# Dams and dam safety

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# Number of dams in Norway

Number of registered dams in 2019: >4250

Number of large dams in 2019: 348

(Unregistered small dams > 3000 )

*Figures and information from Grethe Holm Midtømme and Lars Grøttå NVE*

# Dam safety concept from the Norwegian Water Resources and Energy Directorate (NVE)

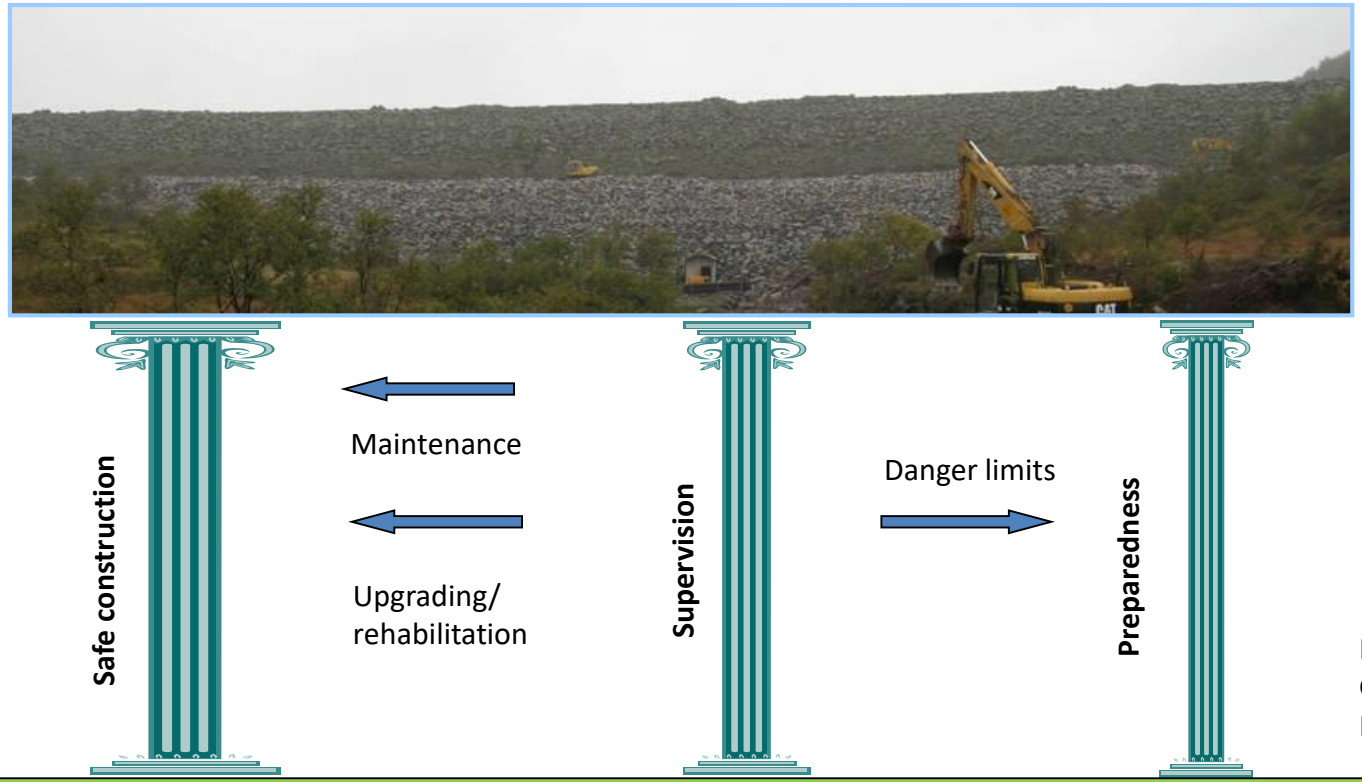
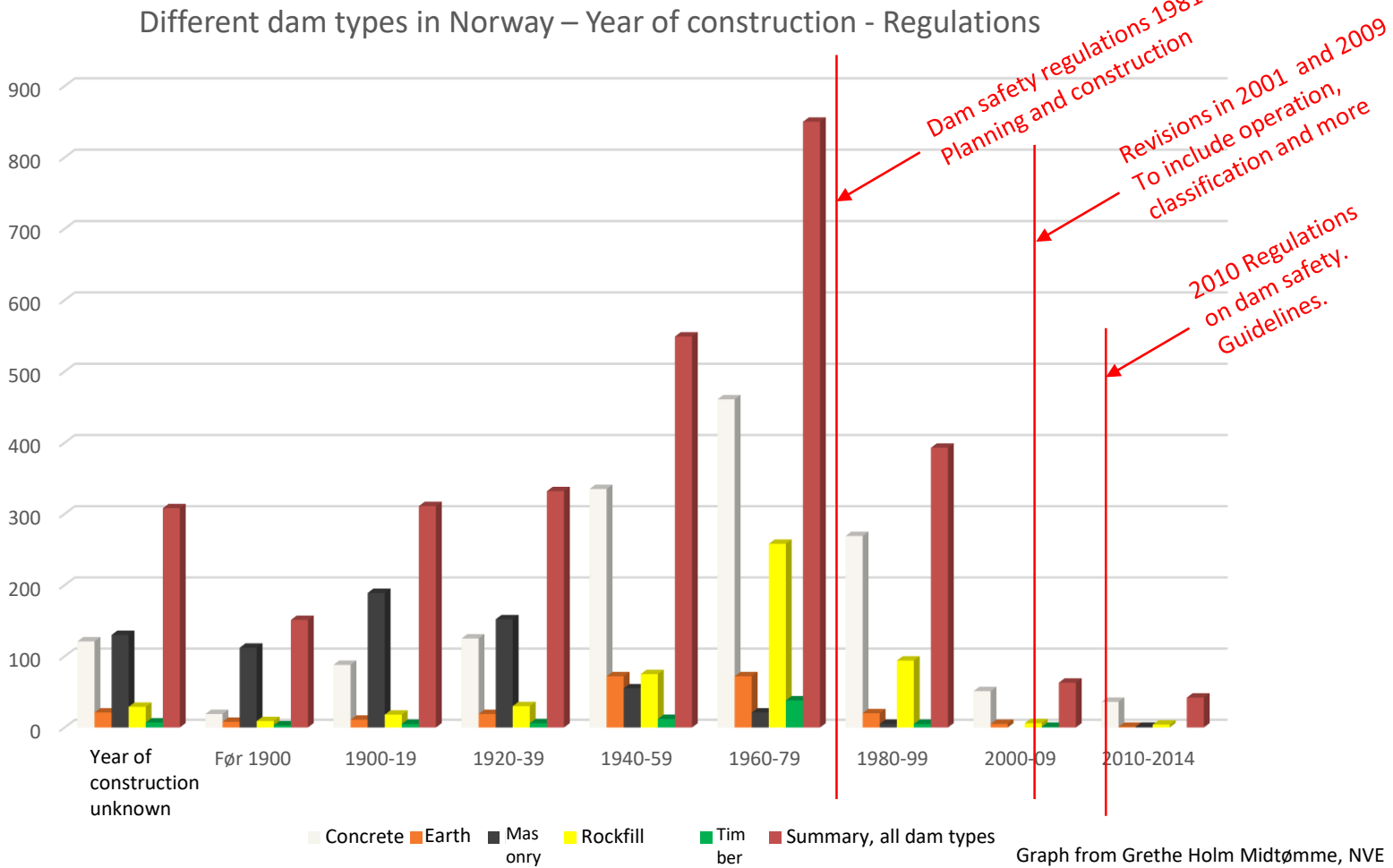



Figure from Grethe Holm Midtømme, NVE

# Classification –extra foundation

- Consequence classes provides basis for prioritizing the safety supervision of the dams along with design criteria.
- Requires a reasonable estimate of the breach opening, to obtain breach discharges for estimating inundated area downstream.




Graph from Grethe Holm Midtømme, NVE

Oldest known dam constructed in the Viking era (1028)



NTNU

# Rockfill dams

- Number of registered rockfill dams: ca 600 (ca 720)
- Highest rockfill dam: Oddatjørn (142m)


Photo fra Lars Grøttå


Photo: Agder Energi

Dam Skjerkevatn i Åseral

# WP 1 Hydropower structures
# WP1.2 Dam construction & dam safety

2 Activities=
2 PhD
students

- 2 PhD (+1+1)
- 5 MSc students directly related to the activities
- 4 MSc students on other dam related subjects

# A1.2.1 og 2: Embankment dam safety under extreme loading conditions

## A1.2.1

PhD Student: Ganesh H.R. Ravindra – *Embankment dam safety under extreme loading conditions: Dam toe*

Focus on dam toe under loading conditions resulting in overtopping of a dam with placed riprap on the downstream slope. Thus, continuation of the previous PlaF project is favoured, adding focus on the toe and effect of the toe support on the riprap failure mechanism. The factors affecting the behaviour will be studied. Additionally, the seepage through the dam and particularly in the downstream slope and abutments will be considered.

Continuity: PlaF SBED

## A1.2.2

PhD Student – Geir Helge Kiplesund
*Embankment dam safety under extreme loading conditions: Stability and breaching*

Activity A1.2.2 entails investigations into stability and breaching of embankment dam. The embankment dam studied will consider requirement in the Norwegian regulations for material zoning and structure, e.g. requiring protection of the downstream slope with placed riprap.

Continuity: SBED, PlaF, A1.2.1

(SBED: Stability and breaching of embankment dams)

Storvatn Dam
(bilde fra Tore Valstad)

# WP1.2 A1.2.1 & 2: Extreme loading conditions

Overtopping (core/damcrest) ->Breaching
Extreme leakage/throughflow

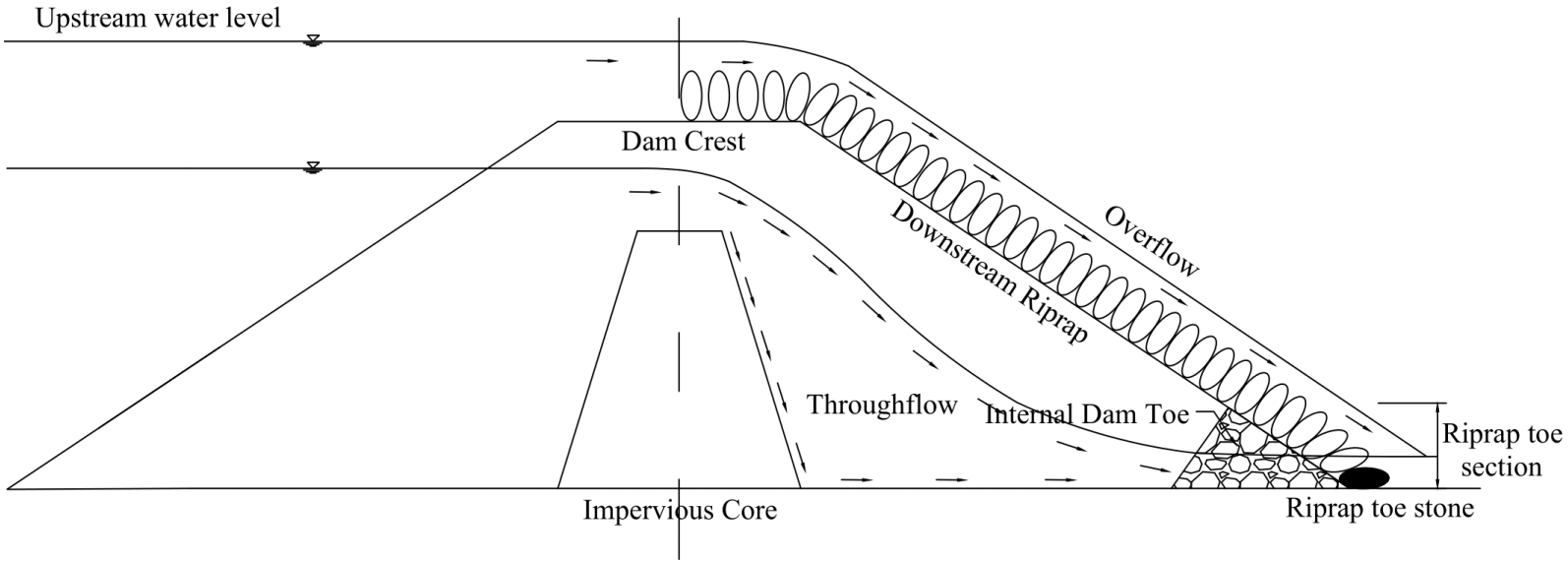
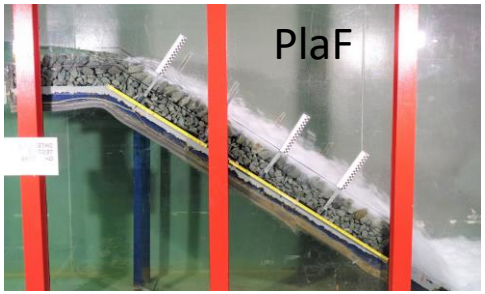



Figure from Ganesh H.R. Ravindra

NTNU
Kunnskap for en bedre verden

HydroCen
NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY




Placed riprap with toe support

Placed riprap without toe support

- Physical models
- Continuity

Rockfill dam without toe

Rockfill dam with internal toe

Rockfill dam with combined toe

Rockfill dam with external toe

Rockfill dam with placed riprap

Rockfill dam with dumped riprap

Rockfill dam with placed riprap and internal toe

# Field surveys

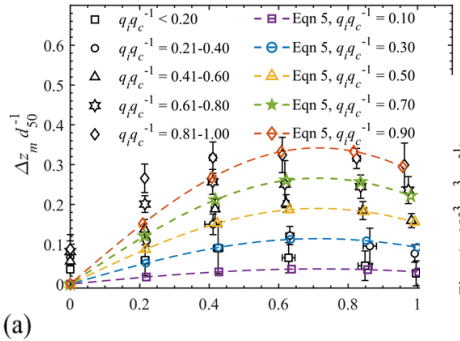
Oddatjørn dam

Akersvass dam

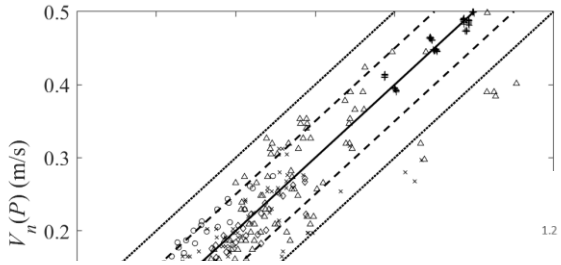
# Investigated and analysed data collected from large scale tests (2001-2003)

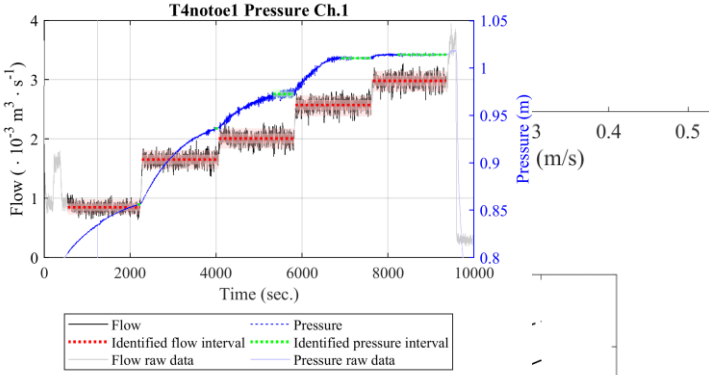
*(6 m high test dam at Rossvatn, Norway)*

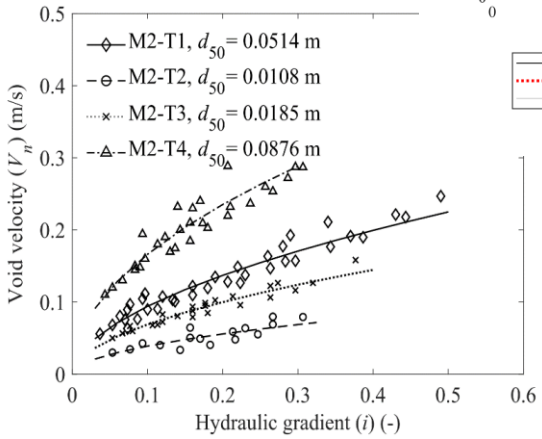
# Analysis

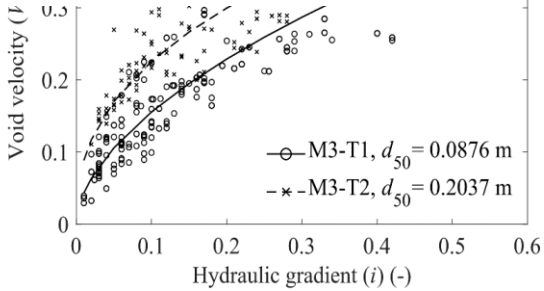



(a)

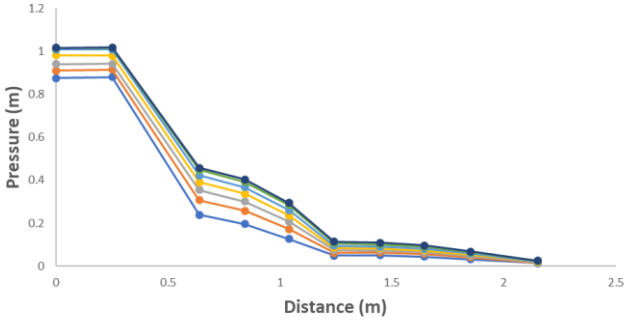


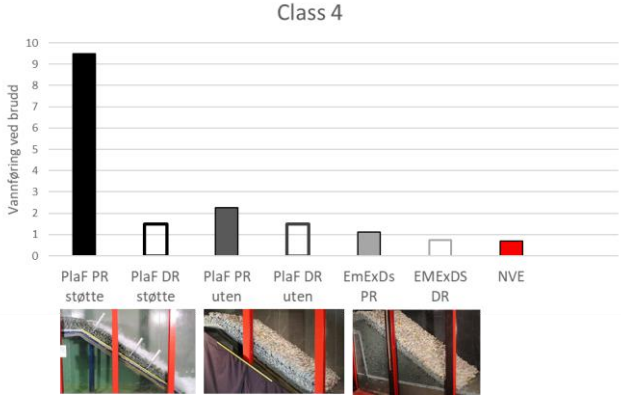




Phreatic surface development – Internal toe case



# Further research

- Further analysis of data
- Physical model of the full rockfill dam cross section.
- Larger physical model to investigate the breach opening.
- Large scale tests anticipated

New physical model to investigate breach formation

Large scale field tests anticipated

# Other projects on dams and dam safety

- Structural health monitoring of dams  (also in real time)
- Geohazards and dams (Geohazard monitoring)
- Landslides into reservoirs
- Environmental loads on embankment dams
- Fuse plugs
- Ice load in steep rivers
- Rock anchors
- Proposed project: Alkali reaction in concrete dams

# Publications


Ravindra, G.H.R., Sigtryggsdottir, F.G., Asbølmo, M.F., Lia, L., 2019a. Toe support conditions for placed ripraps on rockfill dams- A field survey. Vann.

Ravindra, G.H.R., Sigtryggsdottir, F.G., Høydal, Ø.A., 2019b. Non-linear flow through rockfill embankments. J. Appl. Water Eng. Res)

Ravindra, G.H.R., Sigtryggsdottir, F.G., Lia, L., 2019c. Buckling analogy for 2D deformation of placed ripraps exposed to overtopping. J. Hyd. Res (Accepted).

Gronz, O., Dost, B., Sigtryggsdóttir, F.G. 2019. Failure mechanism in placed riprap on steep slope with unsupported toe. Journal paper under review.

Ravindra, G.H.R., Sigtryggsdottir, F.G., Lia, L., 2018a. Evaluation of Design Criteria for Downstream Riprap of Rockfill Dams, in: Proceedings of the 26th Congress on Large Dams. Vienna.

Ravindra, G.H.R., Sigtryggsdottir, F.G., Lia, L., 2018b. Protection of embankment dam toe and abutments under overtopping conditions, in: 3rd International Conference on Protection against Overtopping, UK.

Høydal, Ø.A., Ravindra, G.H.R., Sigtryggsdottir, F.G., 2018. Stability of rockfill dams, Report: Norwegian Geotechnical Institute, Oslo, Norway.

Ravindra, G.H.R., 2018. Literature review on stability of rockfill dams under overtopping conditions, Report: Norwegian Geotechnical Institute, Oslo, Norway.

# Publications, continued


Sigtryggsdottir, Fjola Gudrun; Snæbjörnsson, Jonas Thor. (2019) Geological challenges and geohazard monitoring of a mega engineering hydropower project in Iceland. Engineering Geology. vol. 259.

Sigtryggsdottir, Fjola Gudrun; Snæbjörnsson, Jonas Thor; Grande, Lars Olav. (2018) Statistical model for dam-settlement prediction and structural-health assessment. Journal of Geotechnical and Geoenvironmental Engineering. vol. 144 (9). https://doi.org/10.1061/(ASCE)GT.1943-5606.0001916

Tessema, Netsanet Nigatu; Sigtryggsdottir, Fjola Gudrun; Lia, Leif; Jabir, Asie Kemal. (2019) Case Study of Dam Overtopping from Waves Generated by Landslides Impinging Perpendicular to a Reservoir's Longitudinal Axis. Journal of Marine Science and Engineering. vol. 7 (7). 221; https://doi.org/10.3390/jmse7070221

Tessema, N.N.; Sigtryggsdóttir, F.G.; Lia, L.; Jabir, A.K. (2020) Physical model study on discharge over a dam due to landslide generated waves. *Water* 2020, *12*(1), 234; https://doi.org/10.3390/w12010234

Sigtryggsdóttir F.G., Snæbjörnsson J.T. (2019) Systematic Methodology for Planning and Evaluation of a Multi-source Geohazard Monitoring System. Application of a Reusable Template. In: Proceedings of the International Conference on Earthquake Engineering and Structural Dynamics. ICESD 2017. Geotechnical, Geological and Earthquake Engineering, vol 47. Springer, Cham https://doi.org/10.1007/978-3-319-78187-7_29

Sigtryggsdóttir, FG, Pálmason, PR, Hákonardóttir, K., Atladóttir, A, Hrafnsdóttir, H og Káradóttir, ÓR (2019). Design of fuse plugs in earth-rockfill dams in Iceland. Proceedings of the XVII ECSMGE-2019. Reykjavík, Ísland.

# Final remarks

- There is a need to investigate the Norwegian rockfill dam design considering extreme load conditions, throughflow and overtopping. In this the following is investigated.
  - Requirements of downstream protections with placed riprap
  - Requirements for the downstream dam toe.
  - Breach formation and discharge.
- The ongoing research in HydroCen has favored continuity of previous research project on rockfill dams in Norway.
- Other research projects relating to dams and dam safety are also ongoing at NTNU or planned in the near future.


Thanks for your attention

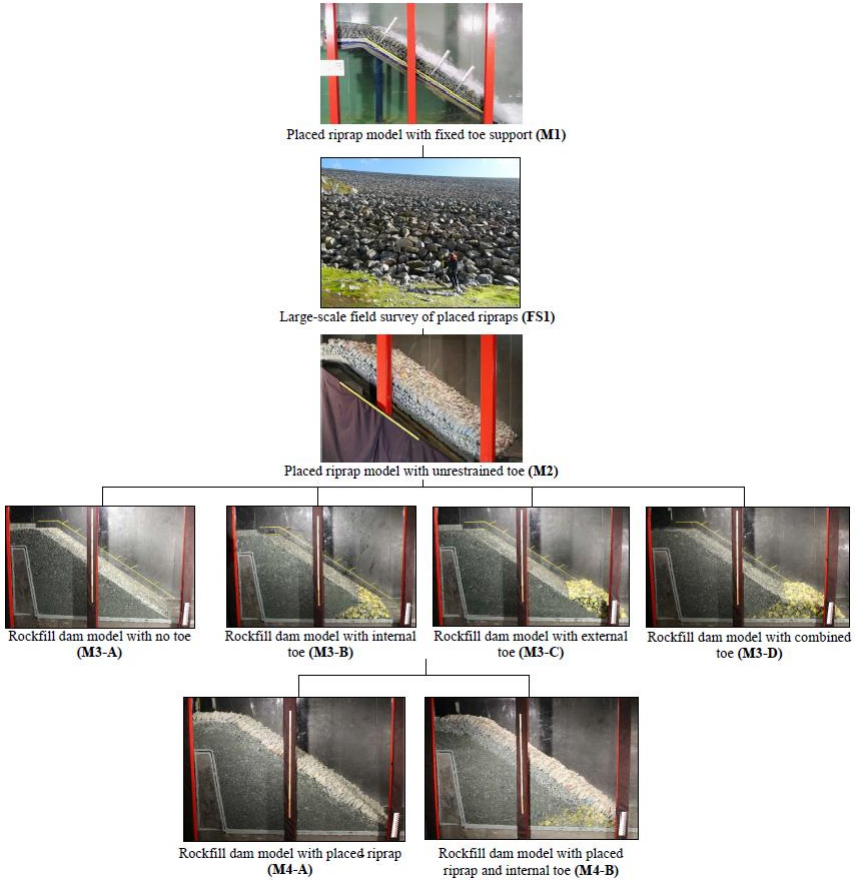



Figure from Ganesh H.R. Ravindra