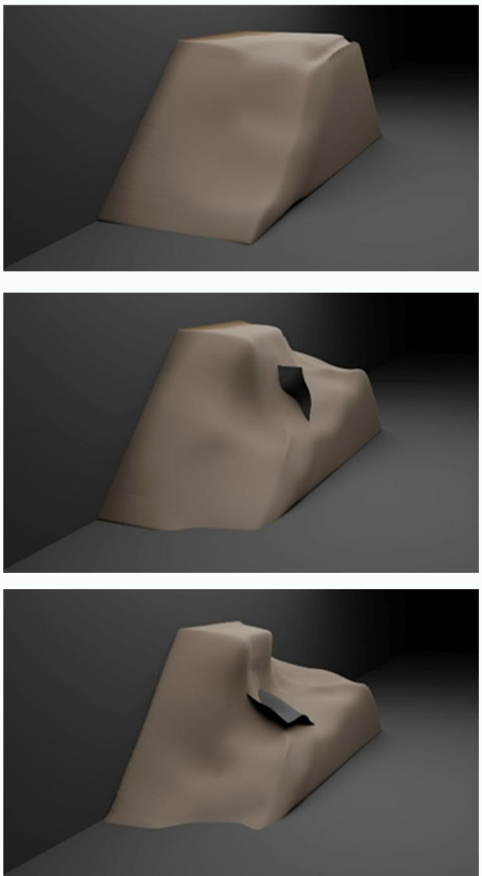


Figure 3: 3D model of the breach process



Til minne om Elmo DiBiagio (1931-2021)

Nekrolog

Elmo DiBiagio

Elmo DiBiagio ble født i Pennsylvania, USA, i 1931 og kom til Norges Geotekniske Institutt (NGI) som Fullbright-stipendiat i 1955. Han studerte ved Princeton og University of Illinois, der han mottok sin PhD i 1965. I Norge traff han Jorunn, og det gjorde at han skulle bli i Norge. Elmo døde 16. mai 2021, 89 år gammel.

Elmo ledet utviklingen ved NGI av instrumentering og sikkerhetsovervåking for ulike typer bygg og anlegg. Han var som skapt for denne oppgaven, med sin solide teoretiske bakgrunn og oppfinnsomhet kombinert med usedvanlig teknisk og praktisk innsikt. Han markerte seg tidlig internasjonalt og bidro sterkt til å etablere NGI som et anerkjent senter for forskning og utvikling, f.eks. for dam- og tunnelanlegg, offshorekonstruksjoner og fundamentering av vindturbiner på havbunn.

Hans store antall foredrag på internasjonale konferanser og unike evne til å fremlegge og illustrere sine foredrag, gjorde ham verdenskjent. Ved markeringen av Elmo som pensjonist kom det inn hilsener fra alle verdenshjørner. Professor Ralph Peck, USA, en internasjonal ener innen fagområdet geoteknikk, uttalte: «Your genius and ingenuity have made you Mr. Instrumentation for the entire geotechnical world.»

Det er med ydmykhet, takknemlighet og stolthet vi tenker tilbake på vår kollega og venn og alle opplevelsene vi fikk dele med ham. Elmo var genuint interessert i sine omgivelser, enten det gjaldt teknologi eller medmenneskelighet. Han bidro til å bygge oss opp både faglig og menneskelig og var, med sine pedagogiske evner, en sann mentor.

Elmos dyktighet, engasjement og personlighet er en viktig del av NGIs historie. Vi lyser fred over hans minne, takker ham og sender våre tanker til Jorunn og familien, som har bidratt til å gjøre Elmo til den han var.

Fra kolleger og venner på NGI.

Kaare Høeg

Elmo liked to quote Lord Kelvin: ***"To measure is to know. If you cannot measure it, you cannot improve it."*** He lived by these words, both scientifically and personally.

Suzanne Lacasse

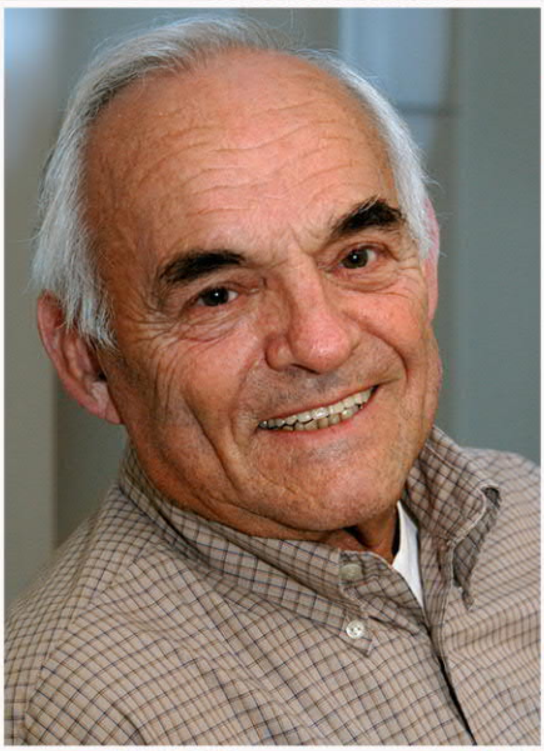
Fra NGIs nettside: Geoteknikere arbeider i to verdener: en teoretisk verden hvor ideer og hendelser kan ble representert med tall og beregnet til ønsket antall desimaler, og en praktisk verden hvor observasjoner og hendelser kun kan bli beskrevet i generelle vendinger og termer. Instrumentering og overvåking (monitorering), knytter de to verdener sammen kvantitativt.

Professor Ralph B. Peck, "oppfinneren" av observasjonsmetoden i geoteknikk, innså tidlig i sin egen yrkeskarriere som ingeniør viktigheten og nytteverdien av instrumentering og observasjon av hvordan konstruksjoner og byggverk oppførte seg i det virkelige liv. Han gjorde en stor innsats for å fremme denne kunnskapen og bruken av den.

NGIs tidligere instrumenteringsekspert,
Elmo DiBiagio, som studerte under Professor Ralph B. Peck, samlet mange eksempler, "case histories", fra NGI-prosjekter gjennom årene, i det Peck kalte "One-page-summaries" for å illustrere viktigheten og variasjonene innen instrumenteringsprosjekter på NGI.

Link til Elmos «case histories»:
https://www.ngi.no/Tjenester/Instrumentering-og-feltforsoek/Case-histories

Link til minneord:
https://www.ngi.no/Nyheter/Aktuelt-fra-NGI/Minneord-om-Elmo-DiBiagio-1931-2021



Example 20 (2007) - Observational method applied to a large tailings dam

CATEGORY	MAIN OBJECTIVE	MAIN BENEFIT
Construction control	Input for the Observational Method	Design modified on basis of measurements

BACKGROUND AND DESCRIPTION OF PROJECT

This case history deals with the Zelazny Most tailings dam in south-west Poland, Figure 1. The ring-shaped dam has a perimeter of 15 km, area of 20 km^2, and is one of the largest tailings dams in the world. Approximately 80,000 tons of waste are transported hydraulically to the dam every day. Deposition of tailings started in1975. The current height of the dam is between 22 to 60 m above the original ground surface.

Fig. 1. Aerial view of the Zelazny Most tailings dam

The elevation of the dam is raised by the upstream method of construction as illustrated in Figure 2.

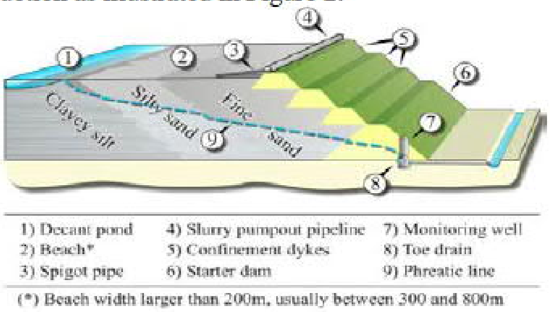


Fig. 2. Cross section of part of the dam

SCOPE OF INSTRUMENTATION

The monitoring program includes measurements of:

- Mining-induced seismicity: 2 seismographs and 10 biaxial accelerometers.
- Pore water pressure and elevation of the phreatic line: 1800 open standpipe piezometers and 300 vibrating-wire piezometers in boreholes. The latter were installed by the fully grouted method (Mikkelsen and Green 2003).
- Surface displacements: 350 benchmarks for geodetic and GPS measurements plus an automatic Total Station with 23 target mirrors.
- Measurements of subsurface displacements of the dam and foundation: ~50 Inclinometer installations.

PERFORMANCE OF THE DAM

Since the tailings dam is built by the upstream construction method, Figure 2, the main concern initially was instability due to potential flow liquefaction of the tailings. Therefore, the first inclinometer installations installed through the dam into the foundation were fairly shallow. However, after a few years of operating the dam, geodetic data and inclinometer measurements showed some sections of the dam were moving more or less as semi-rigid bodies, and deeper inclinometers were installed in 2003.

Subsequent measurements have disclosed zones of concentrated deep displacements far below the dam as can be seen in Figure 3. The Pliocene clay has been pre-sheared during two periods of glaciations, and the friction angle is probably reduced down close to its residual value. Figure 3, for example shows the measured horizontal displacements at the North dam between 2011 and 2012. The dam and subsoil above elevation 80 m are sliding along a shear plane in the Pliocene clay at about elevation 80 m. This is at a depth 35 m under the original ground surface. There is also a zone of concentrated shear at about elevation 70 m.

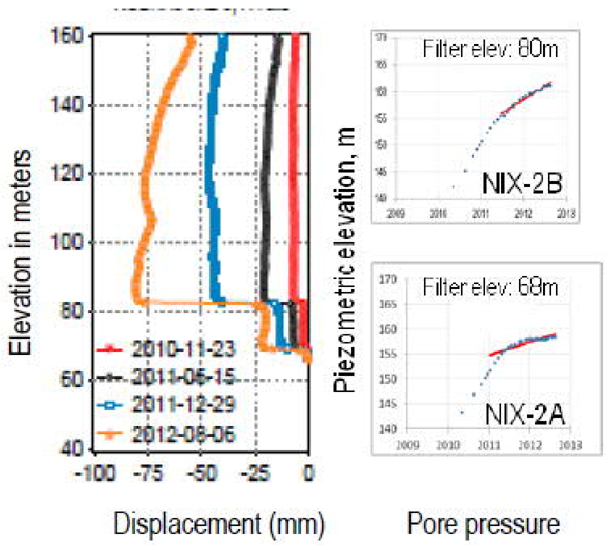


Figure 3. Measured horizontal displacements and pore pressure in the shear zones at the North dam

MOST SIGNIFICANT INORMATION DERIVED

The design and operation of the Zelazny Most tailings dam is an excellent example of the use of the *Observational method* in geotechnical engineering. Measurements have resulted in design changes and remedial measures such as:

- moving the dam crest upstream to flatten the average downstream slope;
- constructing stabilizing berms at the tam toe; and
- installing relief wells in the foundation to reduce pore water pressures.

REFERENCE: Jamiolkowski, M. et al. (2010)

Se vedlegg 1: «In praise of monitoring and the Observational Method for increased dam safety» (Lacasse & Höeg, 2019)

CALIBRATION OF FE-MODEL WITH MEASURED BEHAVIOR OF AN EXISTING CONCRETE ARCH DAM

S. BJØNNESS, N.RAKSTAD, V. KRATHE, T. KONOW

Dr.techn. Olav Olsen

This paper describes the general process involved in using data from instrumentation in order to verify the capacity of an existing concrete arch dam. The data from the instrumentation is used as a basis for load definition and as a calibration/verification of a global finite element (FE) model.

The geometry of the model is based on original drawings and a recent laser scan of the entire dam, verifying the geometry.

During the first year of use leakages were observed towards the foundation of the arch. This was sealed off with the injection of grout the following year. Seventy years later some of the same leakage was observed. This was sealed again a few years ago with new grouting underneath the foundation. Simultaneously, the work of instrumentation, and analysis of the dam was initiated in order to improve the documentation of the dam.

When looking at the deformation and temperature data, it was clear that the dam was highly influenced by temperature load. When emptying and filling the dam, the change in structural response was small compared to the change caused by the varying temperature.

The temperature both in the water and behind the isolation wall for this dam is constant across the height of the dam unlike most dams which has a varying temperature distribution over the upstream face.

The sensitivity for temperature load and local marginal capacity induced a need for precise analysis and the use of measured data. External temperature data, together with both thermodynamic analysis and machine learning, was used to estimate a longer time series from the relatively short data that was available.

The non-linear behavior of the material and the foundation can be found based on an iterative analysis of the global model. This analysis is performed using ShellDesign, which is a design tool for reinforced concrete, owned and developed by Dr.techn. Olav Olsen.

PLANNING AND DESIGN OF TEMPORARY COFFERDAMS – THE CASE OF A COFFERDAM FAILURE IN BERGEN, NORWAY

Fjóla Guðrún SIGTRYGGSDÓTTIR
Department of Civil and Environmental Engineering, NTNU, Trondheim

Cofferdams are required to dewater a construction site placed in rivers and streams such as for dam construction and rehabilitation. While such cofferdams are temporary structures, they need to be planned and designed considering health and safety of the construction workers, safety of the downstream area and safety of the permanent structure under construction. For any project, due consideration of the hydrological conditions and diversion of potential floods during construction are important.

Incidences related to cofferdams have been reported, such as leakage problems during the Folsom Dam Auxiliary Spillway Project in California in 2016, and incidents of construction floods at the Jackson Lake Dam in 1986, Roosevelt dam in 1993 and Glendo Dam in 2010 and 2011, and the special case of the Auburn Cofferdam breach in 1986 . These are all cases from the USA, however, incidents at cofferdams have without a doubt occurred worldwide on dam projects.

In this paper a recent case of a cofferdam failure in Bergen, Norway during rehabilitation of an existing dam on the reservoir Munkebotnsvatn, is outlined and discussed in the framework of the Norwegian Dam Safety Regulation as well as this in selected other countries. The case demonstrates that a cofferdam, originally identified to be only of risk for the construction site, can quickly become a threat for a larger area further downstream. For example, if an existing or permanent dam is partly weakened or removed, thereby leaving the cofferdam the last barrier between the reservoir and the downstream area. The threat posed by the cofferdam in Bergen was identified some days before the failure, thus in time for an evacuation plan to be activated. The police evacuated 133 people and closed a major road before the cofferdam failure released a flood which damaged a marina, cars, hiking trails and more. Only the cleanup after the event was estimated to 5 million NOK. Bergen Municipality instigated both an internal and external investigation of the cofferdam failure, additionally, the case was investigated by the police who proposed corporate penalties of 300 000 NOK to be paid by both the Dam Owner and the Designer. However, in 2020 the public prosecutor transferred the case to the Norwegian Water Resources and Energy Directorate (NVE) for further evaluation and actions. The external investigation instigated by the Bergen Municipality concluded that the risk associated with the cofferdam in Bergen was misjudged by everyone involved in the project. It was only a few days before the failure that it was recognized that the cofferdam was a dam of consequence.

FLOODING INCIDENT IN THE TINGUIRIRICA VALLEY, CHILE IN 2017

Manuel Ignacio Sabat, Tinguiririca energia, Chile
Lars Ødegård, Statkraft, Norway

The two run-of-river hydropower plants of La Higuera and La Confluencia, owned by Tinguiririca Energía, were hit by a severe flash flood on 25th February 2017. The flash flood was unusual for this time of the year and developed very suddenly. The weather forecast gave no warning and resulted in loss of lives in the upstream village of Termas del Flaco. Much of the infrastructure in the Tinguiririca Valley was impacted, including two intake dams.

RIPRAP AND ROCKFILL DAM EXPERIMENTAL MODELS EXPOSED TO OVERTOPPING EVENTS

Théo DEZERT
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Ganesh Hiriyanna Rao RAVINDRA
Project Leader, Trondheim Kommune

Fjóla Guðrún SIGTRYGGSDOTTIR
Associate Professor, Norwegian University of Science and Technology

Embankment dams, built with locally excavated rockfill or earth fill materials represent 78% of the total existing dams worldwide. The ones composed of coarse-grained material for over 50% are classified as rockfill dams and stand for 13% of the whole world dam population. There are currently over 360 large dams (over 15 m high) in Norway and over 180 of these are rockfill dams. A constant trend in society comprises an increase in the safety requirements for all critical infrastructure. Indeed, for the last years, there has been an important increase of the demand on dam safety standards, particularly in the most developed countries. This has led to new and more demanding dam safety regulations and guidelines. This trend is also valid as applied to the Norwegian dam infrastructure. Many Norwegian rockfill dams are expected to be upgraded in the future to meet new requirements of dam safety regulation...

Recent experimental and analytical studies conducted at the Department of Civil and Environmental Engineering at NTNU (Trondheim) have been directed towards investigating failure mechanisms in ripraps and rockfill dam models subjected to throughflow and/or overtopping conditions. It is of major importance to study and to understand the breakage process, according to the type of dam structure and to the discharge water level. Such research would be extremely valuable to predict and assess the risk of rupture. Results from experimental studies are also useful to improve construction and reinforcements techniques of rockfill dams and ripraps. Here, the purpose of this article it to introduce and display 5 experimental setups that have been submitted to overtopping events with increasing water discharges. Their resistance to overtopping is analysed and discussed, according to their respective critical discharge values and associated failure mechanisms. A comparison of discharge scaling factor from experimental model with discharge scaling factors recommended by the NVE for different consequence classes of dams is also proposed.

PHYSICAL AND NUMERICAL RESEARCH ON ROCKFILL DAMS SUBJECTED TO THROUGHFLOW DUE TO CORE OVERTOPPING

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Ganesh Hiriyanna Rao RAVINDRA
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Climate change is projected to have significant impacts on regional hydrological features and especially, on the intensity and frequency of extreme flood events. Modified weather patterns and in turn modified hydrological flow regimes pose a severe threat to the safety of hydraulic structures. Rockfill dams are generally designed to handle floods with a 1000-year return period or other specific design criteria. The probable maximum flood (PMF) is also considered in the design process. However, due to the impacts of climate change on regional flood frequency characteristics in a future climate, future floods with a 1000-year return period might have significantly higher magnitudes. This inevitably dictates re-evaluation and possibly redesign of existing dams to safely handle these extreme flood events. Hence, understanding the vulnerabilities of dams and understanding the risks posed by dams is important in order to make the appropriate decisions on dam safety measures.

Embankment dams represent 78% of the world's large dams according to ICOLD Worlds Register of Dams. Although a significant proportion of embankment dams built globally are typically earthfill dams, rockfill dams have been the preferred choice of dam type in Norway. This can be attributed to local availability of construction materials. Thus, understanding the mechanisms governing stability and breaching of these structures is of great importance.

Dams and especially embankment dams are vulnerable to extreme flood events which can lead to accidental overtopping of the dam core or the crest. This poses a major threat to the safety of the dam as embankment dams seldom are designed to handle overtopping flows as the dam structure comprises mainly of pervious and erodible materials. ICOLD statistics show that overtopping is the main cause of failure in earthfill dams, appearing as the main factor in 31% of the total number of failures, and it is also involved in another 18% of failures as a secondary cause. During the last decades, there has been a gradual increase in the society's demand on dam safety standards, especially in the most developed countries. This has resulted in new, and more demanding dam regulations and guidelines, for example in Norway.

Illustrations of embankment dams being exposed to various loading scenarios are presented in Fig. 1

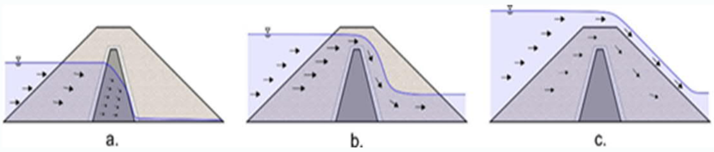

Fig 1. Load scenarios for a rockfill dam

(a) Rockfill dam in regular operation
(b) Rockfill dam in core overtopping situation
(c) Rockfill dam in crest overtopping situation

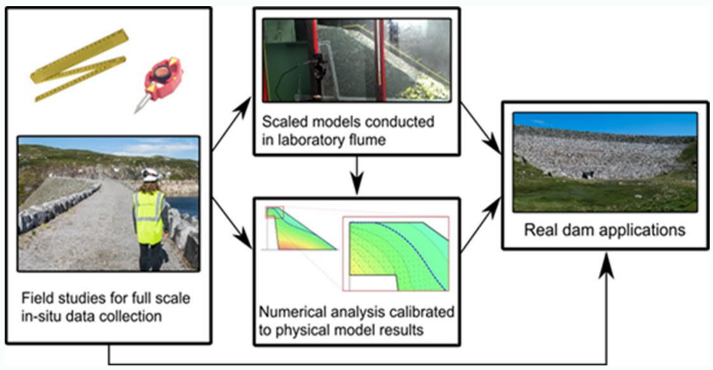

Fig. 2 Schematic overview of research agenda

This paper provides an overview of recent research conducted at NTNU, Trondheim to better understand the behavior of rockfill dams under overtopping conditions. The overarching research agenda is presented in Fig. 2, where initial studies are proposed on the basis of findings from large-scale field surveys as well as requirements in dam safety regulations. Further, basing on the outcomes from the field studies, physical scale models are constructed to examine the effects of toe configurations on flow through rockfill dams. Subsequently, numerical models have been designed to calibrate and examine use of software for approximating nonlinear flow.

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- PP - Position Paper - Dam Safety and Earthquakes (Wieland)
- B159 Supplement to the Position Paper on Dams and the Environment
- B161 Dams and Water Transfers – an Overview
- B162 The Interaction of Hydraulic Processes and Reservoirs – Management of the impacts through construction and operation – Downstream impacts of large dams
- B173 Integrated Operation of Hydropower Stations and Reservoirs
- B175 Dam Safety Management: Pre- operational Phases of the Dam Life Cycle
- B181 Tailings Dams Design - Technology Update

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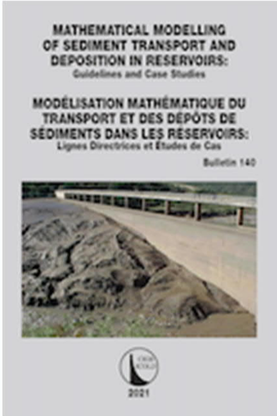

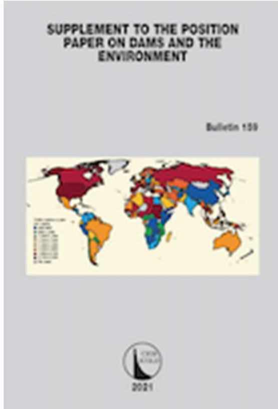

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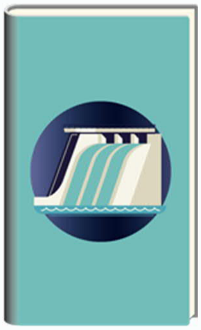

KALENDER 2022

- 2nd Nordic seminar 8.– 9. nov. 2022 Helsinki, Finland
- ICOLD 27th Congress - 89th Annual Meeting - Marseille (France) 27.5-3.6. 2022 https://cigb-icold2022.fr/en
- Frist for nominasjon for Damkrona 2022 er 1.11.2022 Juryen ønsker at forslag og nominasjoner tilsendes per epost til Mari Hegg Gundesen (jurysekretær, mhg@nve.no) eller Hilde Johnsborg (juryformann, hide.johnsborg@multiconsult.no).
- ICOLD 90th Annual Meeting - Göteborg (Sweden) 11-15.6.2023 - Submission of abstracts: October 2022, https://icold-cigb2022.se/

ICOLD 27th Congress - 89th Annual Meeting - Marseille (France) 27.5-3.6.2022

Kongress tema:

- **104 - CONCRETE DAM DESIGN INNOVATION AND PERFORMANCE**
- **105 - INCIDENTS AND ACCIDENTS CONCERNING DAMS**
- **106 - SURVEILLANCE, INSTRUMENTATION, MONITORING AND DATA ACQUISITION**
- **107 -DAMS AND CLIMATE CHANGE**

ICOLD Anual Meeting 11-15 June, 2023

The Swedish Exhibition Centre, Gothenburg

Symposium Sessions

1.Dam safety management

2.Surveillance and condition monitoring

3.Analysis, modelling and decision making

4.Rehabilitation and dam safety measures

5.Climate & environmental adaption

6.Innovation

- Registration opens: October 2022
- **Submission of abstracts: October 2022**
- **Submission of technical paper: January 2023**
- Meeting dates 11-15 June 2023

Hold av datoen

The 2nd Nordic ICOLD Seminar

8 November 2022, Helsinki

The Nordic ICOLD committees would like to welcome You to our 2nd Nordic seminar on dam safety. Save the date!

Topics will be:

* Current issues in each country
* Incidents or problems with dams
* Tailings dams

On behalf of the organizing committee:
Anne Marit Ruud, Guðlaugur Þórarinsson, Maria Bartsch and Jyrki Kotola

Icelandic Committee on Large Dams

FINCOLD

https://www.fincold.org/post/2nd-nordic-seminar

Hold av datoen for den **2nd. Nordic ICOLD seminar** -

mer info kommer både på NNCOLD web side og: www.fincold.org og https://twitter.com/FINCOLD_Finland

ICOLD Nordic professional network, https://www.linkedin.com/groups/13791014/

Registrering så snart som mulig på www.fincold.org, og ikke senere enn 10.10.2022.

Presentasjonene fra den 1st Nordic ICOLD seminar som ble holdt i Oslo finnes på https://nncold.no/skolesider/

Mer info om European Club Symposium i 2023 kommer - følg våre nettsider.

Riktig god påske - Hilsen fra NNCOLD

VIL DU BLI MEDLEM?

Hva er NNCOLD?

Den Norske Damkomiteen, medlem i ICOLD, EURCOLD

En ideell organisasjon med inntil 14 styremedlemmer og per i dag 30 firmamedlemmer

Hvem er vi?

Medlemmer fra: forskning og undervisning, rådgivere, dameiere, forvaltning og entreprenører

Hva omfatter dam?

Dammer av alle typer og formål i utvidet forstand, samt deres komponenter, funksjon og innvirkning på samfunnet og fag forbundet med dette:

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Hva er vi engasjert i?

Aktiv deltakelse nasjonalt og internasjonalt: ICOLD-symposier og årsmøter, EURCOLD og nylig etablerte "Nordisk ICOLD", inkludert:

- Deltakelse i ICOLDs tekniske komiteer (ref. spesielt utarbeidelse av ICOLDs faglige bulletiner – til nå nesten 200 stykker!)

- Deltakelse i EURCOLDs European Working Groups (ref. spesielt deres rapporter)

- Støtter, tar initiativ og formidler norske bidrag (artikler og presentasjoner) til konferanser og seminarer

- Støtter og inkluderer Young Engineers Forum i Norge

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- Promotering av fagområdet generelt, spesielt tildeling av Damkrona!

Hva resulterer dette i?

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Kan påvirke regelverk og "best praksis" og innovasjon innenfor faget, internasjonalt og nasjonalt (gjensidig), dette gjelder både teknisk, regulatorisk samt på miljø og sosiale forhold.

Eksponere norsk teknisk og annen relevant kunnskap internasjonalt.

Hvem benytter denne kunnskapen og miljøet?

Verdensbanken, diverse "offentlige" regionale banker og finansinstitusjoner, regionale banker, private investorer, offentlige og private bistandsorganisasjoner, forskjellige nasjonale myndigheter og regionale og lokale myndigheter, dameiere, rådgivere, entreprenører, flere?

Bli medlem:

Medlemskap i NNCOLD er basert på **firmamedlemskap**. NNCOLD medlemskap kan fåes gjennom NNCOLDs sekretariat (henvendelse e-post gog@nve.no) mot en årlig medlemsavgift på kr. 4 950,-.

Medlemskap i NNCOLD inkluderer blant annet abonnement på ICOLDs tekniske bøker (bulletiner), informasjon fra ICOLD tekniske komiteer og andre relevante organisasjoner knyttet til ICOLD. Medlemmene får invitasjoner til NNCOLDs årlige fagseminarer og ICOLDs årsmøter/kongresser.

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ICOLD

(International Commission On Large Dams)

Etablert I 1928. Samler og bearbeider kunnskap knyttet til planlegging, bygging, drift, sikkerhet og miljø ved store dammer (over 15m). Arbeidet skjer gjennom tekniske   komiteer, som utgir opptil fem tekniske bøker (bulletenger) årlig. Hvert tredje år arrangeres en kongress der opptil 300 artikler presenteres.

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NNCOLD representerer Norge i ICOLD, som kontaktledd for å opprettholde norsk kompetanse og profilere vannkraftmiljøet utad. NNCOLD fungerer også som kunnskapsformidler fra ICOLD til det norske miljøet. Norge har de senere årene vært svært aktive i ICOLD og er representert i mange av ICOLDs tekniske komiteer.

VEDLEGG 1

In praise of monitoring and the Observational Method for increased dam safety

L'approche observationnelle de Ralph Peck pour assurer la sécurité des barrages

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ABSTRACT: The Observational Method has served the geotechnical profession well in most areas of practice, such as bridge foundations, culvert construction, tunnels and dams. This paper summarizes one case history where the Observational Method played a key role in helping make risk-informed decisions during the construction and operation of the Zelazny Most tailings dam in Poland. The Zelazny Most dam is the largest tailings dam in Europe. For this dam, the i*n situ* measurements followed (and continue to follow) the movements and pore pressure in the foundation during operation. The use of the Observational Method resulted in significant design changes, including moving the dam crest, the construction of stabilizing berms and the installation of relief wells in the foundation. The Observational Method, when correctly applied, can be a most useful tool for follow-up of a dam design. The paper describes the Observational Method, its advantages and its affinities with the statistical Bayesian updating approach. It also describes briefly the observations at the Zelazny Most sites and discusses how the Observational Method was a key instrument for "risk-informed" decisions.

RÉSUMÉ: L'approche observationnelle proposée les professeurs Terzaghi et Peck est un outil qui a bien servi tous les domaines de la pratique de l'ingénierie géotechnique, tels que les fondations de ponts, la construction de ponceaux, les tunnels et les barrages. Cet article résume une histoire de cas où la méthode d'observation ("Observational Method") a joué un rôle clé en aidant à prendre des décisions éclairées en fonction des risques pour l'exploitation future de grands barrages, y compris le barrage de résidus de Zelazny Most en Pologne, le plus grand barrage de résidus en Europe. Pour ce barrage, les mesures in situ ont suivi (et continuent de suivre) les mouvements et la pression interstitielle dans le sol pendant la construction et l'exploitation. L'utilisation de la méthode d'observation a entraîné d'importants changements dans la conception, notamment le déplacement de la crête du barrage, la construction de bermes de stabilisation et l'installation de puits de secours dans les fondations. La méthode d'observation, lorsqu'elle est correctement appliquée, peut être un outil très utile pour la gestion des barrages. Le document discute de la méthode d'observation et de ses avantages, et la compare avec la mise à jour bayésienne. La méthode d'observation est considérée comme un instrument clé pour "des décisions éclairées par le risque" ("risk-informed decision making").

1 INTRODUCTION

It is now (2019) 50 years since the Observational Method (OM) was first published as Professor Ralph B. Peck's Rankine Lecture (Peck 1969). Peck recognized the importance of field observations and performance monitoring for the practice of geotechnical engineering. Lord W.T. Kelvin (1824-1907) once wrote:

> *"When you measure what you are speaking about and express it in numbers, you know something about it. But when you cannot express it in numbers your knowledge about it is of a meagre and unsatisfactory kind."*

A recurring factor in geotechnical failures is that modifications made during construction and operation did not follow the original script. Examples include the Aznalcóllar (Spain) and the Mount Polley (Canada) tailings dams where, among several factors, the downstream slopes were significantly steeper than intended in design. These failures reinforce the need for the "Observational Method", a seminal deterministic method in geotechnics.

The paper discusses briefly the Observational Method and its advantages, and presents a case history following Ralph B. Peck's philosophy of monitoring and evaluating the performance, and implementing mitigation measures. This paper includes for project description, soil conditions, instrumentation, performance and concerns, iimplementation of the Observational Method and the benefits of the application of the method. The paper closes with a suggestion to complement the Observational Method with Bayesian updating to enable "risk-informed decisions" and the optimisation of the construction and rehabilitation.

2 THE OBSERVATIONAL METHOD

Karl Terzaghi (1961) wrote:

> *"Soil engineering projects […] require a vast amount of effort and labor securing only roughly approximate values for the physical constants that appear in the equations. The results of the computations are not more than working hypotheses, subject to confirmation or modification during construction. In the past, only two methods have been used for coping with the inevitable uncertainties: either adopt an excessively conservative factor of safety, or make assumptions in accordance with general, average experience. The first method is wasteful; the second is dangerous. A third method is provided that uses the experimental method. The elements of this method are 'learn-as-you-go:' Base the design on whatever information can be secured. Make a detailed inventory of all the possible differences between reality and the assumptions. Then compute, on the basis of the original assumptions, various quantities that can be measured in the field. On the basis of the results of such measurements, gradually close the gaps in knowledge, and if necessary modify the design during construction."*

Terzaghi's observation follows Terzaghi's 1929 warning about the important effect of minor geologic details on the safety of dams. The Observational Method, described by Professor Ralph B. Peck in his Rankine Lecture in 1969, is a formalisation of Terzaghi's philosophy. The Observational Method consists of:

1. Exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.
2. Assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions. In this assessment geology often plays a major role.
3. Establishment of the design based on a working hypothesis of behaviour anticipated under the most probable conditions.
4. Selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis.

5. Calculation of values of the same quantities under the most unfavourable conditions compatible with the available data concerning the subsurface conditions.
6. Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.
7. Measurement of quantities to be observed and evaluation of actual conditions.
8. Modification of design to suit actual conditions.

The Observational Method (OM) is particularly useful for the design of dam foundations, tunnels, cuts, deep excavations and large foundations. In many cases, the results of the early design computations are not more than working hypotheses, subject to confirmation or modification during construction, with the help of the OM.

The degree to which each step is followed depends on the nature and complexity of the project. Geotechnical engineers work in both a theoretical dimension and a practical dimension. Both have aleatoric and epistemic uncertainties[1], which can be reduced, but never completely eliminated. Because of the uncertainties, there is always a finite, even if very small, probability that a failure may occur.

The Observational Method has many advantages, but requires a robust set of procedures throughout a project: the method adopts the "most probable" design parameters, as opposed to conservative parameters; it assesses a range of probable behaviour; it sets out modifications in construction to be implemented if the parameters or the behaviour turn out to be less favourable than assumed in the design; it monitors the behaviour of the structure and soil, providing indication of whether mitigation measures are required or not; and it analyses the data and triggers the implementation of contingency plans.

Costly overdesign can be avoided without compromising on safety or the environment. One key aspect is the advance selection of a course of action for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.

3 THE ZELAZNY MOST TAILINGS CONTAINMENT FACILITY IN POLAND

3.1 *Project Description*

The Zelazny Most tailings storage facility (TSF) in southwest Poland is a ring-shaped dam with a perimeter of about 14 km and area of 20 km^2 (Figs 1 and 2). It is the largest tailings dam in Europe. Approximately 18 million m^3 of copper mining waste are transported hydraulically to the facility every day. Deposition of the tailings started in 1975, and by 2019, the maximum dam height is 71 m. The crest elevation of the dam is at 185 m. The original ground surface at the facility was saddle-shaped, as a river has crossed the site, and the eastern and western portions of the ring dam are higher than those to the north and south.

The dam was raised by the upstream method of construction (Fig. 3). Circumferential drains were installed as the dam was being raised. The drains were placed at El. 147, 153, 162 and 175 m asl (Fig. 4). The dam crest was raised at a rate of about 1 to 1.4 m/year, with an average downstream slope of 3.5 horizontal to 1 vertical. The operations are planned to continue until 2042.

3.2 *Complex Geology and Soil Conditions*

The Zelazny Most tailings storage facility is located in a complex geological environment (Jamiolkowski 2014). From the ground surface, the foundation soils consist of Pleistocene deposits, including silty lake clays and outwash sands, few sandy gravel inclusions and silty sands. These

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[1] *Aleatoric* uncertainty (also known as statistical uncertainty) is the natural randomness of a property or a load, e.g., soil strength and ocean wave height. The aleatoric uncertainty cannot be reduced.

Epistemic uncertainty (also known as systematic uncertainty) is the uncertainty due to lack of knowledge, e.g., measurement uncertainty and model uncertainty. The epistemic uncertainty can be reduced by, for example, increasing the number of tests, improving the measurement method and/or verifying the calculation procedure with model tests.

are underlain by thick layers of freshwater Pliocene clays of medium to high-plasticity. The Pliocene deposits overlie Triassic strata, below which the copper ore body is encountered.

Figure 1. Zelazny Most copper tailings dam in Poland and areal view of dam (Jamiolkowski *et al* 2010).

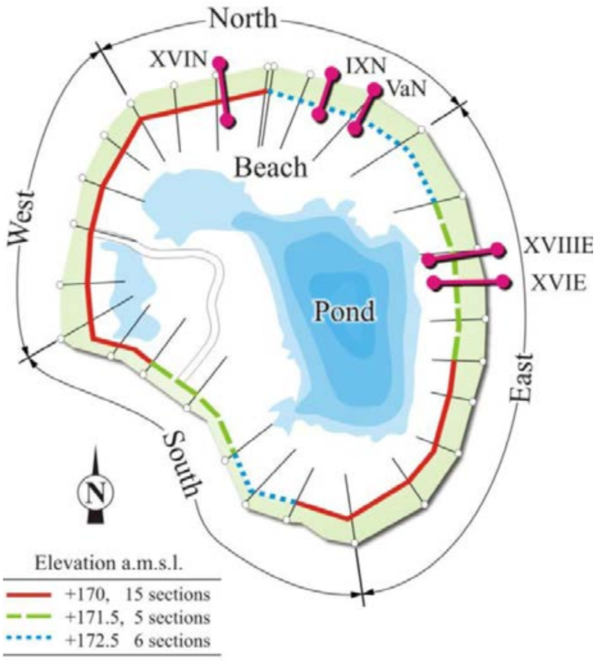

Figure 2. Bird's eye view of Zelazny Most Dam and elevations in 2010 (after Jamiolkowski *et al* 2010).

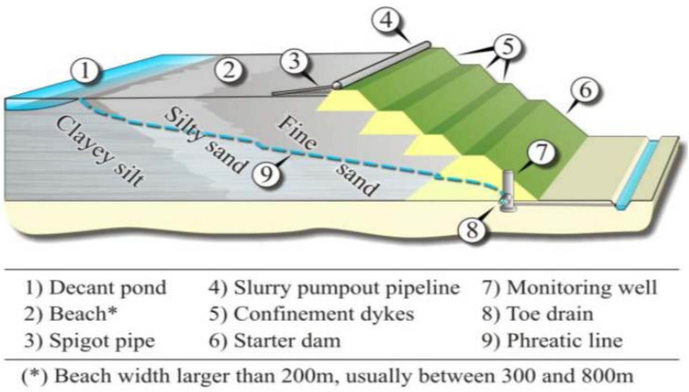

Figure 3. Schematic cross-section and phreatic line (after Jamiolkowski *et al* 2010).

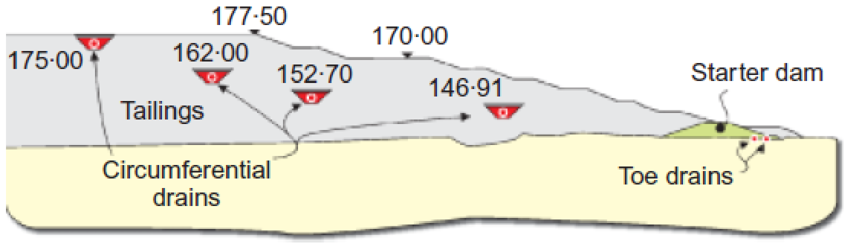

Figure 4. Circumferential drains in Zelazny Most ring dam (after Jamiolkowski, 2014).

The complexity of the deposit is due to a Pleistocene succession of ice sheets moving from north to south over central Europe. At least six major ice advances occurred in south Poland, whereof no less than three passed over the Zelazny Most area. The ice sheets, believed to have been at least 1000 m thick, have induced widespread glacio-tectonic features extending to depths of about 100 m which greatly affected the Pliocene clays. As a consequence, the soils have been intensely sheared, folded and generally disturbed. In places, the initially horizontally bedded freshwater Pliocene sediments have Pleistocene deposits thrusts within them.

The glacio-tectonic phenomena left a permanent imprint on the Zelazny Most geotechnical environment, especially extended shearing and folding of the Pliocene deposits. The ice sheets are believed to have imposed a stress field resembling that of simple shear, generating several shear surfaces. Laboratory tests showed that the shear surfaces are found mainly in high plasticity clay and have a drained shear strength close to the residual. The horizons containing the glacio-tectonic shear planes are probably thin 'zones' of high-plasticity slickensided clay (Jamiolkowski 2014).

For stability analysis and modelling, the soil profile was set to have an upper 10 m consisting of mainly sandy deposits. The Pliocene deposits below consist of mainly freshwater medium to very high-plasticity clay. The shear strength of the slickensided high plasticity clay is close to its residual friction angle of 6.5 to 8º (Jamiolkowski 2014). The sub-planar shear surfaces forming slickensides in the clay have variable shear strength.

The presence of the shear surfaces was established through the application of the Observational Method.

3.3 *Instrumentation*

The monitoring program includes seismographs and biaxial accelerometers for monitoring mining-induced seismicity, open standpipe piezometers and over 300 vibrating-wire piezometers in boreholes. Over 450 benchmarks for geodetic and GPS measurements plus an automatic Total Station were installed. Fifty-six inclinometers, many of them more than 100 m deep, were installed to monitor subsurface displacements (dam and foundation).

Because the tailings dam was built by the upstream construction method (Fig. 3), the initial concern was instability due to potential liquefaction of the tailings. The first inclinometer installations through the dam into the foundation were therefore fairly shallow and did not penetrate deep into the foundation. Deeper inclinometers were installed when the rate of horizontal dam displacement started to increase (DiBiagio, 2013)[2].

3.4 *Performance and Concerns*

The East Dam, with the highest crest elevation and with significant horizontal displacements, is discussed herein[3]. At the end of 1995, when the dam reached the height of 40 m, the rate of horizontal displacement increased. The maximum displacement (about 650 mm) between 2003 and 2013 occurred at cross-section XVIE (shown in Fig. 1). Between 2001 and 2009, the rate of horizontal displacement was 40 to 50 mm/year. The deeper inclinometers quickly disclosed zones

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[2] DiBiagio (2013) published 24 examples of the implementation of instrumentation, monitoring and the OM for a variety of geotechnical engineering problems, including dams, retaining structures, braced excavations, slurry trenches, large scale model tests, avalanche hazards and offshore structures.

[3] Jamiolkowski (2014) presented also results for other parts of the dam.

of concentrated displacements at large depths below the dam, at El. 40 beyond the East Dam toe, and at El. 80 for the North Dam.

As mentioned, the main instability concern was initially the tailings dam itself and not the foundation. The early inclinometers installed through the dam and into the foundation of the East Dam turned out to be too shallow to detect the development of significant shear displacements at large depths. The deep inclinometers installed after 2003 clearly demonstrated movements on a sub-horizontal shear zone in the foundation of cross-section XVIE at about 40 m asl, about 75 m beneath the original ground surface. Figure 5 shows the inclinometer measurements in that cross-section. An interpretation of the results from this and the neighboring inclinometers in sections North (up to cross-section XVIIIE) and South (to cross-section XIVE) of cross-section XVIE indicates that a shear zone at 40–50 m asl extends at least 600 m along the dam axis and at least 150 m from the toe under the dam (Jamiolkowski *et al* 2010). To better define the zone of concentrated shear strain, additional inclinometers were installed. Between 2003-2007, the measured horizontal displacement rates at 40 m asl were about the same as the maximum measured horizontal dam displacement recorded on the crest of the starter dam at cross-section XVIE.

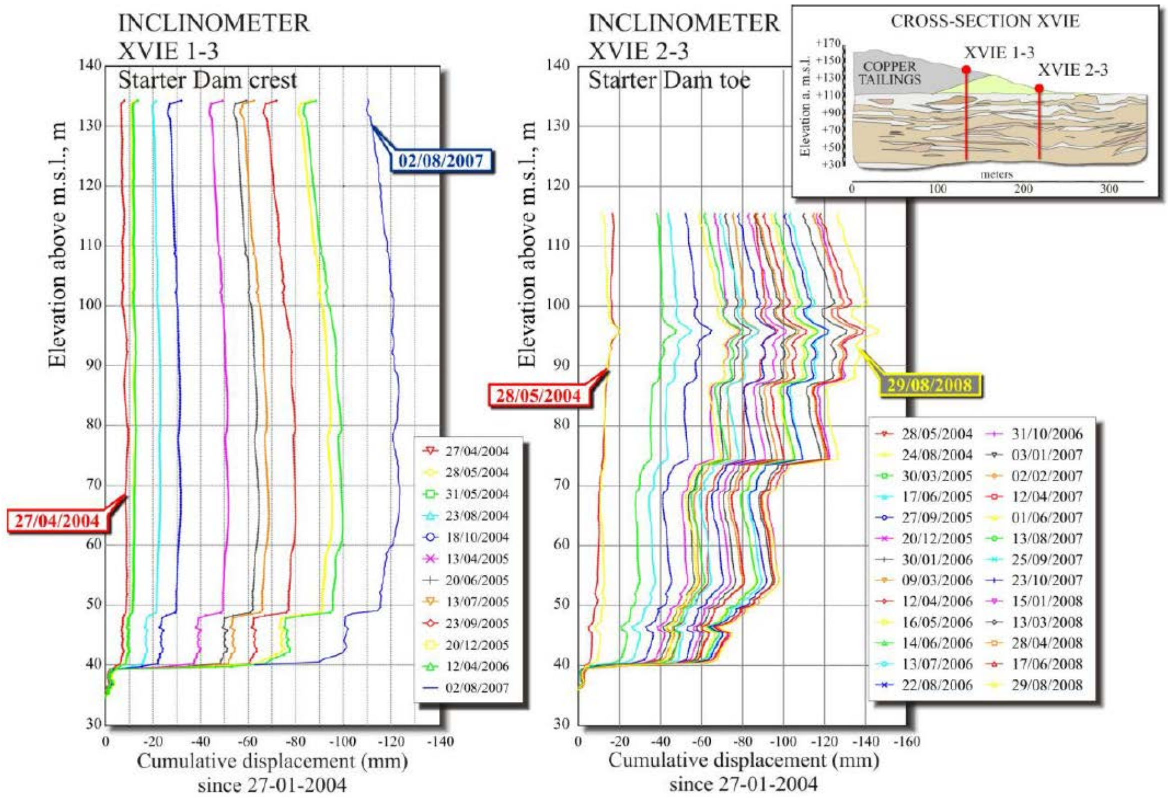

Figure 4. Horizontal displacements measured in deep inclinometers on East Dam (Jamiolkowski *et al* 2010).

Figure 5 presents the 2005 to 2014 measurements at cross-section XVII E5-A on the east side of the dam. At El. 44, this is a plane where the horizontal displacements are larger than anywhere else. Most of the horizontal movement is concentrated along this sub-horizontal glacio-tectonic shear plane. The explanation for the large displacement at elevation 44 m is the presence of a shear plane in the Pliocene clay which was pre-sheared during at least three periods of glaciation. The concern for the critical failure body is illustrated in Figure 6.

3.5 *Implementation of Observational Method*

Tailings deposition started in 1975. In 1993, a four-member International Board of Experts (IBE) was appointed by the operating mining company to give advice on the safe development of the facility. The decision was made to apply as closely as possible and rely on the Observational Method.

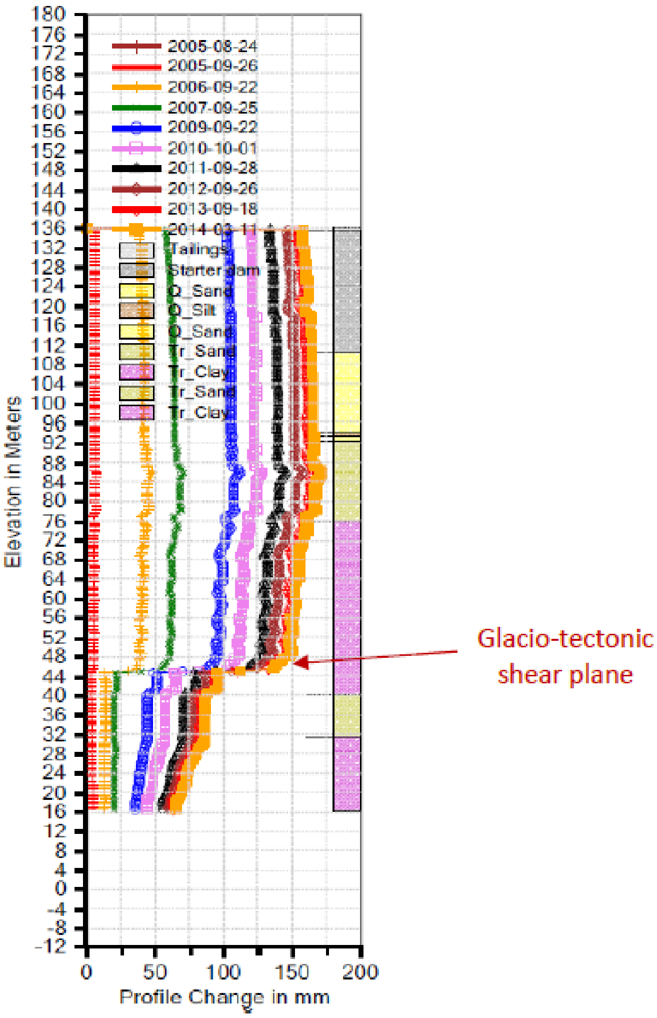

Figure 5. Horizontal displacements from deep inclinometers at cross-section XVII E5-A (project files).

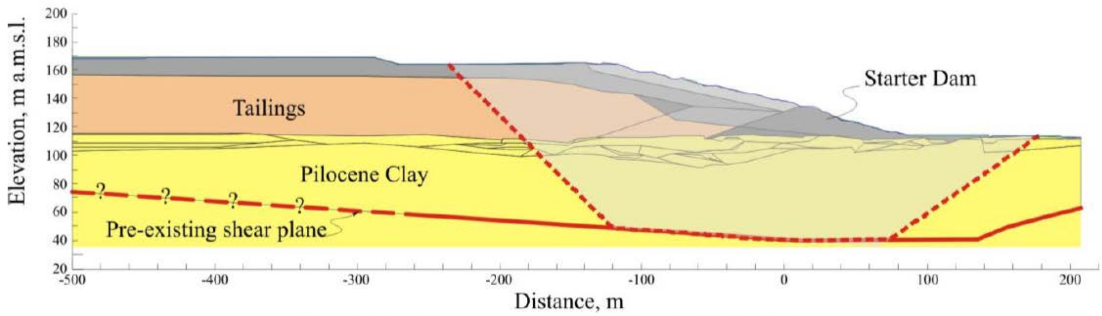

Figure 6. Illustration of stability concern for cross-section XVI-E ((Jamiolkowski *et al* 2010).

3.5.1 *Course of action*

At cross-section XVIE, the following stabilization measures were implemented in the period 2007-2009: (1) construction of a stabilization berm at the toe of the dam; (2) shifting of the dam crest 150 m closer to the pond (Fig. 1); (3) drilling of 20 relief wells, some as far down as 150 m; and (4) extensive, state-of-the-art finite element analyses of the dam under current conditions and with different mitigation measures implemented (Jamiolkowski 2014; NGI 2010, 2011, 2013 a, b; Rocchi and Da Prat 2014).

The evaluation work resulted in a temporary (over 3 to 5 years) idle period for mining waste disposal in the Zelazny Most tailings containment facility. The tailings were deposited in a nearby auxiliary pond.

3.5.2 *Preparedness.*

Additional ongoing measures include (Jamiolkowski 2014): (1) continuous enhancement of the monitoring network, the communication system between monitoring groups and end-users, with the adherence to a strict application of the Observational Method; (2) addition of circumferential drains as the dam was raised further; (3) further geotechnical analyses of the observed displacements of the dam to predict its evolution with increasing dam height; (4) modification of the plans for design and construction in light of the monitoring results and constantly updated stability analyses; (5) development of options as more information become available from the instrumentation; and (6) study of the stabilization potential of large diameter structural shafts and shear keys downstream of the dam toe.

An understanding of the complex geology was and continues to be crucial to conceive and be prepared to implement measures capable of mitigating the horizontal dam displacements. This involves considering the already-known active shear planes, as well as dormant shear planes existing in the foundation clay that may be reactivated by further dam raising.

In light of the presence of shear zones, the continuing horizontal displacements and the construction generated pore pressures, the current plan includes trying to improve tailings deposition and consolidation technology to reduce the volume of tailings already stored and planned to be stored in the facility.

3.6 *Benefit of the Observational Method for Zelazny Most tailings dam.*

The design and on-going operation of the Zelazny Most tailings dam is an excellent example of the use of the Observational Method in geotechnical engineering: after a few years of operation, geodetic data and inclinometer measurements suggested that the East starter dam and foundation soil were moving more or less as a semi-rigid body. After the implementation of the measures to improve the stability in the period of 2007-2009, the East Dam was more stable, with a reduction of the movements of the starter dam by two-thirds. The relief wells were believed to be the most effective of the three measures, and the circumferential drains (Fig. 4) proved to be very efficient in lowering the phreatic surface.

The application of the Observational Method and the ensuing stabilization measures taken helped reduce considerably the risk of instability of the Zelazny Most tailings facility. The measurements and engineering of the tailings containment facility during operation resulted in design changes and rehabilitation measures including: moving the dam crest upstream to flatten the average downstream slope; constructing stabilizing berms at the dam toe; and installing relief wells in the foundation to reduce pore water pressures.

It is appropriate to cite Hutchinson (1995): "In any stability problem the most important question is generally whether or not pre-existing discontinuities, especially shears, are present". The behaviour of the Zelazny Most dam confirms the wisdom in this statement (Jamiolkowski 2014).

4 EXAMPLES OF BENEFITS OF OBSERVATIONAL METHOD

Peck himself used the Observational Method on several embankment dams, but the method has found applications in most of geotechnical engineering works. Fourteen such applications were presented by Geotechnique (1996). In this publication, Peck commented on why he published the Observational Method in 1969: *"My real interest* [with the Rankine Lecture], *instead* [of theoretical research] *was in the ways our existing knowledge could be applied more effectively."*

Dunnicliff and Deere (1991) published a number of works by Ralph Peck where the use of the Observational Method is illustrated. In the section on embankment dams in Dunnicliff and Deere, Peck points out the following provoking thoughts:

- Influence of non-technical factors on the quality of embankment dams.
- "Let's get it straight" about embankment dams (a series of statements organised in a True/False query).
- Where has all the judgment gone?

Peck also wrote a paper on the advantages and limitations of the Observational Method, also included in Dunnicliff and Deere (1991). DiBiagio (2013) presented case histories of embankment dams where instrumentation and monitoring considerably helped making decisions on the next steps. Examples of the additional knowledge and benefits of the monitoring and the Observational Method are presented in Table 1 for three Norwegian dams.

Another example where the OM approach is desirable, or even required, is the design of seepage control and drainage treatment in a dam foundation. Information gained during foundation excavation and further investigations may significantly modify and improve the original design used as a working hypothesis (ICOLD 1993).

Table 1. Benefits of monitoring program for three dams in Norway (compiled from DiBiagio 2013)

Type of dam Dam height Name Year completed	Benefits of monitoring program
Rockfill dam 77-m Moravatn Moraine core 1968	Confirmed need for rehabilitation from the high pore pressure in the dam foundation: - Drove a drainage gallery into the downstream foundation. - Installed a system of drainage and observation holes. Checked that the drainage was efficient. Checked the drop in pore pressures. Pore pressures have remained stable ever since
Rockfill dam 129m Svartevann Zoned dam Moraine core 1976	Documented satisfactory behaviour during construction and operation - Total settlement was somewhat larger than predicted. - Pore pressures in the core were measured during early construction to check stability. Pore pressures were low and allowed construction with a steeper upstream slope than originally designed. - Small leakage.
Rockfill 90 m Storvatn Inclined asphalt core 1987	Documented the deformation behaviour of asphaltic core Used the observations to calibrate the analytical models Provided useful information for future dams of this type

5 BAYESIAN UPDATING AND THE OBSERVATIONAL METHOD

There is a potential for combining the Observational Method (OM) with the Bayesian updating approach. The OM is a practical way to deal with uncertainty. Bayes' theorem provides a framework that enables updates of first estimates with new information. Bayes' theorem is the essential means of adjusting one's opinion in the light of new evidence. In fact, it is a tool made for geotechnics, as most of what geotechnical engineers do is Bayesian! Most often, the estimates of soil profiles, soil properties, model uncertainties and predictions are based on both measurements and earlier experience and engineering judgment. Bayesian thinking was, for instance, used by Alan Turing in solving the German *Enigma* code during WWII (the movie *The Imitation Game*).

Two sets of data (or predictions), in this case the mean value and the standard deviation, can be combined by Bayes theorem, assuming both datasets are normally distributed, to yield an updated estimate:

$$\mu_{updated} = (\mu_1/\sigma_1^2 + \mu_2/\sigma_2^2)/(1/\sigma_1^2 + 1/\sigma_2^2) \qquad \text{(Eq. 1)}$$

$$\sigma_{updated} = (\sigma_1^2 \cdot \sigma_2^2)/(\sigma_1^2 + \sigma_2^2) \qquad \text{(Eq. 2)}$$

where μ_1 and σ_1 are the mean and standard deviation of the first estimate (the prior), μ_2 and σ_2 are the mean and standard deviation of the measurements (the likelihood, the new knowledge), and $\mu_{updated}$ and $\sigma_{updated}$ are the updated (posterior) estimates of the mean and the standard deviation. The result is an updated average weighted by the inverse of the standard deviations.

The Observational Method and the field monitoring during dam operation could be "complemented" with a Bayesian updating formulation in the assessments. In this way, one could associate uncertainties and outcomes with probabilistic estimates (probability of occurrence and consequences) and quantify the scenarios for making decisions. A dynamic updating of the risk picture (means and standard deviations) with the help of continuous real-time measurements and prepared response scenarios would be an easy way to make designs safer and provide support for "risk-informed" decision-making.

Bayesian updating[4] has been applied to continuously update the latest knowledge of the unknown parameters with the knowledge of new observations. For dams, two examples of successful applications of the Bayesian updating approach are: (1) in an uncertainty analysis of overtopping of a flood mitigation dam, Michailidi & Bacchi (2017) improved information on the flood peaks from historical observations by incorporating supplementary knowledge from different sources, including their associated uncertainty and errors; (2) Andreini *et al* (2019) developed probabilistic models to predict the internal erosion rate in embankment dams. They did reliability analysis of earth dams in terms of the critical shear stress and a coefficient of internal erosion. The Bayesian updating approach was used to quantify the uncertainty of the uncertain model parameters on the basis of observations in situ jet erosion tests[5].

Folayan *et al* (1970) were the first to introduce the application of Bayes' theorem to geotechnical engineering. They used Bayesian updating to predict the settlements of a marshland development analysed the associated economic consequences. The approach was also used to illustrate the optimal number of samples to improve the reliability of the prediction. Figure 7 illustrates the overconfidence that can occur in prior subjective estimates of probability distributions, in this case for the compressibility of San Francisco Bay mud.

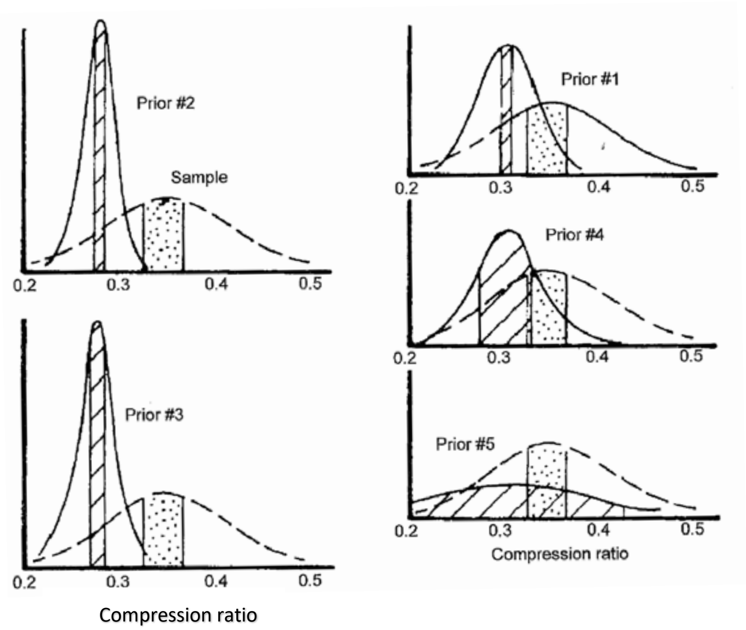

Figure 7. Subjective estimates of the compressibility of San Francisco Bay mud compared to test results (after Folayan et al 1970; Baecher 1972; Hartford and Baecher 2004).

The estimated means in each prior were lower than the measured values (sample), but more significantly, over-confidence (the prior estimates) produced distributions too narrow to encompass the measured data (Baecher 1972; Hartford and Baecher 2004).

With updated means and standard deviations, probabilistic calculations of hazards and risk can be carried out. With today's computer and modelling techniques and real-time access to display data and probabilistic evaluations, the field monitoring program would reflect the geotechnical

[4] Using Bayes' theorem, the unknown parameters can be estimated from $p(\theta \mid y) = \kappa L(y \mid \theta) p(\theta)$, where $p(\theta)$ is the prior density distribution of parameter θ; $p(\theta|y)$ is the posterior distribution with the observed information y; $L(y|\theta)$ is the likelihood function that reflects the information from n observations $y=(y_1,y_2,\cdots, y_n)$; κ is a normalizing factor.

[5] Jet Erosion tests (Hanson & Cook 2004 and Hole Erosion tests (Wan & Fell 2004) are experimental procedures to determine critical shear stress and coefficient of erosion. They have been successful in a number of soils.

engineer's ambition: a coherent combination of observations, analysis, judgment and risk-informed decision-making for optimising from both cost and safety points of view.

Folayan *et al* (1970) also concluded that application of theory of probability provides improved rationality in the evaluation of the meaning of safety factor. The Bayesian approach was also used to show that the probability of success of an engineering analysis depends on the amount and nature of the engineer's previous experience with similar problems (Fig. 7). Several areas of application of the Bayesian approach were exemplified, including applying decision theory to select a course of action. Already in 1970, Folayan *et al* concluded that a probabilistic approach provides a framework that can assist the engineer to organize, accumulate, interpret and evaluate experience, and provide complementary information for analyses under uncertainty.

6 CONCLUSIONS

The Observational Method, very early in our profession, included the aspects of uncertainty and risk in geotechnical design, by looking at the mean and the uncertainty (*"assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions"*)[6], evaluating the hazards *("calculation of values of the same quantities under the most unfavourable conditions"*) and looking at potential mitigation measures *("selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis"* and *"modification of design to suit actual conditions"*).

At the very start of the project, the Zelazny Most tailings dam did not have a plan following the principles and all the steps of the Observational Method. The planning with corrective actions, if unexpected behaviour should occur, was not done from the very start in 1975. However, as unexpected behaviour became more and more apparent in the 1990's, thanks to the instrumentation, the need for the Observational Method emerged.

One advantage of the application of the Observational Method is the planned course of action if and when unexpected behaviour, which helps solve the difficulties because the mitigation measures would have been explored and even put in place to some extent.

For the Zelazny Most ring dam, the use of the Observational Method and the stabilization measures implemented helped reduce considerably the risk of instability. The application of the Observational Method resulted in design changes and rehabilitation measures including moving the dam crest upstream to flatten the average downstream slope; constructing stabilizing berms at the dam toe; and installing relief wells in the foundation to reduce pore water pressures.

Field measurements and monitoring, coupled with Bayesian updating, together can focus on risk on the basis of observations and scenarios. A risk management strategy should integrate all aspects, with focus on communication and "lessons learned". Instrumentation and remote sensing techniques can identify and quantify geohazards and interconnectivity will allow for rapid update of hazard, vulnerability, and risk. New challenges reside in integrating remote sensing, geotechnical engineering and risk assessment and management into innovative and practical risk management tools to reduce risk associated with natural and man-made geo-hazards. The result would be a risk reduction strategy, with robust, documented and practical risk assessment and management tools.

Science and engineering help predict hazards. Knowing the hazards and the risk helps make "risk-informed" decisions, and the effectiveness can be improved with recent innovative information technology and interconnectivity.

This paper is an homage to the late Professor Ralph B. Peck and his seminal "Observational Method". Professor Peck has had a unique influence on the development of our profession and reducing the uncertainty in our predictions.

In closing, the authors wish to tell an anecdote about Professor Ralph B. Peck. When student Elmo Dibiagio discussed his PhD topic (early 1060's) with Advisor Ralph B. Peck, there was at the time rising interest in advanced numerical analysis tools. Student DiBiagio elected "numerical modelling of an unbraced open-cut excavation" as PhD dissertation topic. When the thesis was

[6] The parenthetical statement refers to the wording of the Observational Method presented at the start of the paper.

approved, Professor Peck politely told him: "No theory or mathematical model can be considered satisfactory until it has been checked by actual observations".

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