Anil Chopra Retirement Symposium

Ferc Arch Dam Guidelines

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Federal Energy Regulatory Commission

Division of Dam Safety and Inspections

Dam failures are the result of a critical weakness or flaw that was overlooked, or a loading condition that was not anticipated.

Dams under FERC jurisdiction are checked repeatedly for ability to withstand extreme flood events and earthquake events. This kind of loading IS anticipated.

BLINDSPOTS:

Miss-operation of spillway gates.

Electrical Mechanical failure.

Gee, that’s never happened before.

Underscores the importance of the FERC Potential Failure Mode Analysis requirement.

RECENT FAILURES AND NEAR FAILURES

1987 Morris Sheppard Dam Downstream Sliding:

-Weak clay layer under buttresses, charged with reservoir pressure, provided ideal sliding plane.

1995 Folsom Dam Taintergate failure:

-Trunnion friction not anticipated

-Gate arms were slight with minimal bracing

2005 Taum Sauk

-Upper reservoir had no emergency spillway

-Potential for over pumping never considered

2011 Thomson Power Canal Failure:

-Power canal was regulated by upstream gate structure

-Canal embankment elevation lower than that of the dam

-Possibility of gate structure overtopping combined with loss of power house discharge never anticipated

2014 Wanapum Crack:

-Nominal (30psi) tensile strength required on lift joints

-Thermal stresses not considered

2016 Oroville Spillway

-Spillway chute designed for rock foundation

-Portions of spillway were on soil

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What we are really saying here in all these examples is that the governing failure modes had not been identified.

Without a failure mode in the back of your mind:

- Instrument readings will be misinterpreted or ignored
- Inspections will be focused on the wrong things
- Analyses will be aimed at answering all the wrong questions

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WHEN IS BRUCE GOING TO START TALKING ABOUT ARCH DAMS?

Chapter 11 Arch Dam Guidelines Rewrite - Overview of Changes

New (2017)	Old (1999)
Potential Failure Mode Driven	Analysis Driven
Acceptance Criteria in the context of failure modes	Acceptance criteria was a table of allowable stresses
Large emphasis on abutment stability, rock wedge stability, and erosion	Large emphasis on the finite element method and stress within the body of the dam
When analysis is required, non-linear analysis is advocated	Guidance was almost exclusively on linear elastic analysis
100 pages	175 pages

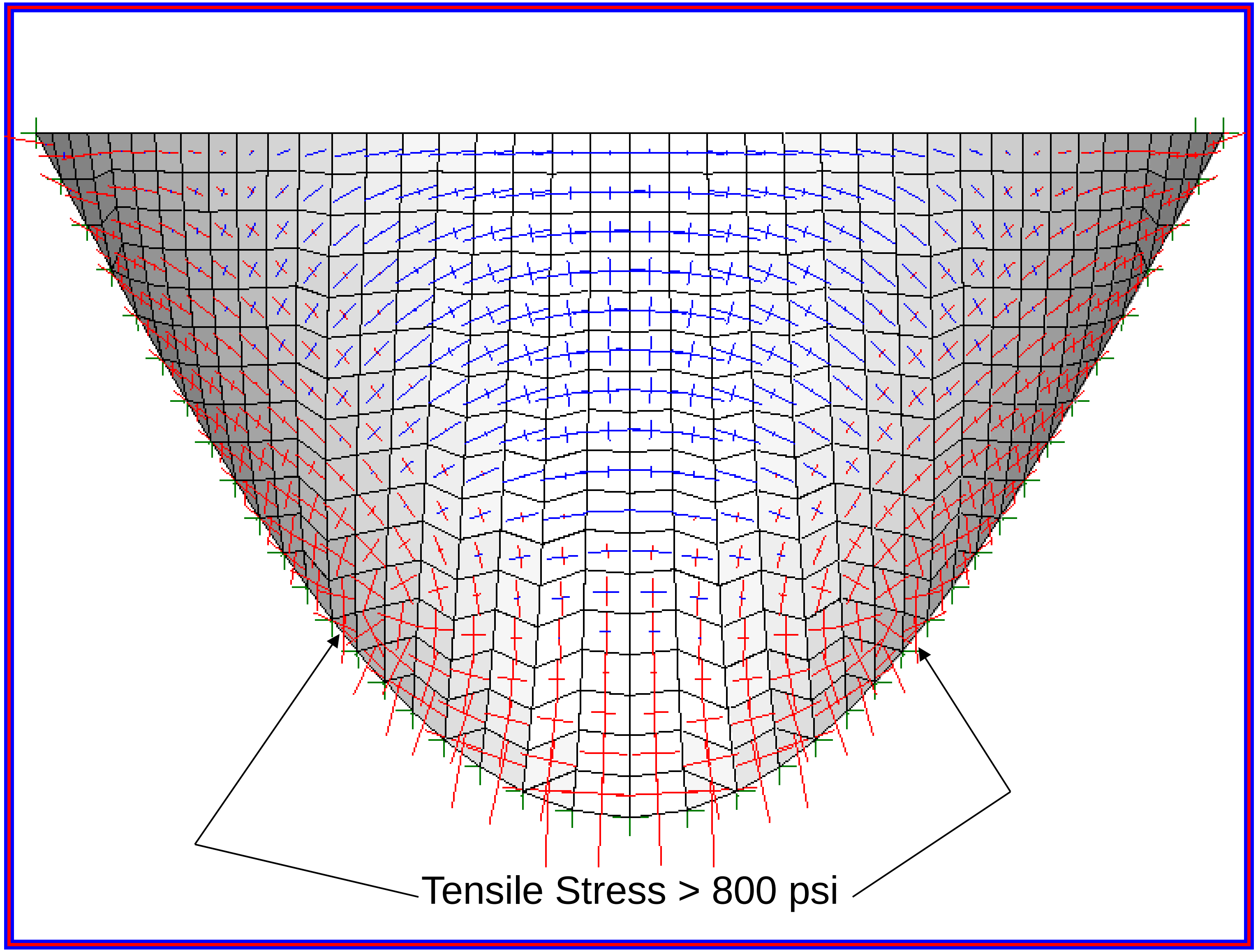
OLD GUIDELINE

Table 11-1.1 Factors of Safety for Existing Arch Dams

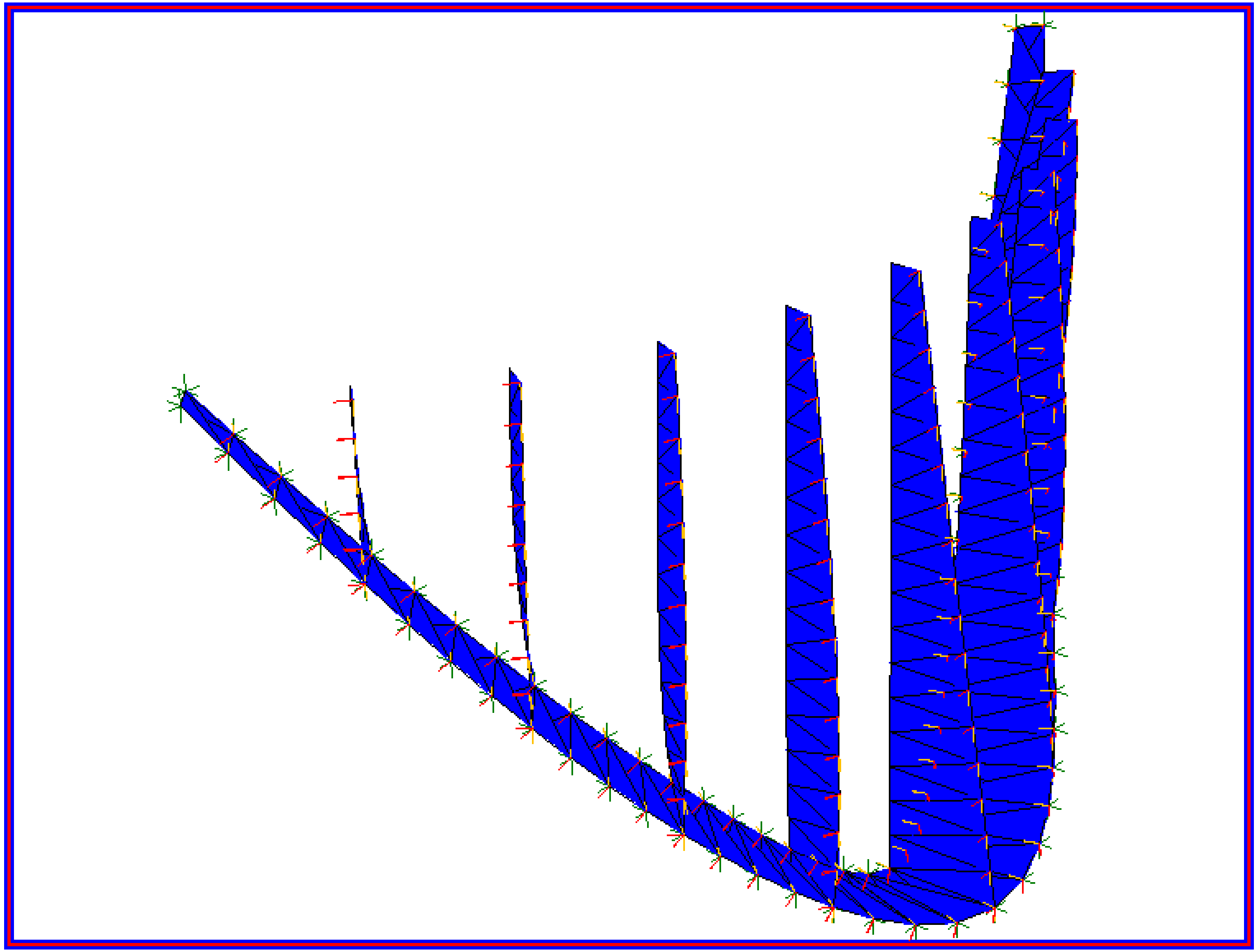
Loading Combination	Compressive Stresses	Tensile Stresses	Internal Shear Stresses	Sliding [1] Stability
Usual (normal operating)	2.0	1.0	2.0	1.5
Unusual (flood condition)	1.5	1.0	1.5	1.5
Extreme (seismic)	1.1	1.0	1.1	1.1

[1] Factors of safety valid for the assumption of no cohesion.

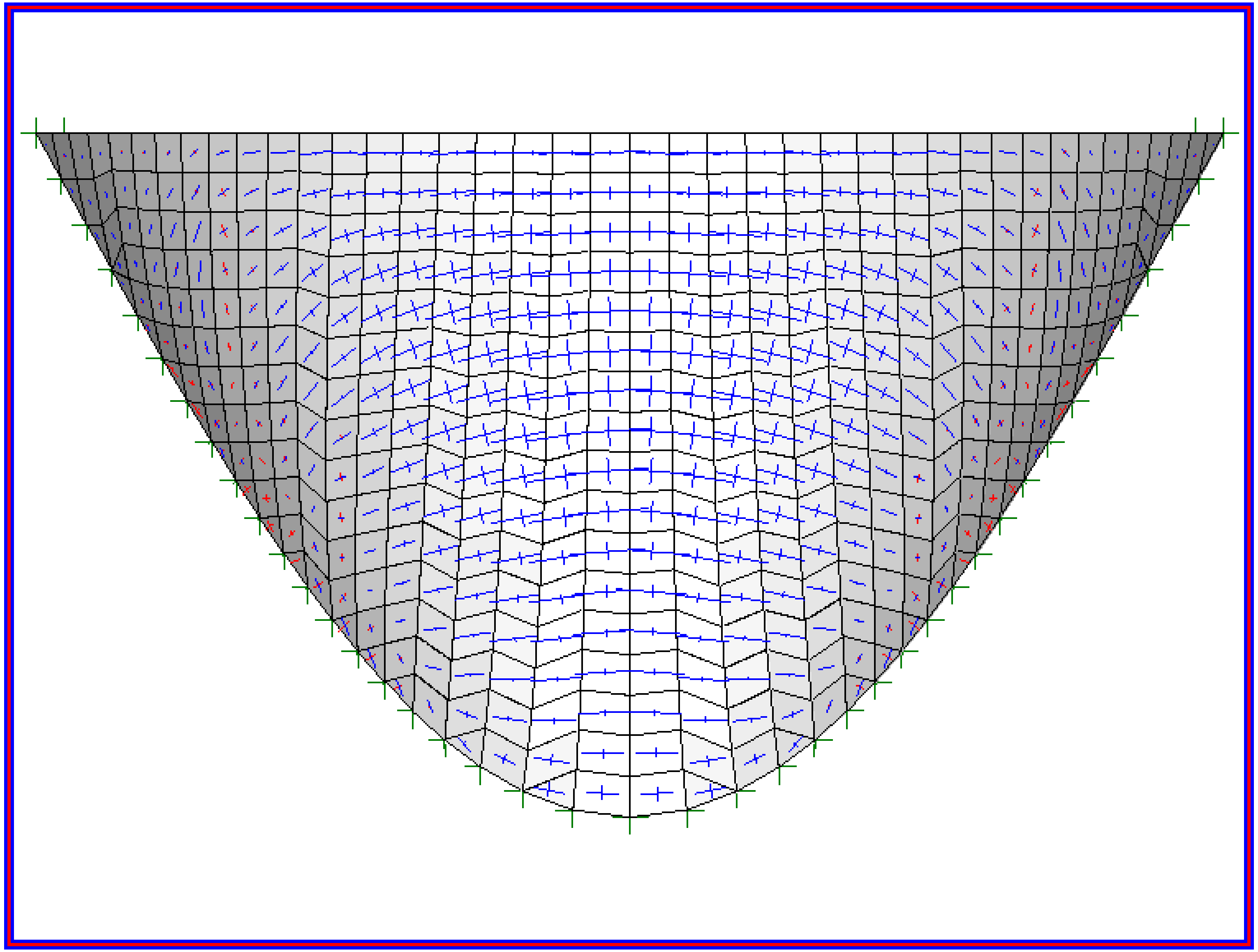
Arch Dam Behavior Linear Elastic, Crack Free 25° Temp Decrease Upstream



Arch Dam Behavior Non-Linear



Arch Dam Behavior Non-Linear 25° Temp Decrease



OLD GUIDELINE

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NEW GUIDELINE

11-1.1 Purpose

The intent of this chapter is not to mandate new analyses and investigations regardless of whether or not they are needed. Rather, the variety of issues addressed and computation methods put forward are an attempt to anticipate the variety of problems that could be encountered. This chapter should not be interpreted as requiring every test, analysis, and investigation that it describes at every dam. It may well be that for a given dam, specific failure mechanisms suggested in this chapter are not pertinent. Analysis should always be directed at evaluating the viability of potential failure modes. **If there are no failure modes of concern, then no analysis is necessary.**

11-1.4 Evaluation Criteria

Evaluation of safety involves the identification of all possible failure modes, and then demonstrating through engineering principles that the failure modes are not credible. For explanation of the potential failure mode analysis (PFMA), see Chapter 14 of this guideline.

LOADS ON DAMS

2 BASIC TYPES:

Follower Forces Capable of Doing Work	High Frequency Dynamic Forces or Forces Relieved by Slight Motion
Gravity	Seismic
Reservoir/Hydrostatic	Thermal
Active Earth	Passive Earth
Uplift	AAR
Ice/Debris Impact	Ice Expansion

Only Follower Forces can fail a structure, However other forces can cause damage making it easier for follower forces to fail a structure.

NEW GUIDELINE

11-4 LOADING

Loads can be categorized into two basic types; static and dynamic. Static loads are sustained loads that do not change, or change slowly compared to the natural periods of vibration of the structure. Static loads can be further divided into follower and non-follower loads. Follower loads are loads that do not change due to the dam's deflection. Examples of these are gravity and hydraulic pressure. Because follower loads can follow the dam's deflection, they have the ability to do work. Non-follower loads are loads that are relieved by dam deflection and therefore cannot do work. Examples of these are thermal or AAR expansion, and loads due to thermal expansion of ice.

Dynamic loads are transitory in nature. They are typically seconds or less in duration. Because of the speed at which they act, the inertial characteristics of the dam as well as its stiffness affect the dam's behavior. Examples of dynamic loads include earthquake-induced forces, blast-induced forces, fluttering nappe forces, or forces caused by the impact of ice, debris, or boats. Because of their short duration, and in the case of earthquake constant reversals, they cannot do work.

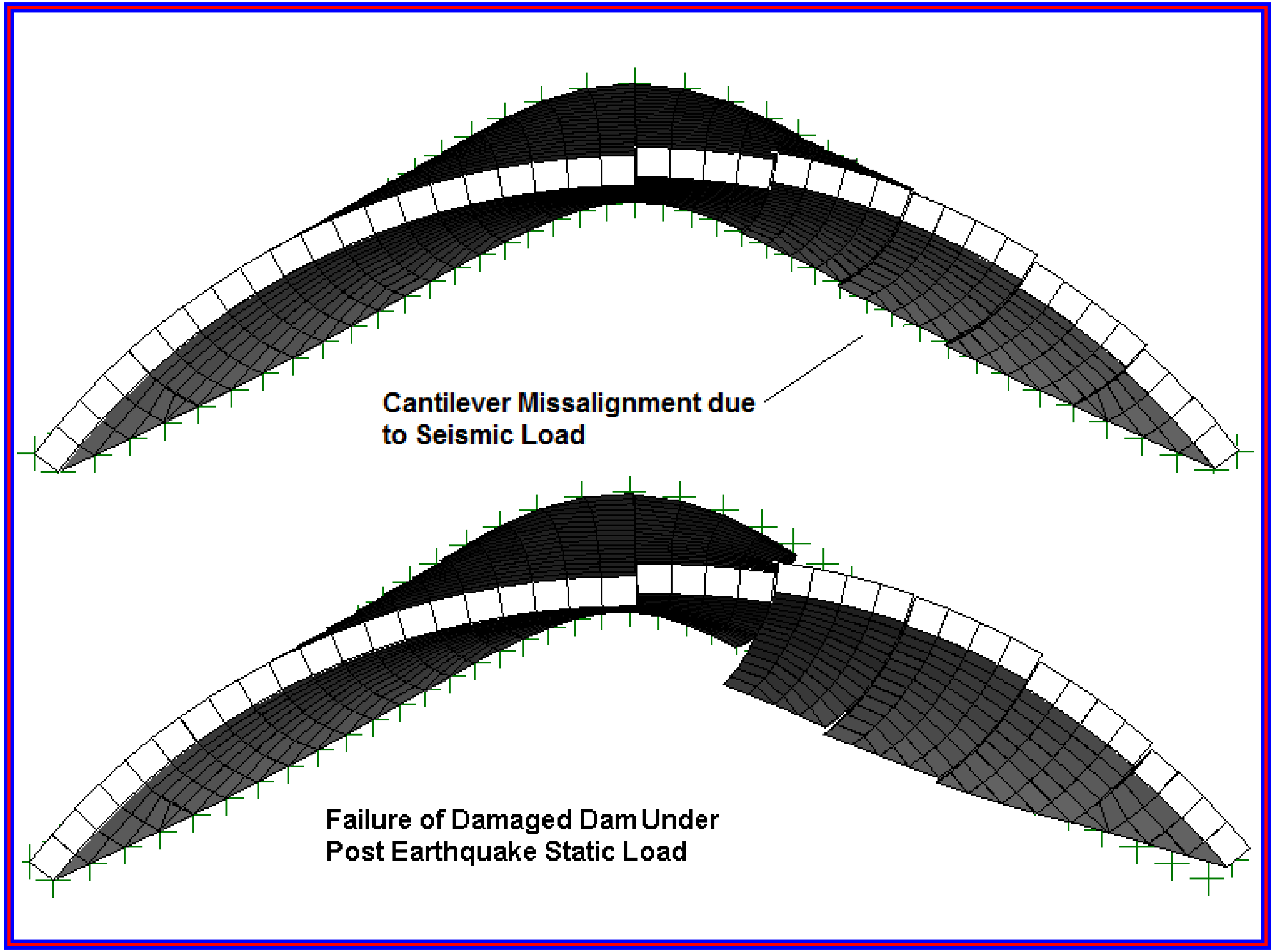
NEW GUIDELINE

Event Tree Process:

- Severe seismic shaking causes opening of vertical contraction joints and a set of large cracks near the foundation approximately parallel to it.

-Misalignment of cantilevers is such that arch action is no longer present over large areas of the dam.

-In damaged state, static reservoir loads produce enough movement of now free cantilevers that the dam fails.



NEW GUIDELINE

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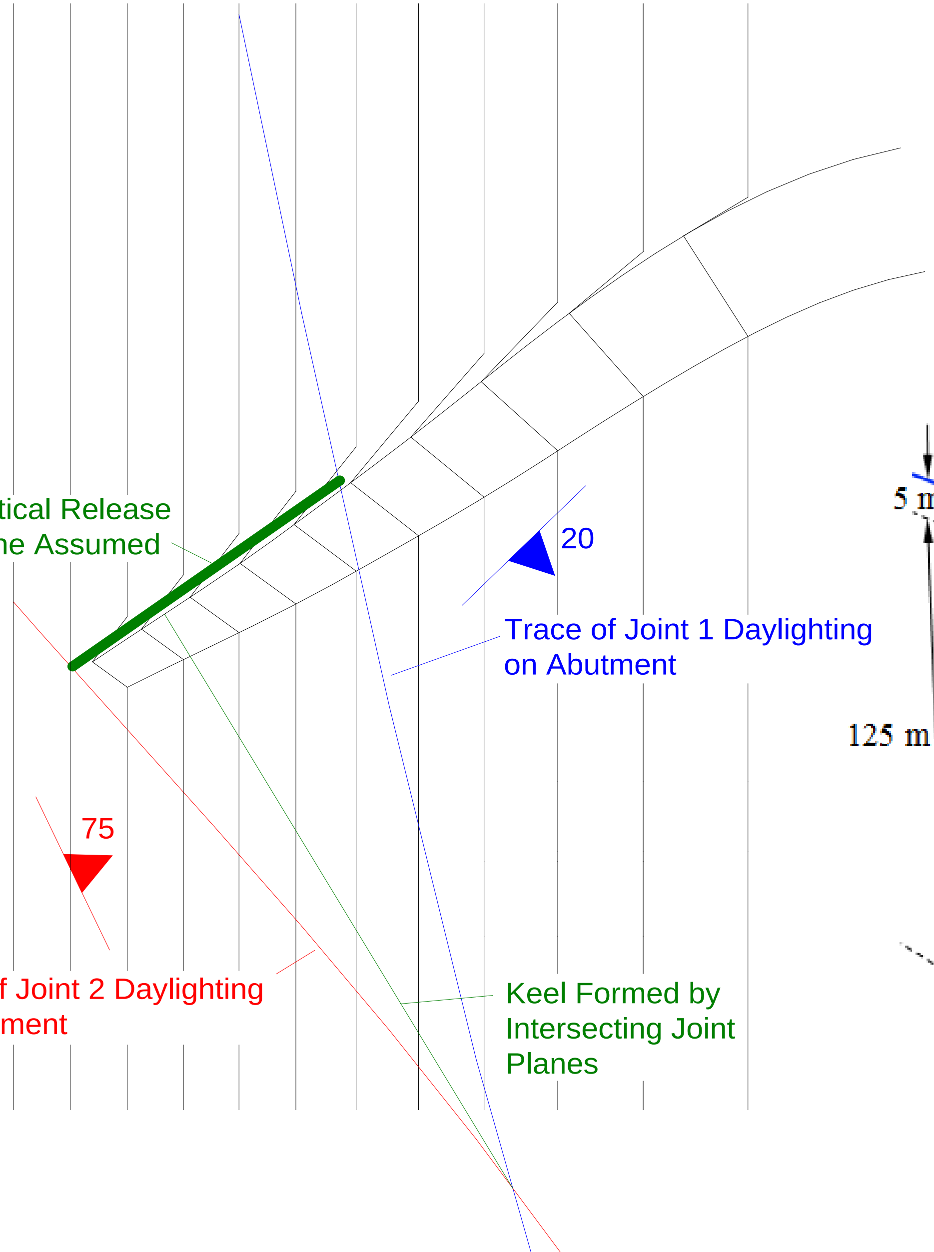
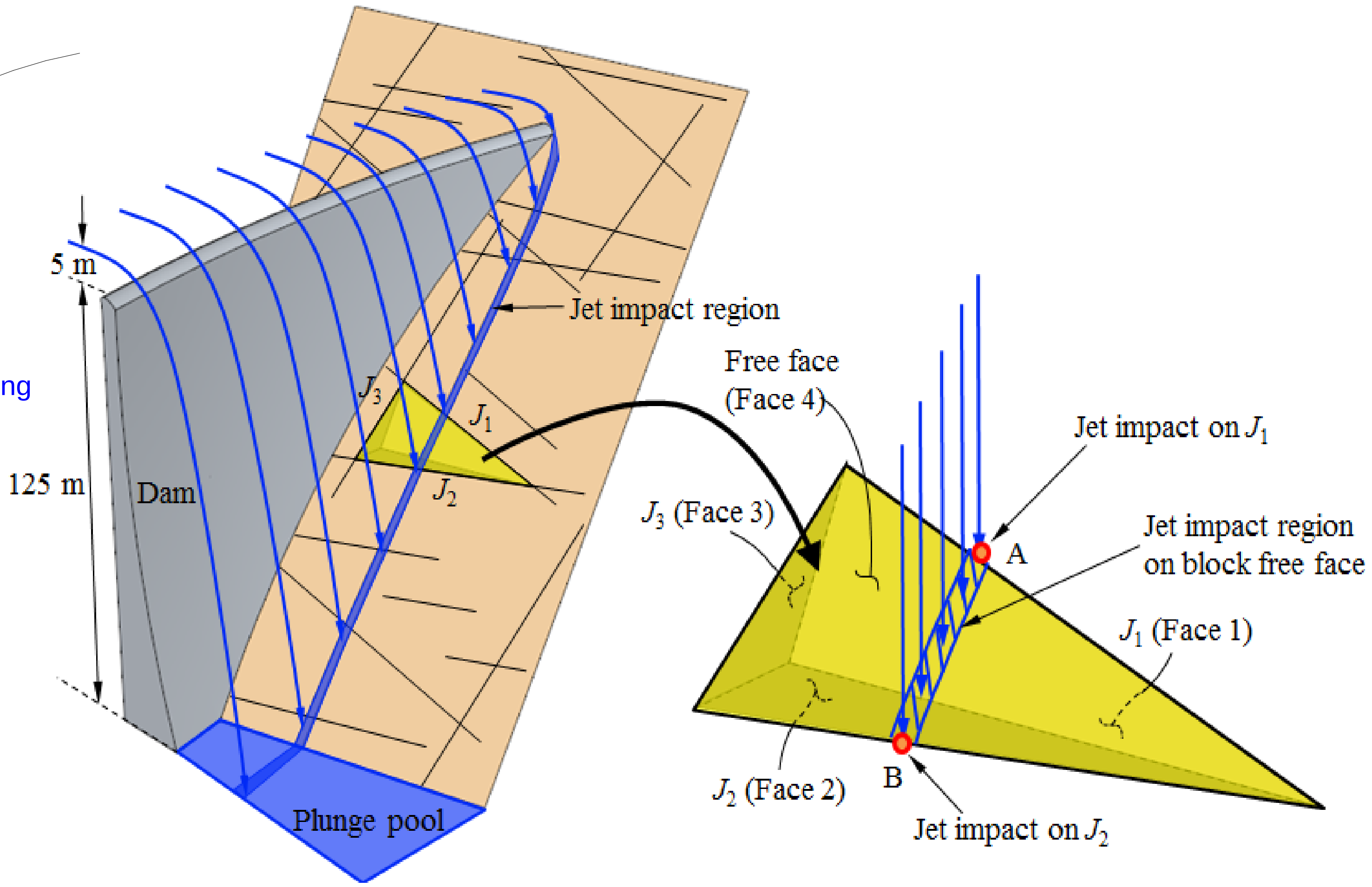


Rock Erosion (Dr. George Annandale)



https://www.ferc.gov/industries/hydropower/safety/guidelines/eng-guide.asp

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Questions?
¿Preguntas?