

# **ARCH DAM GEOMETRY GENERATOR & DAM APPLICATION**

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dePouplana I., Oñate E.

International Center for Numerical Methods in Engineering (CIMNE)

# Overview

## DAM GEOMETRY

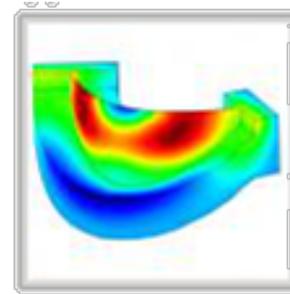
DaGGer

 Dam  
Geometric  
Generator



## NUMERICAL SIMULATION

Dam Application



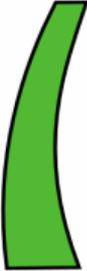
**KRATOS**  
MULTI-PHYSICS 



# Overview

## DAM GEOMETRY

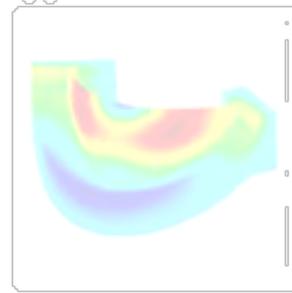
DaGGer

 Dam  
Geometric  
Generator



## NUMERICAL SIMULATION

Dam Application



KRATOS  
MULTI-PHYSICS 



# *What is a dam?*

It is a **wall to hold back water** forming a **reservoir**



Almendra dam, Spain

# *What is an arch dam?*

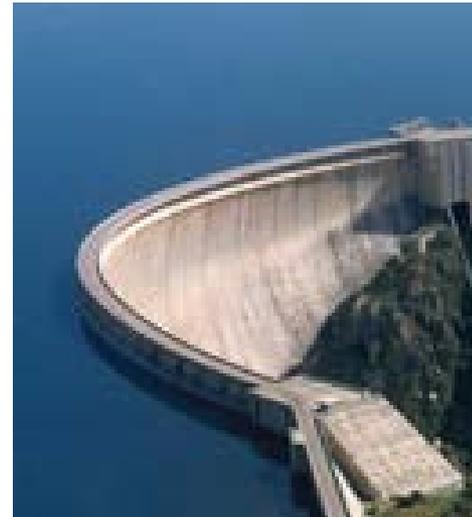
It is a **concrete** dam with **curved shape**

**Straight dam**



Itoiz dam, Spain

**Arch dam**



Almendra dam, Spain

## *What is an arch dam?*

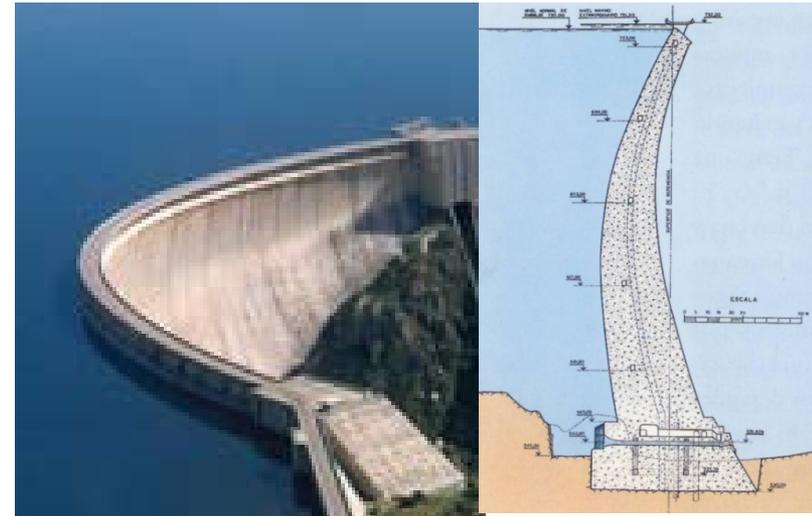
It is a **concrete** dam with **curved shape** that allows defining **thinner sections** than straight dams and **saves concrete**

Straight dam



Itoiz dam, Spain

Arch dam



Almendra dam, Spain

## What is an arch dam?

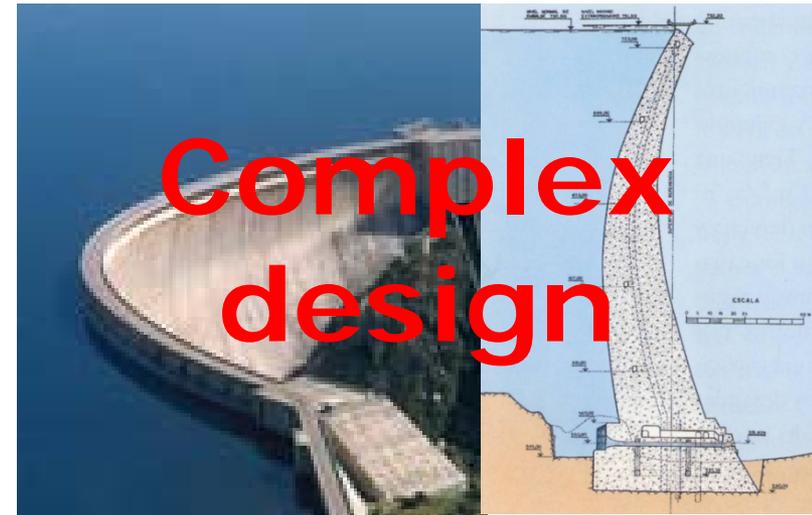
It is a **concrete** dam with **curved shape** that allows defining **thinner sections** than straight dams and **saves concrete**

Straight dam



Itoiz dam, Spain

Arch dam



Almendra dam, Spain

## *Why are arch dams complex?*

- The **dam shape** that minimizes concrete stress **depends on** the **geology of the foundation** and the **valley shape**.
- Each dam has **its own design**



El atazar dam, Spain

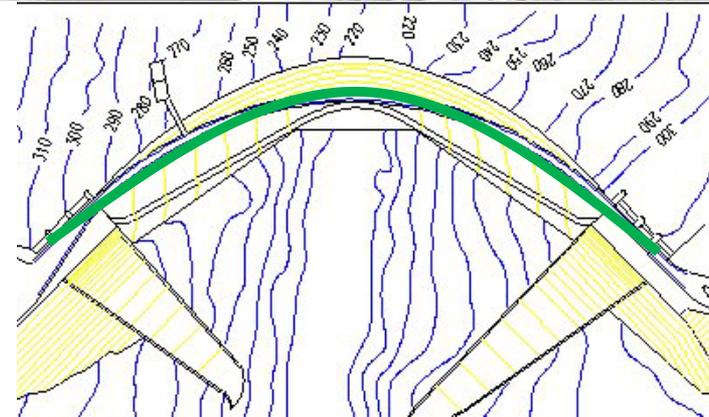
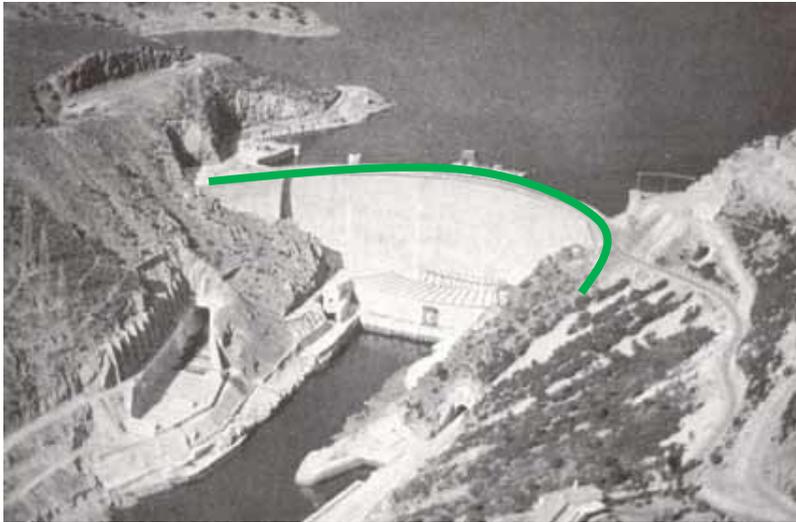


Gordon dam, New Zeland

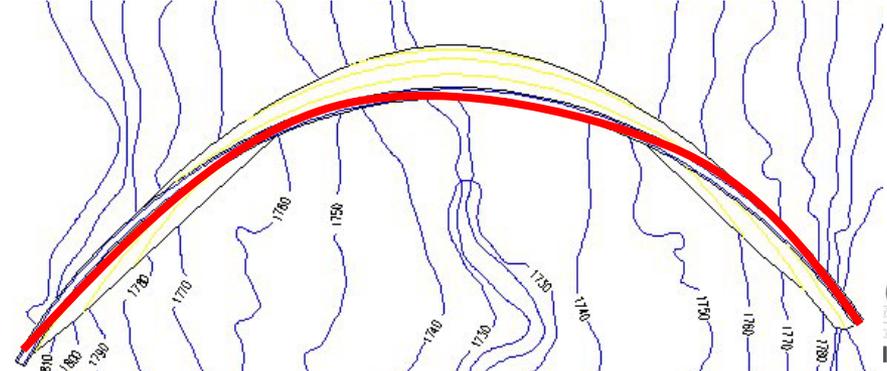
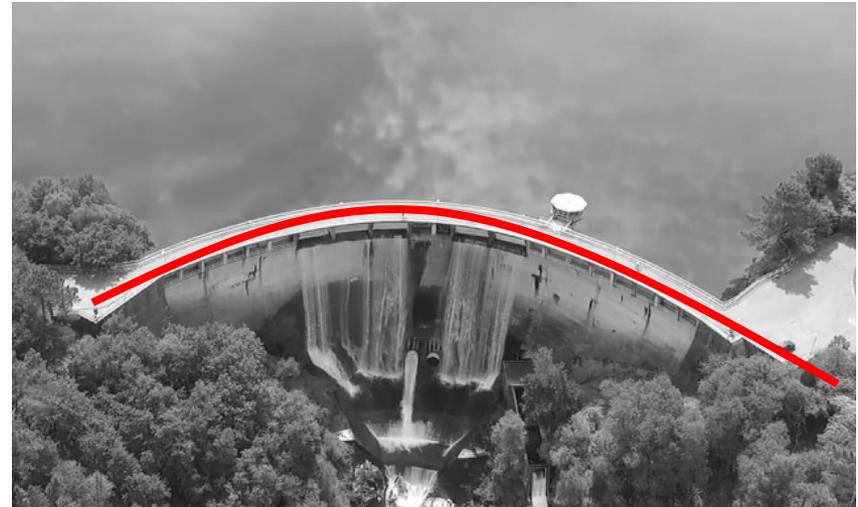
## Why are arch dams complex?

- Each dam has **its own curvature**

Belesar dam, Spain



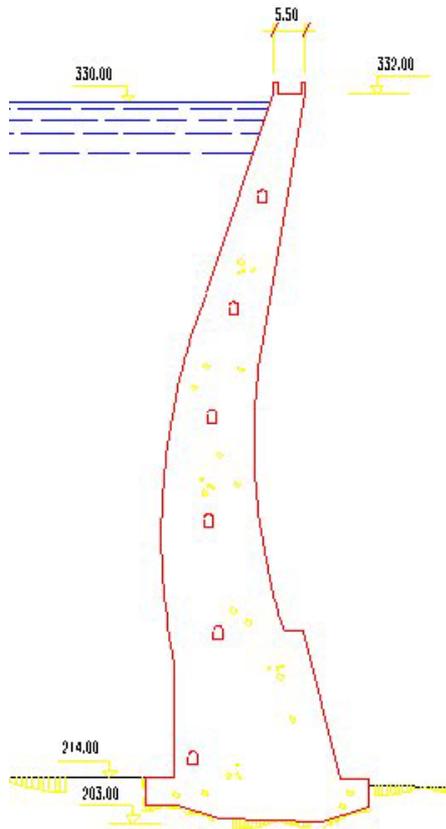
Eirás dam, Spain



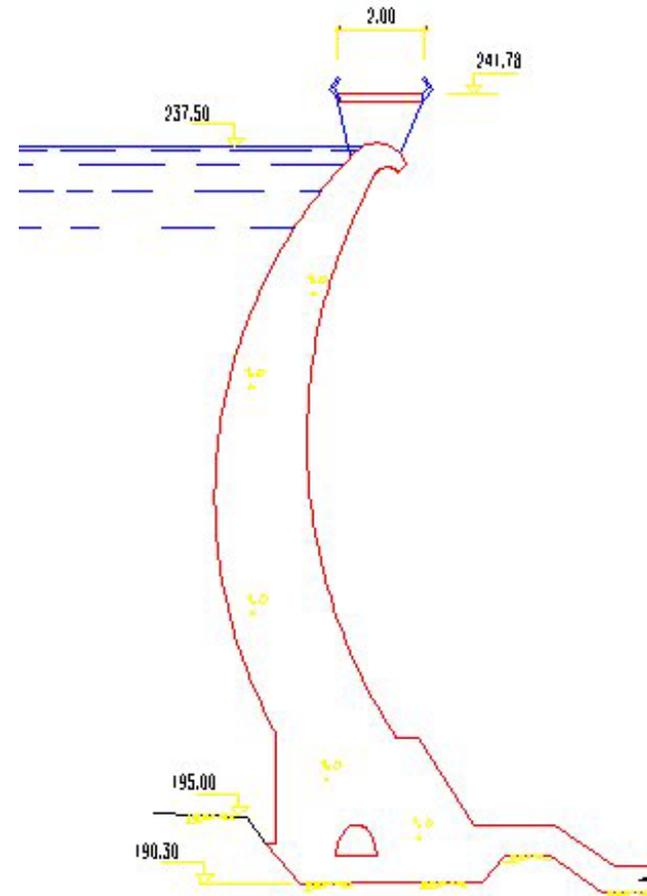
## Why are arch dams complex?

- Each dam has **its own cross section**

Belesar dam, Spain

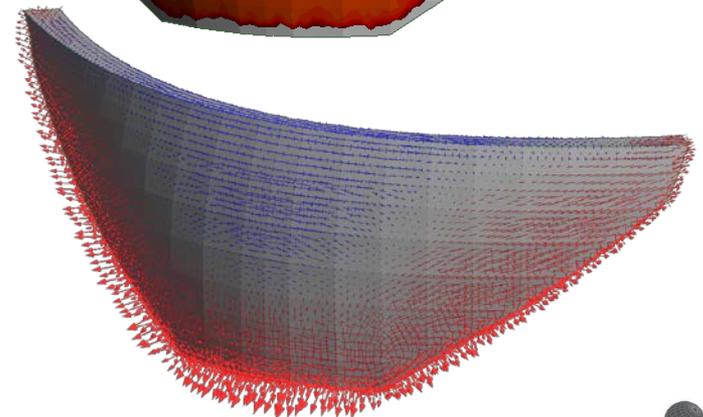
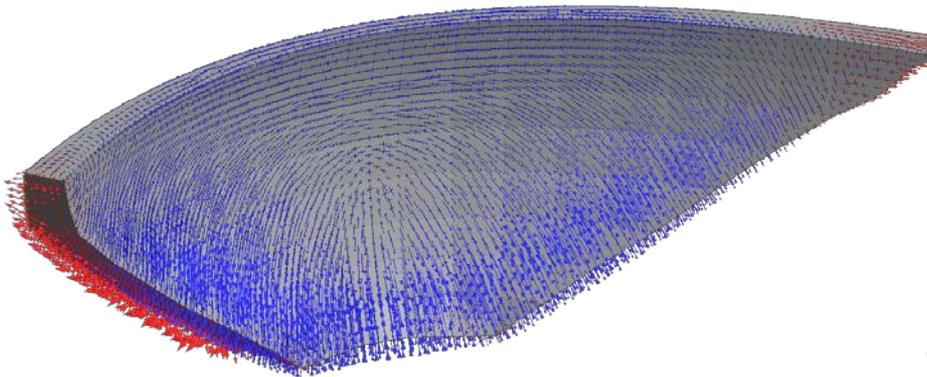
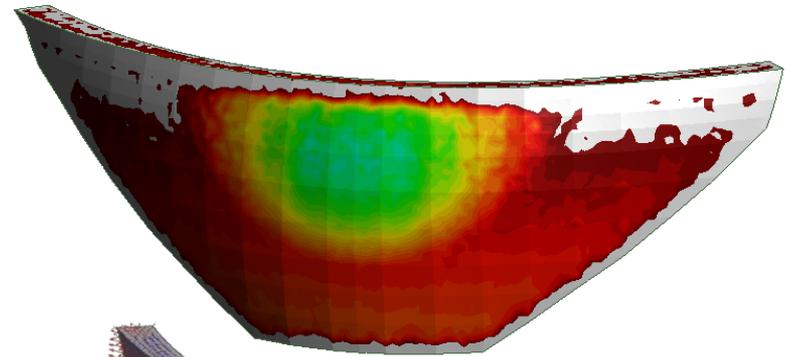
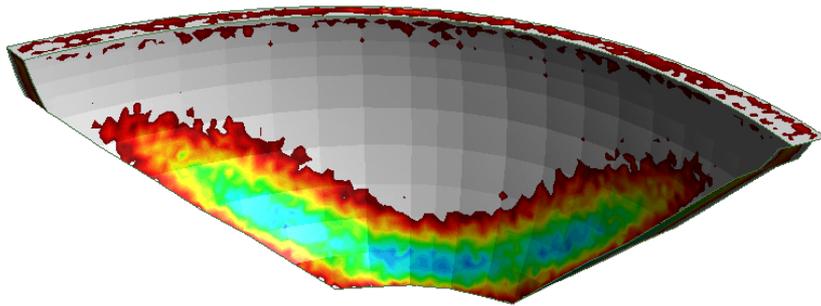


Eirás dam, Spain



## Why are arch dams complex?

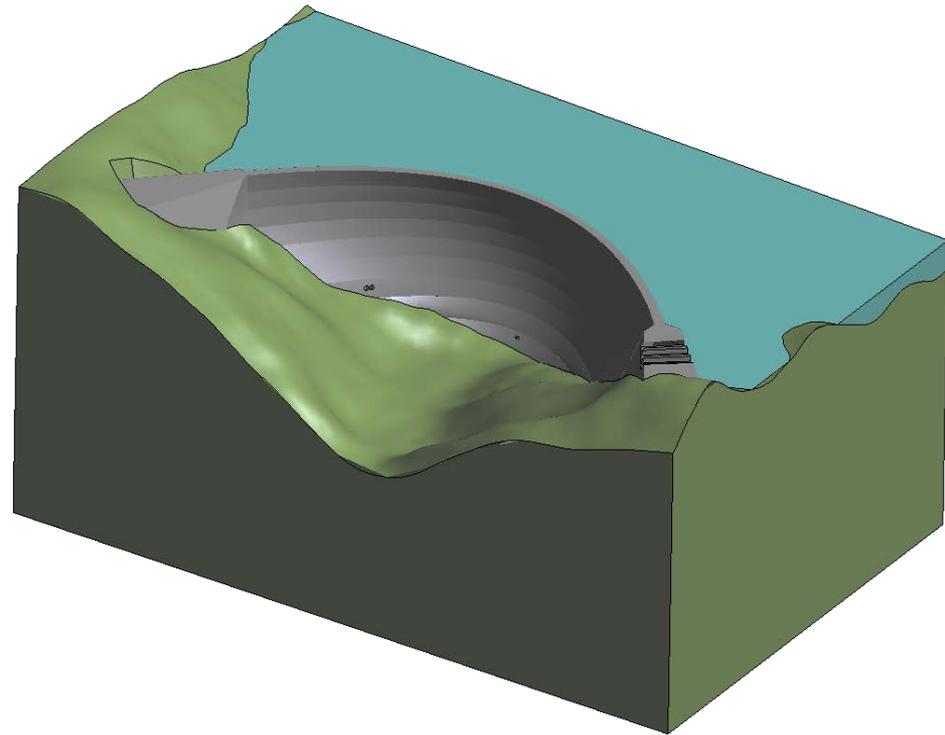
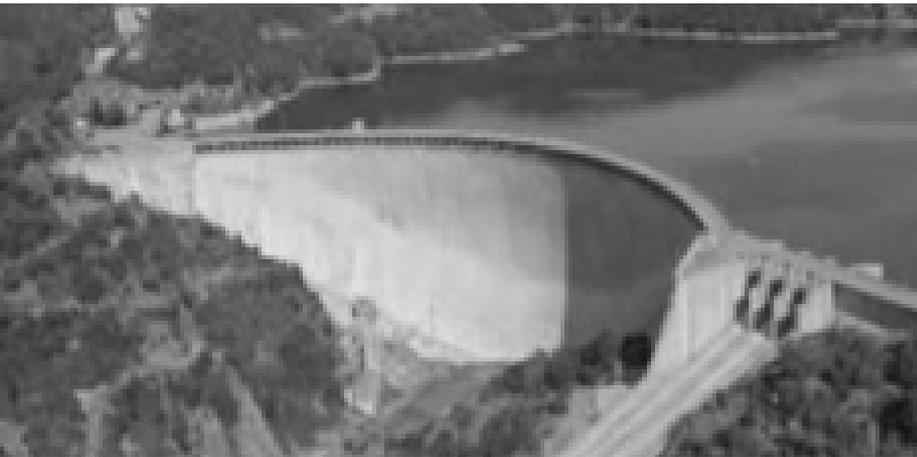
- Each dam needs **specific numerical simulations** to ensure a proper behavior.



Baserca dam, Spain

## *Why are arch dams complex?*

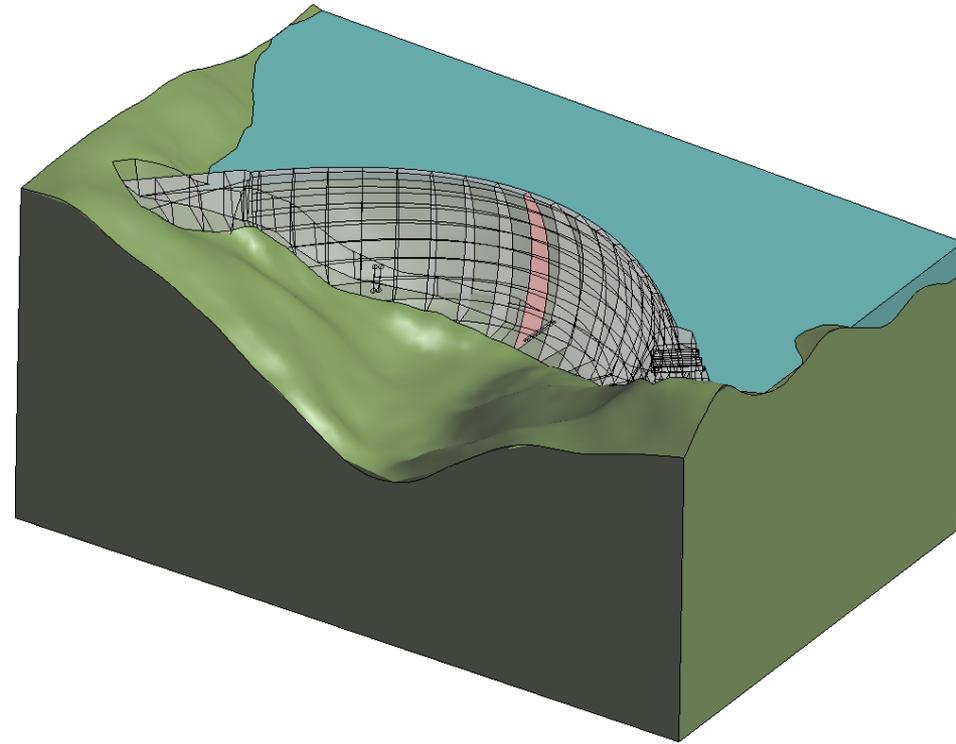
- The definition of a **3D model** is a **hard issue**



La Baells dam, Spain

## *Why are arch dams complex?*

- The definition of a **3D model** is a **hard issue**

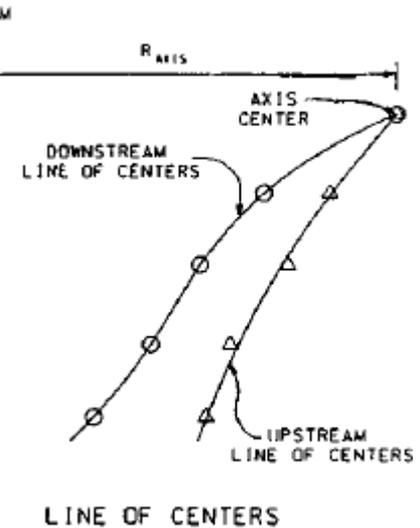
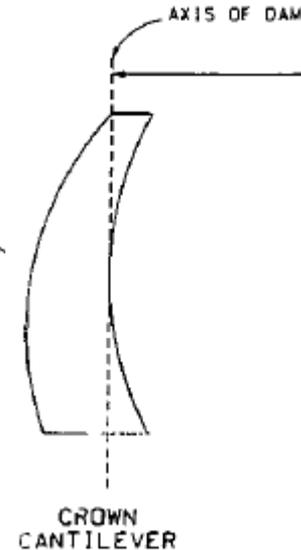
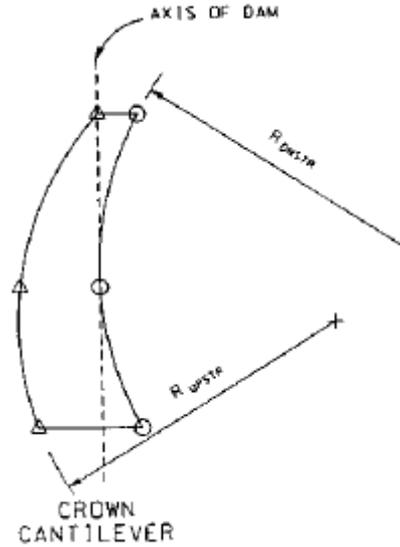
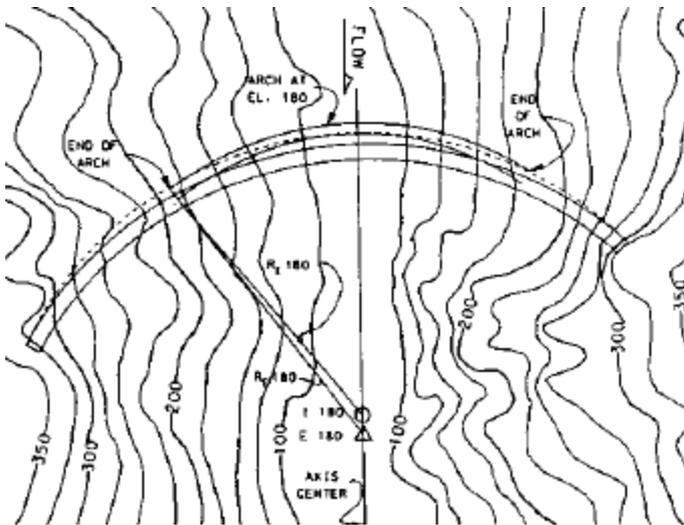


La Baells dam, Spain

## How can we design arch dams?

### ➤ USBR method (1977)

Curvature and cross sections are defined by circular arch in a **manual trial-error process** to obtain the final design

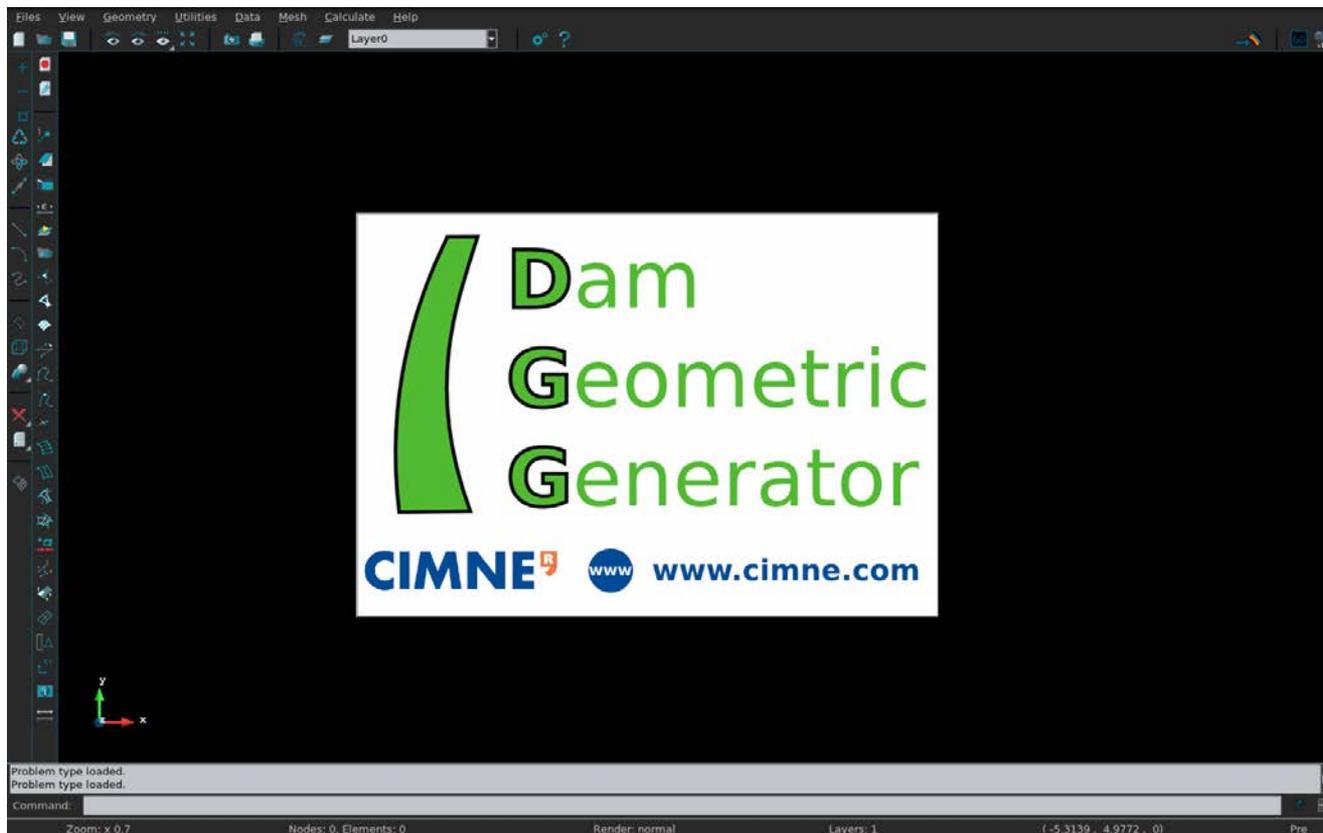


$$v = 0.000002H^2L_2 \frac{(H + 0.8L_2)}{L_1 - L_2} + 0.0004HL_1 [H + L_1]$$

## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

Interactive tool based on GiD for automatic designing of arch dams, and definition of 3D models in a few steps.



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

**Dam Geometric Generator**

Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

**Topography**

Select interval between contour lines and press load.

Contour lines interval (m) 5 1.- Load

**Placement**

Select on GiD window focus and vertex of parabola.

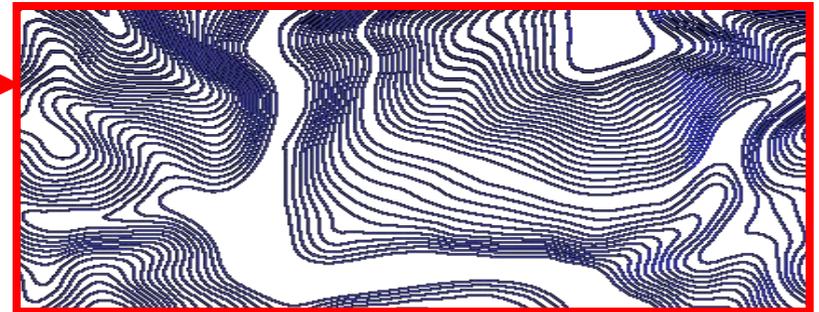
Crest level (m) 565.00  
Initial excavation of crest (m) 4.00  
Riverbed excavation (m) 9.00

2.- Create parabola

The screenshot shows the software interface for the 'Topography' step. It features a 'Contour lines interval (m)' dropdown menu set to '5' and a '1.- Load' button. Below this is a preview window showing a topographic map with contour lines. The 'Placement' section below has three input fields for 'Crest level (m)' (565.00), 'Initial excavation of crest (m)' (4.00), and 'Riverbed excavation (m)' (9.00), along with a '2.- Create parabola' button. A red box highlights the 'Topography' section, and a red arrow points from it to the topographic map on the right.

### ➤ Step 1A

Creation of topography from a DTM list of points



## How can we design arch dams?

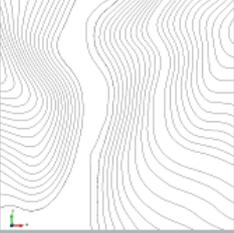
### ➤ DaGGer (Dam Geometric GenERator)

**Dam Geometric Generator**

Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

**Topography**

Select interval between contour lines and press load.



Contour lines interval (m)

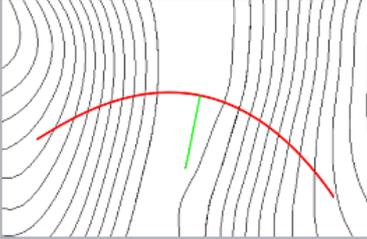
**Placement**

Select on GiD window focus and vertex of parabola.

Crest level (m)

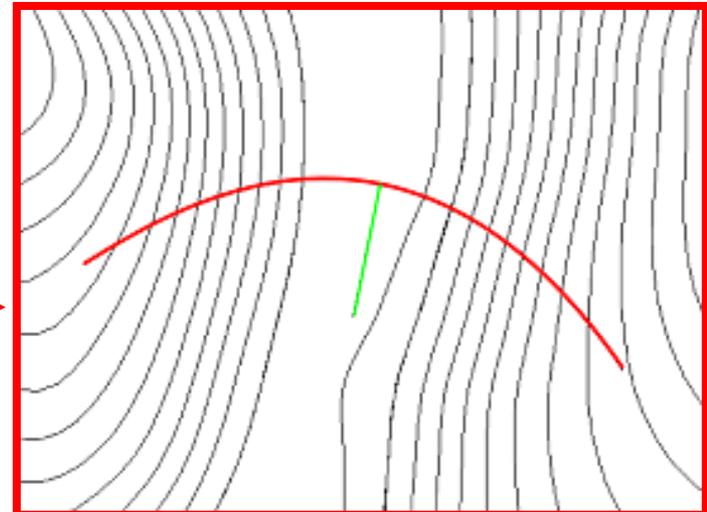
Initial excavation of crest (m)

Riverbed excavation (m)



### ➤ Step 1B

Selection of **placement and curvature** of dam, based on **parabolic or elliptic shapes**



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

Dam  
Geometric  
Generator

Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

### ➤ Step 2

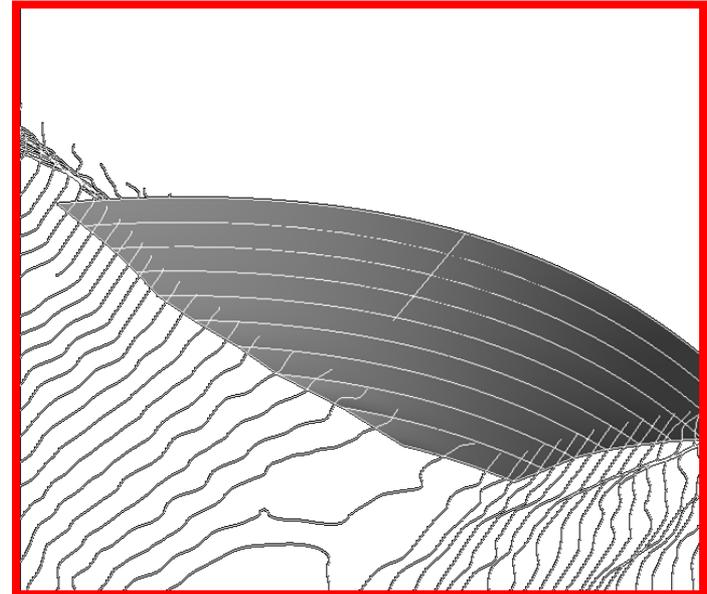
### Definition of excavation depth

Foundation depth

Define foundation depth at each level and side (scheme downstream view)

L1	5.00	R1	5.00
L2	5.00	R2	5.00
L3	5.00	R3	5.00
L4	5.00	R4	5.00
L5	5.00	R5	5.00
L6	6.00	R6	6.00
L7	7.00	R7	7.00
L8	8.00	R8	8.00
L9	9.00	R9	9.00
L10	10.00	R10	10.00

3.- Reference cylinder



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

Dam Geometric Generator

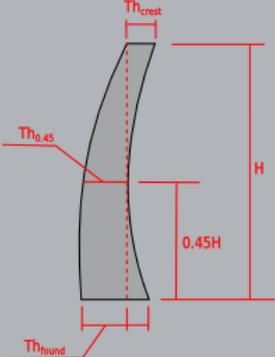
Step 1 Step 2 **Step 3** Step 4 Step 5 Step 6 Step 7 Step 8

### ➤ Step 3

## Definition of cross section shape

**Crown catilever section**

Define crown catilever section from percentage values (USBR default) or user rearrange option.



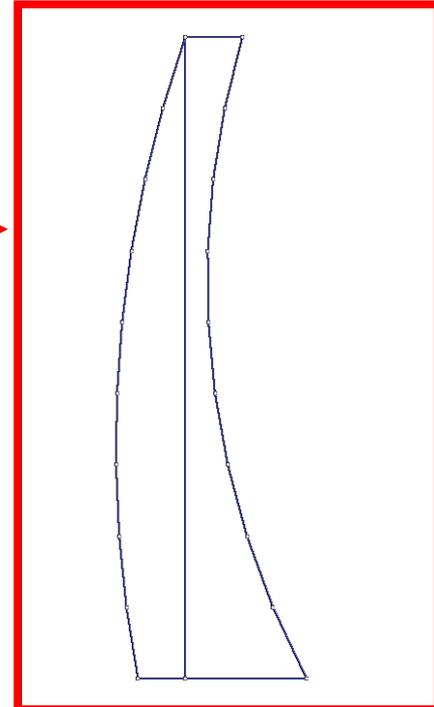
Th Crest (%)	0.0
Th 045 (%)	0.0
Th foundation (%)	0.0
Th045 downstream axis (%)	0.0
Th foundation downstream axis (%)	33.3

User rearrange

x movement of point (m), U=upstream, D=downstream, 1=crest level, 10=foundation level

U2	10.0	U3	10.0	U4	10.0	U5	10.0	U6	10.0	U7	10.0	U8	10.0	U9	10.0	U10	10.0		
D1	10.0	D2	10.0	D3	10.0	D4	10.0	D5	10.0	D6	10.0	D7	10.0	D8	10.0	D9	10.0	D10	10.0

**4.- Create**      **5.- Confirm**



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 4A

Definition of curvature laws for intrados and extrados

**Dam Geometric Generator**

Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

#### Thickenesses of dam

Define thickenesses of dam from vertex-focus length

Length vertex-focus (m), U=upstream, D=downstream, 1=crest level, 10=foundation level

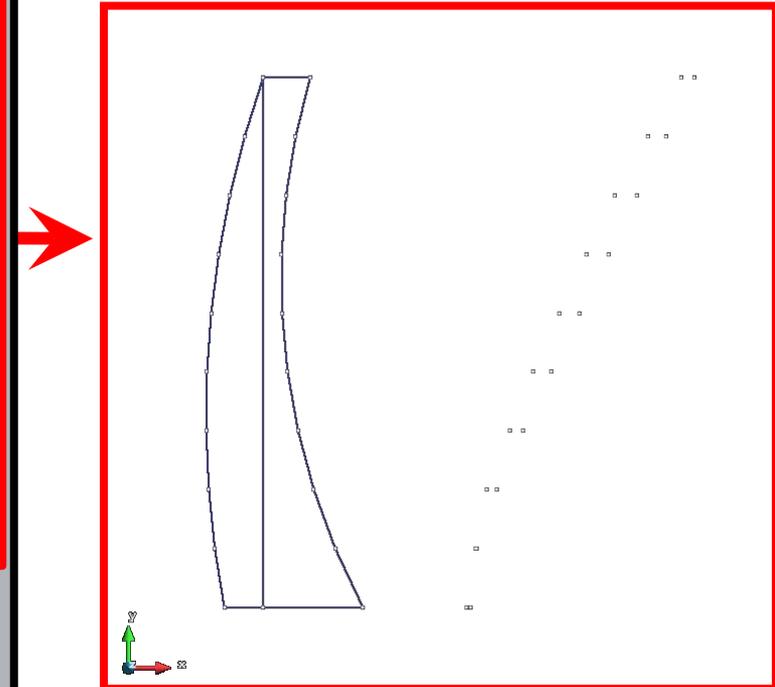
U2	50.0		D1	40.0
U3	50.0		D2	40.0
U4	50.0		D3	40.0
U5	50.0		D4	40.0
U6	50.0		D5	40.0
U7	50.0		D6	40.0
U8	50.0		D7	40.0
U9	50.0		D8	40.0
U10	50.0		D9	40.0
			D10	40.0

6.- Fix lengths      7.- Thickenesses

#### Create dam volume

8.- Create dam

Navigation: [Back] [Forward]



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 4B

Creation of dam volume

**Dam Geometric Generator**

Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

#### Thicknesses of dam

Define thicknesses of dam from vertex-focus length

Length vertex-focus (m), U=upstream, D=downstream, 1=crest level, 10=foundation level

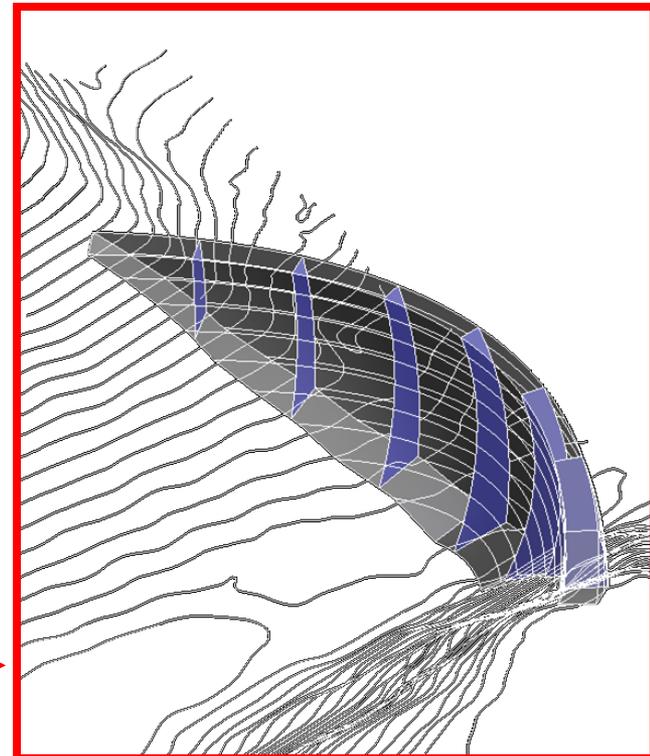
U2	50.0		D1	40.0
U3	50.0		D2	40.0
U4	50.0		D3	40.0
U5	50.0		D4	40.0
U6	50.0		D5	40.0
U7	50.0		D6	40.0
U8	50.0		D7	40.0
U9	50.0		D8	40.0
U10	50.0		D9	40.0
			D10	40.0

6.- Fix lengths      7.- Thicknesses

#### Create dam volume

8.- Create dam

Navigation: [Back] [Forward]



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 5 (Optional)

Creation of abutments

**Dam Geometric Generator**

Step 1 Step 2 Step 3 Step 4 **Step 5** Step 6 Step 7 Step 8

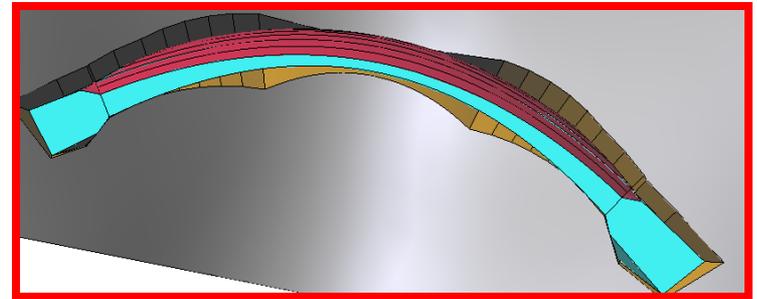
#### Abutments

Create abutments

Length axis-left abutment (m)	-70.00	Length axis-right abutment (m)	70.00
Left transition length (m)	5.00	Right transition length (m)	5.00
Left increase of thickness (°)	5.00	Right increase of thickness (°)	5.00
Left downstream slope (°)	70.00	Right downstream slope (°)	60.00

A.-Crest shape    B.-3D Abutments    C.-Confirm

←    →

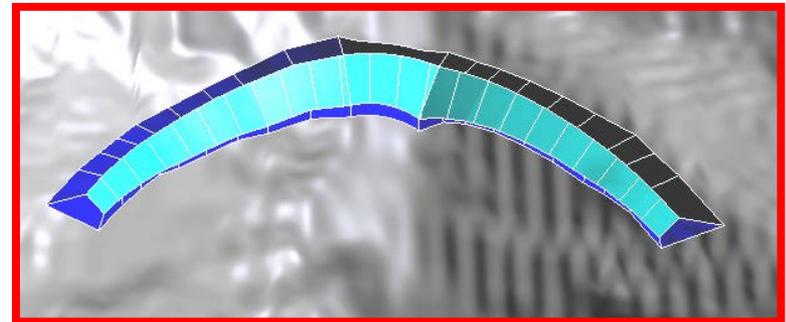
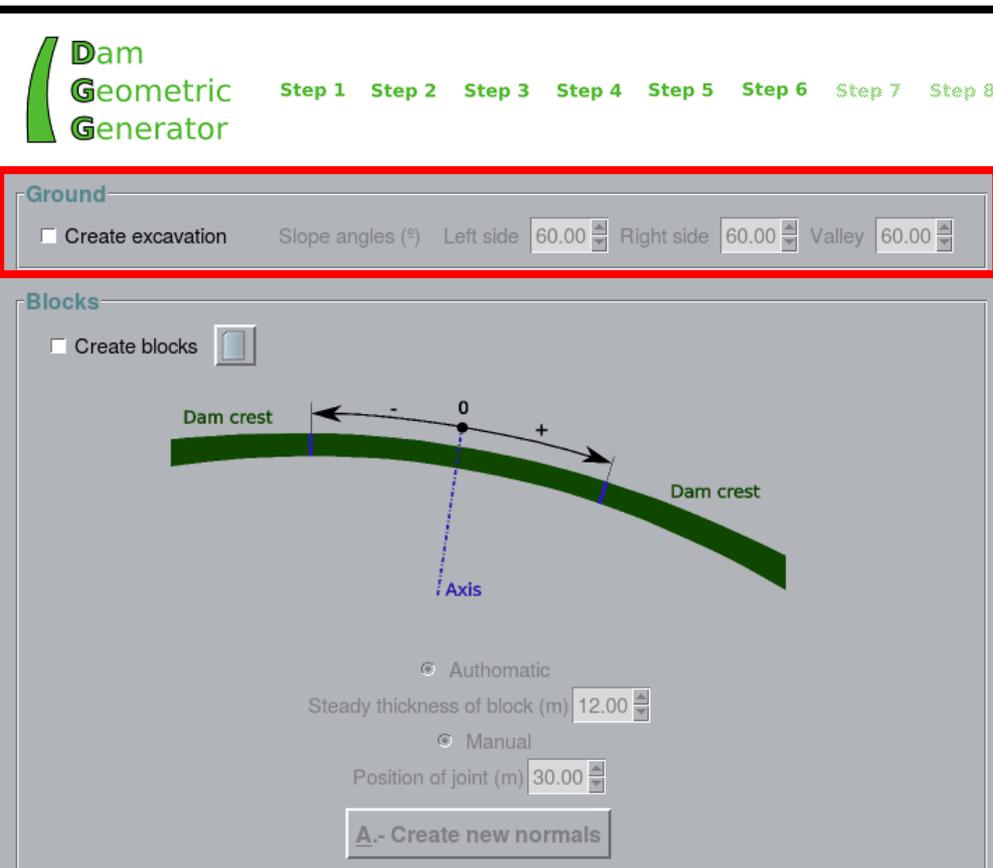


## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 6A (Optional)

Creation of excavation

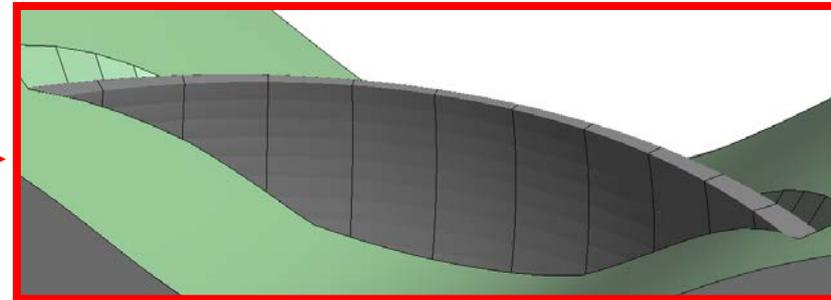
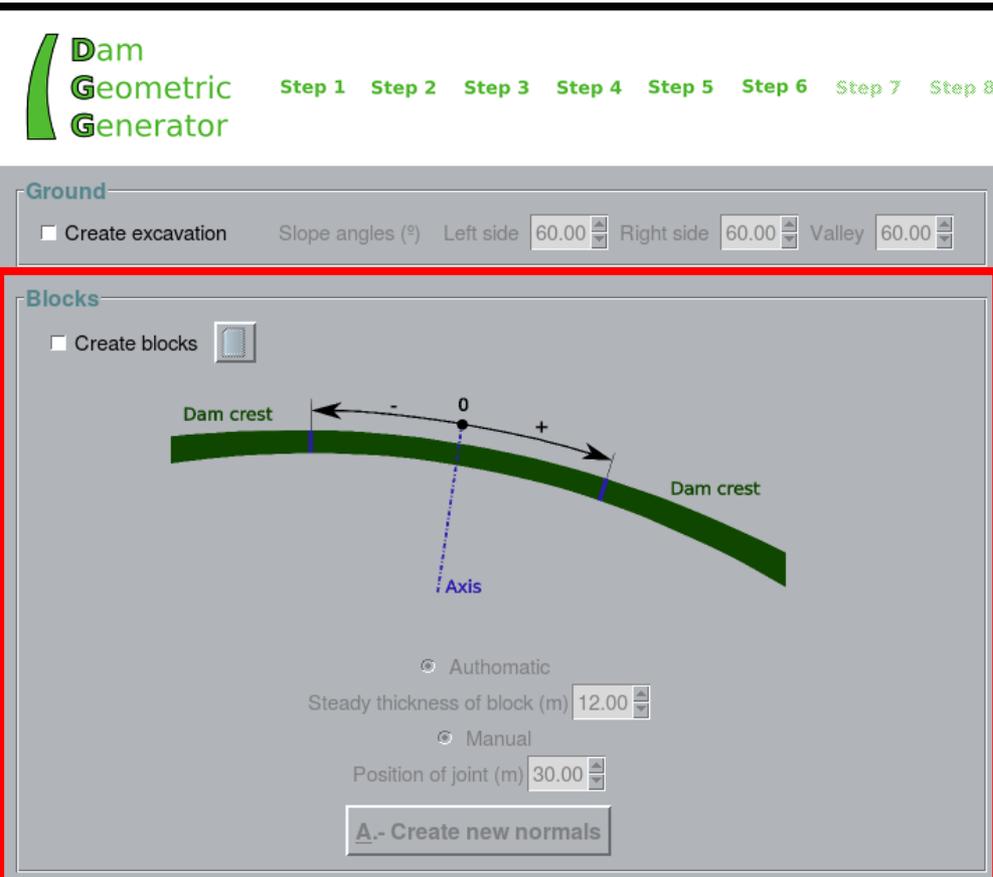


## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 6B (optional)

Creation of construction **blocks**



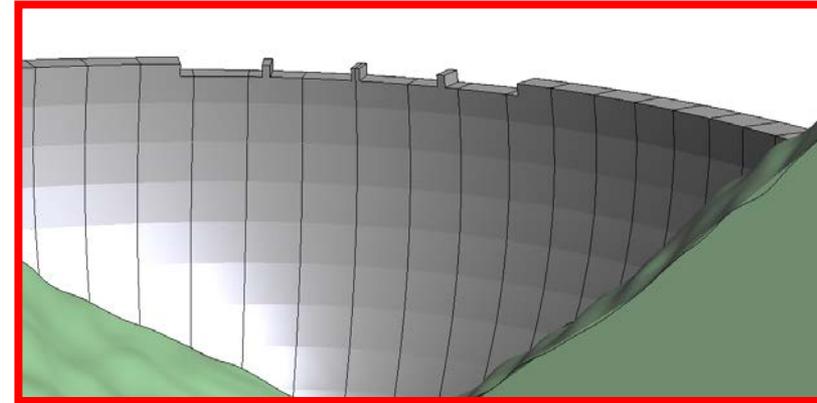
## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 7 (optional)

Creation of **spillway**

The screenshot shows the DaGGer software interface. At the top, the title "Dam Geometric Generator" is displayed. Below it, a progress bar indicates steps 1 through 8, with Step 7 highlighted. The main window is titled "Dam model" and contains a button labeled "9.- Create model". Below this, the "Spillway" section is active, with the instruction "Create as many spillway bays as you want one by one". A checkbox labeled "Create spillway bays" is checked. A diagram shows a cross-section of a dam with a spillway bay highlighted in red. The diagram labels the "Dam crest", "Left sidewall", "Right sidewall", "Spillway bay", and "Axis". Below the diagram, there are input fields for "Length axis-sidewall (m)" with "Left" set to -15.00 and "Right" set to 15.00, and "Ogee crest level (m)" set to 560.00. A button labeled "A.- Spillway bay" is at the bottom of the spillway section.



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 8A (optional)

Creation of **bottom outlets**

**Dam Geometric Generator** Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

**Bottom outlets works**  
Create as many bottom outlets as you want one by one

Create bottom outlets

Length axis-outlet (m) 5.00 Level (m) 533.00 Diameter (m) 3.00

A.- Bottom outlet

**Ground layers**  
Create as many ground layers by 3 points as you want, one by one from top to bottom

Several ground layers

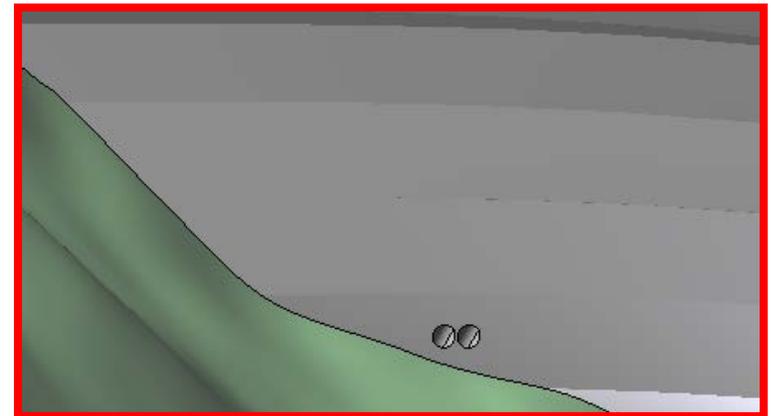
P1 (m)	X	45.10	Y	-91.00	Z	552.20
P2 (m)	X	-68.40	Y	-61.10	Z	552.20
P3 (m)	X	-32.40	Y	68.80	Z	545.30

A.- Ground layer contact

**Confirm model**

10.- Confirm model

Navigation icons: back, forward



## How can we design arch dams?

### ➤ DaGGer (Dam Geometric GenERator)

#### ➤ Step 8B (optional)

Creation of ground layers

**Dam Geometric Generator** Step 1 Step 2 Step 3 Step 4 Step 5 Step 6 Step 7 Step 8

**Bottom outlets works**  
Create as many bottom outlets as you want one by one

Create bottom outlets

Length axis-outlet (m) 5.00 Level (m) 533.00 Diameter (m) 3.00

A.- Bottom outlet

**Ground layers**  
Create as many ground layers by 3 points as you want, one by one from top to bottom

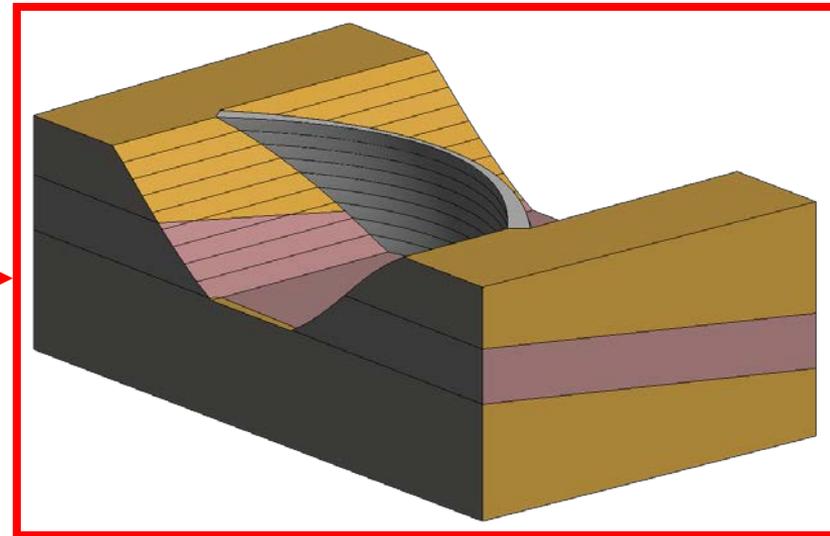
Several ground layers

P1 (m)	X	45.10	Y	-91.00	Z	552.20
P2 (m)	X	-68.40	Y	-61.10	Z	552.20
P3 (m)	X	-32.40	Y	68.80	Z	545.30

A.- Ground layer contact

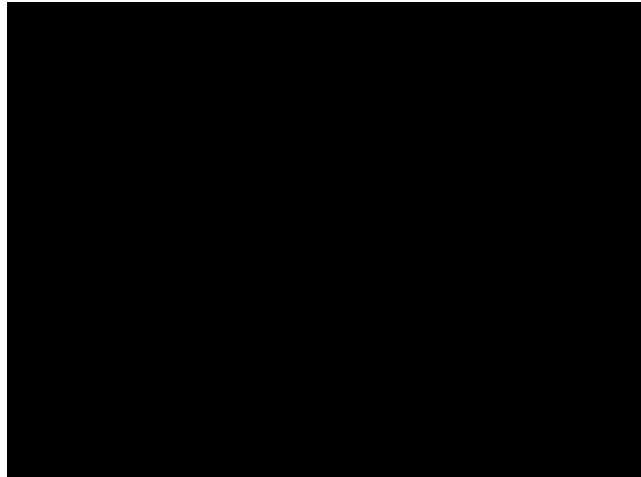
**Confirm model**

10.- Confirm model



## ***How can we design arch dams?***

- **DaGGer (Dam Geometric GenERator)**



## ***What are the advantages of DaGGer?***

Dam Geometric GenERator allows obtaining:

- **Complete definition of the dam in a few minutes**, even considering elements such as **outlets, abutments, spillways, excavation shape and ground layers**.
- **Volume of dam body and excavation** in an automatic way. That is imperative to obtain the **optimum solution**, regarding to **minimize** concrete and excavation **volumes** among several solutions **during preliminary studies**.
- **Geometry to export** to other environments **to carry out structural numerical simulations**.

# Overview

## DAM GEOMETRY

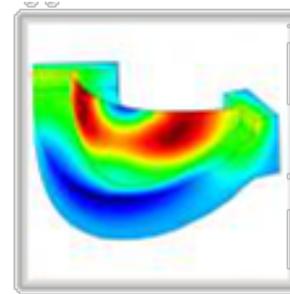
DaGGer

 Dam  
Geometric  
Generator



## NUMERICAL SIMULATION

Dam Application



**KRATOS**  
MULTI-PHYSICS 



# What is the Dam Application?

➤ Numerical modeling tool to analyze Dams



Preprocess  
Calculation  
Postprocess

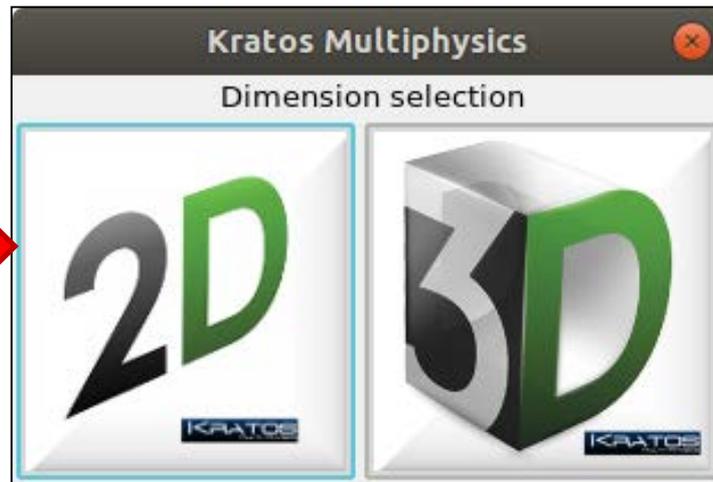
The GiD logo is a blue square with the text 'GiD' in white. To its right are three horizontal bars representing the software's workflow: a red bar for 'Preprocess', a full red bar for 'Calculation', and a red bar for 'Postprocess'.



MULTI-PHYSICS

- Solid Mechanics
- Convection Difussion
- Poro Mechanics

The KRATOS logo features the word 'KRATOS' in a large, bold, black font, with 'MULTI-PHYSICS' in a smaller font below it. To the right is a 3D cube icon. Below the logo is a list of capabilities: 'Solid Mechanics' (red), 'Convection Difussion' (blue), and 'Poro Mechanics' (black).



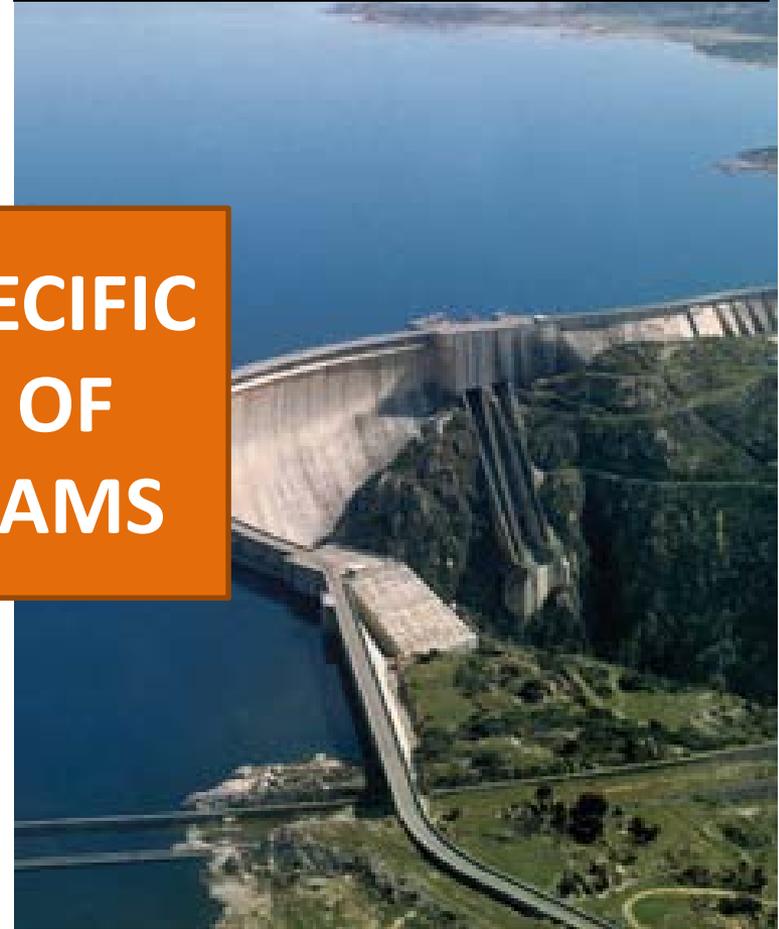
# *Why Dam Application?*

**CONSTRUCTION**



Zillergründl dam, Austria

**OPERATION**



Almendra dam, Spain

**SIMULATE SPECIFIC  
PROCESSES OF  
CONCRETE DAMS**

## *Operation phase*

Challenges found to simulate this phase

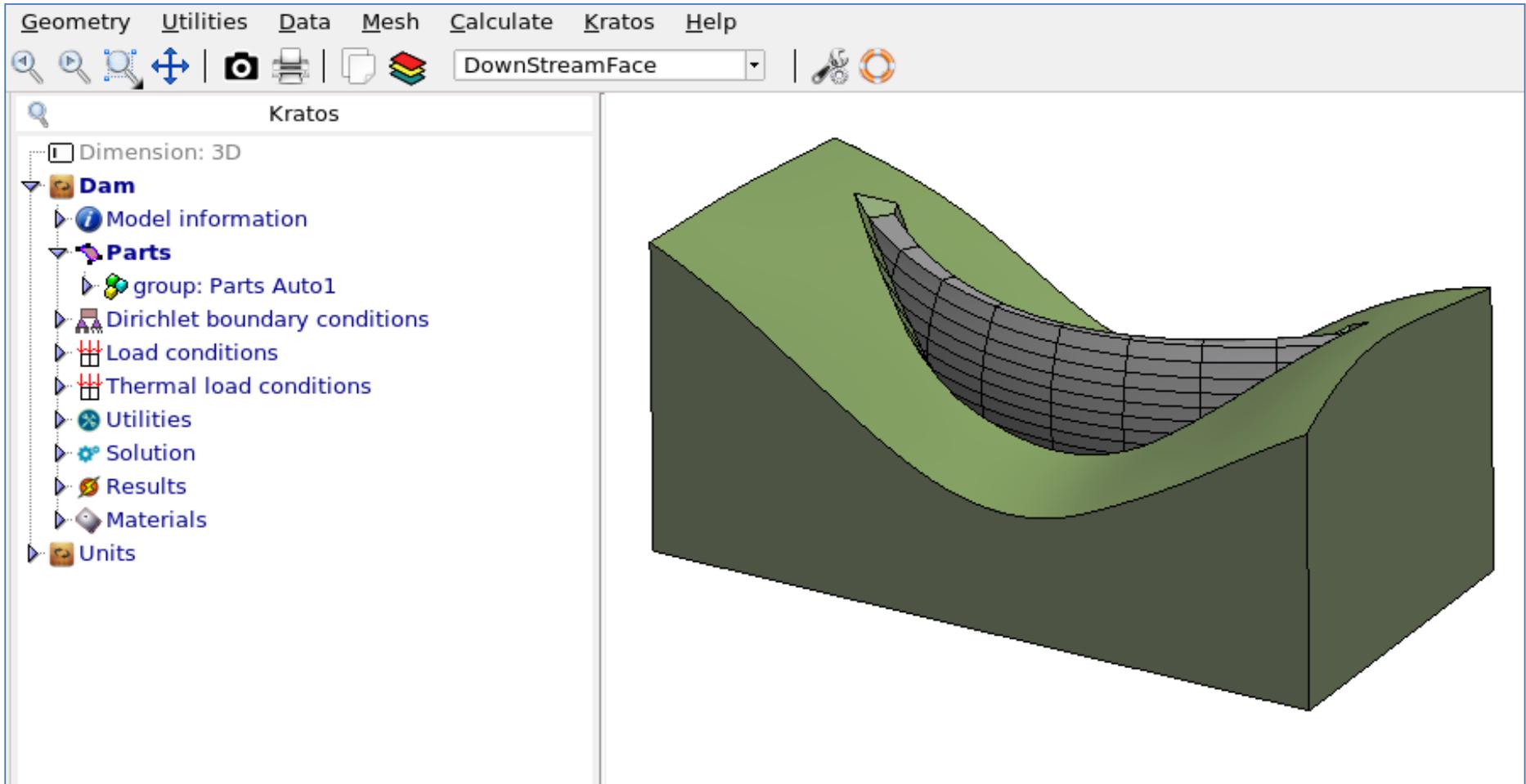
### **Processes and utilities**

- Transient analysis (tables)
- Time scale: seconds to weeks; different steps for calculation & writing results
- Mechanical loads: self-weight, hydrostatic pressure
- Thermal actions: dam-air exchange (fixed temp. or flux) and water temperature



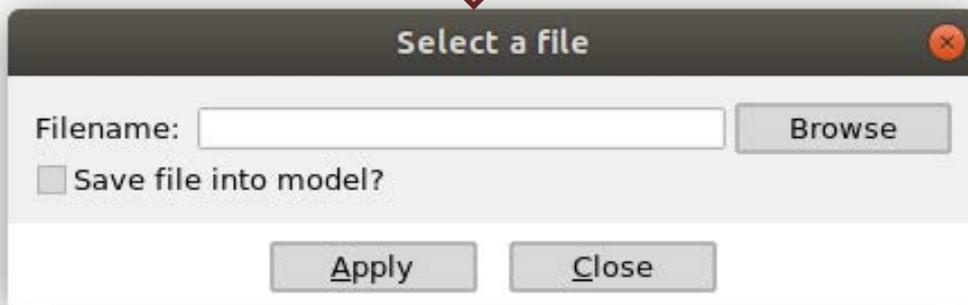
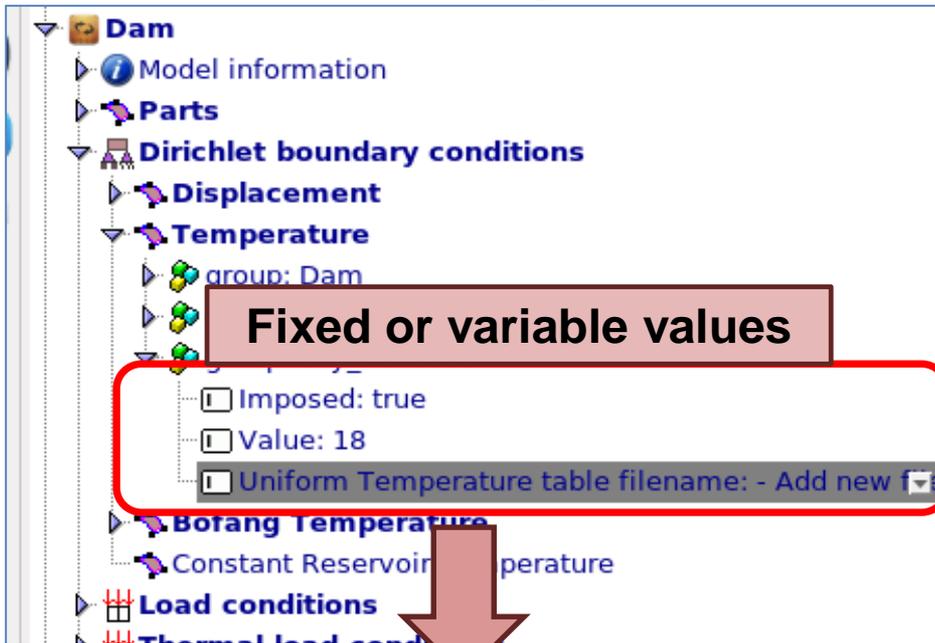
Almendra dam, Spain

## Operation phase

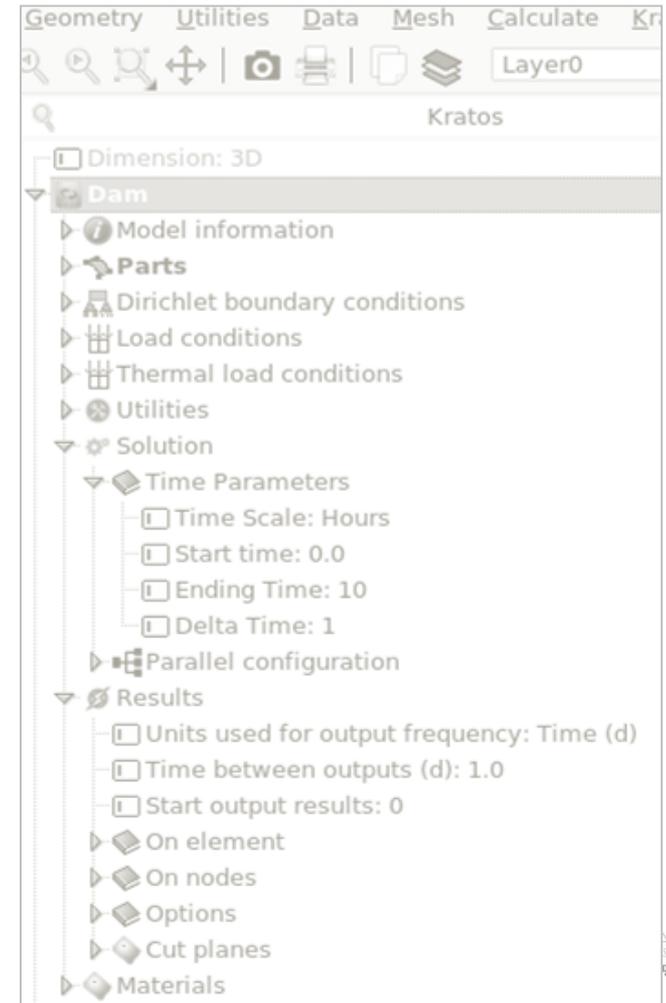


## Operation phase

### Transient analysis (tables)

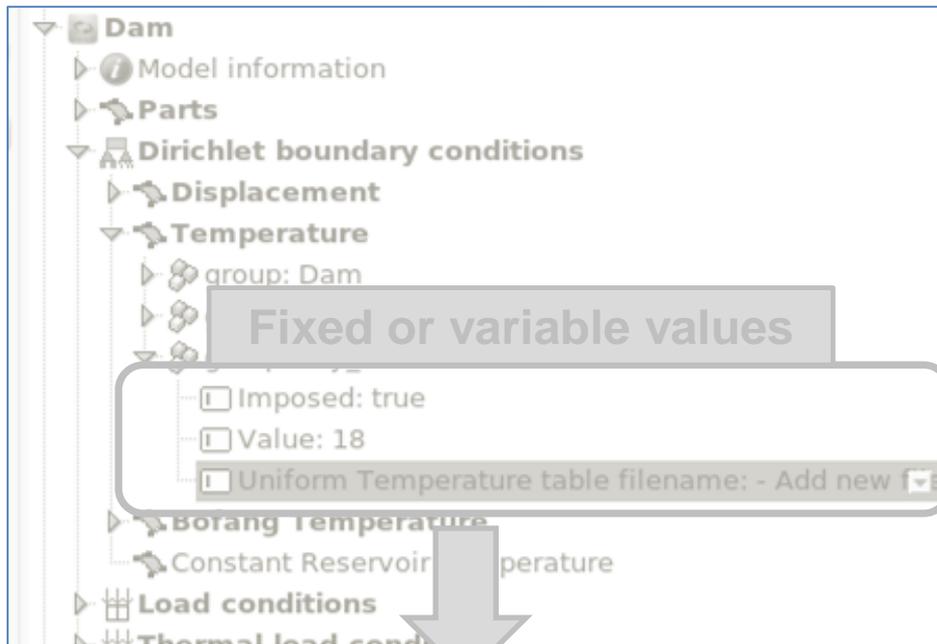


### Time scale



# Operation phase

Transient analysis (tables)



## Time scale

Calculation (e.g. hours)



Results writing (e.g. days)

# *Operation phase*

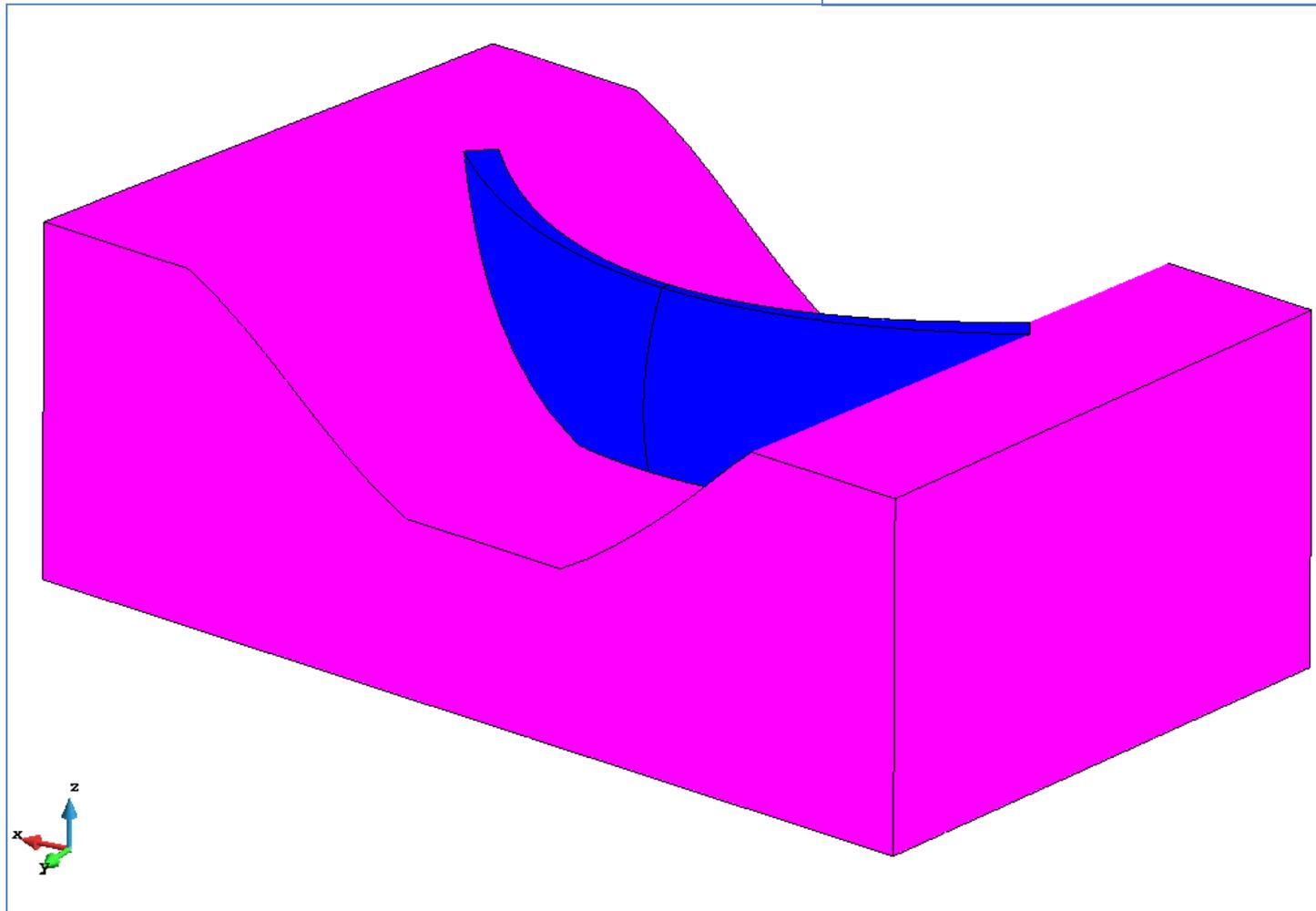
Thermal change: transient analysis

**DISPLACEMENT**

40 °C

TEMPERATURE

0 °C

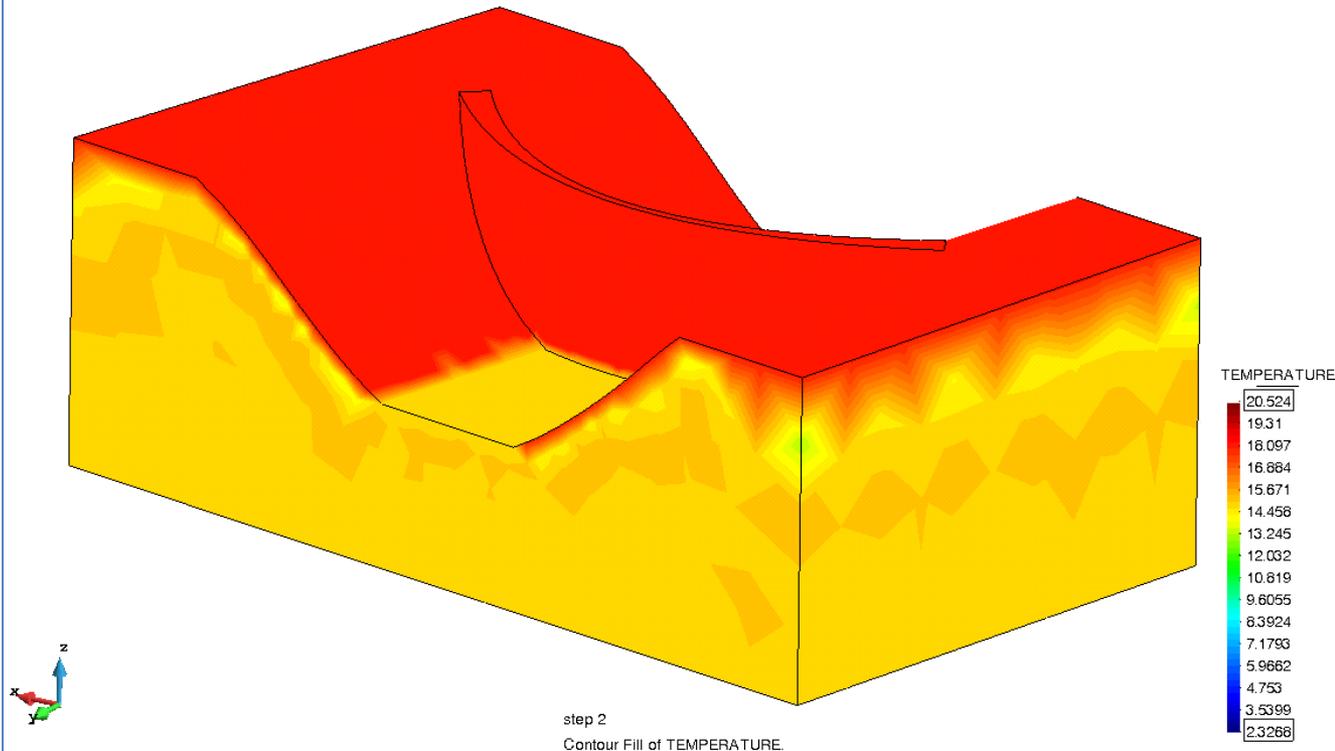


# Operation phase

Level change: transient analysis

Water temperature

TEMPERATURE



# Operation phase

Level change: transient analysis

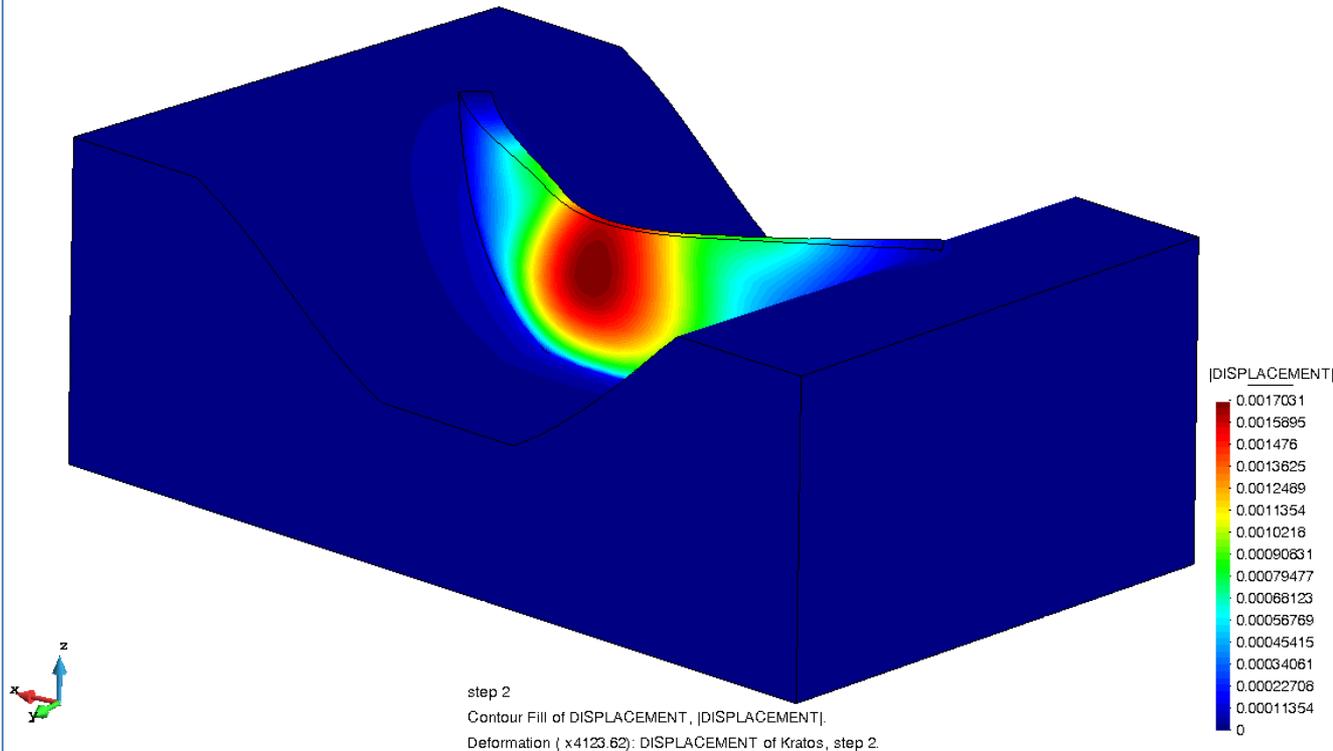
Water temperature



Mechanical Load

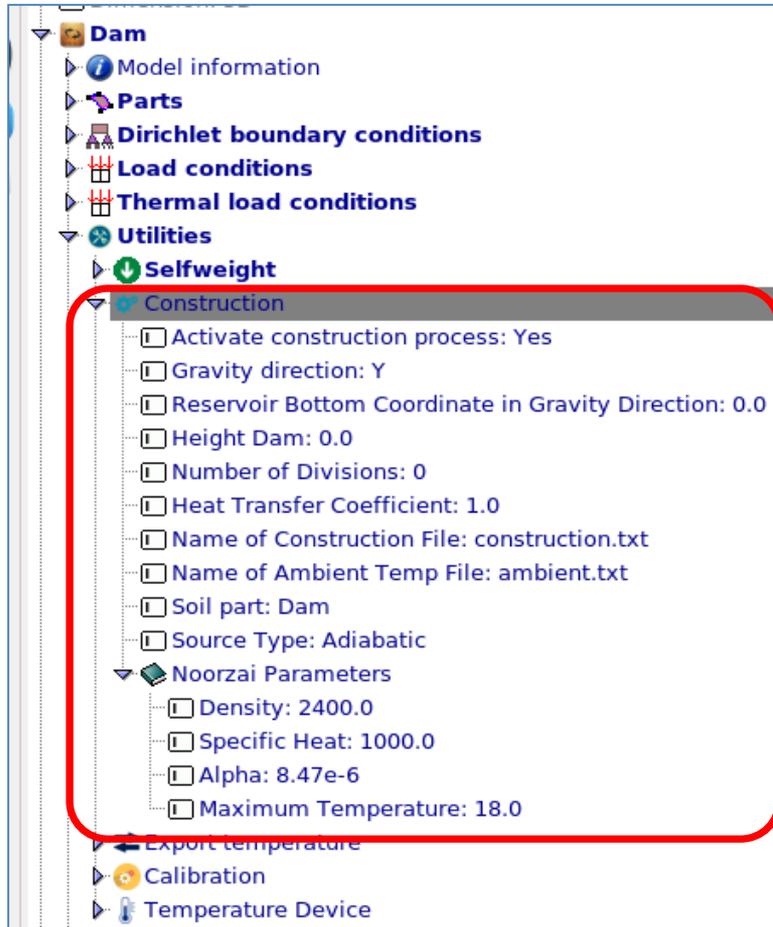


DISPLACEMENT



## Construction phase

Challenges found to simulate this phase



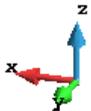
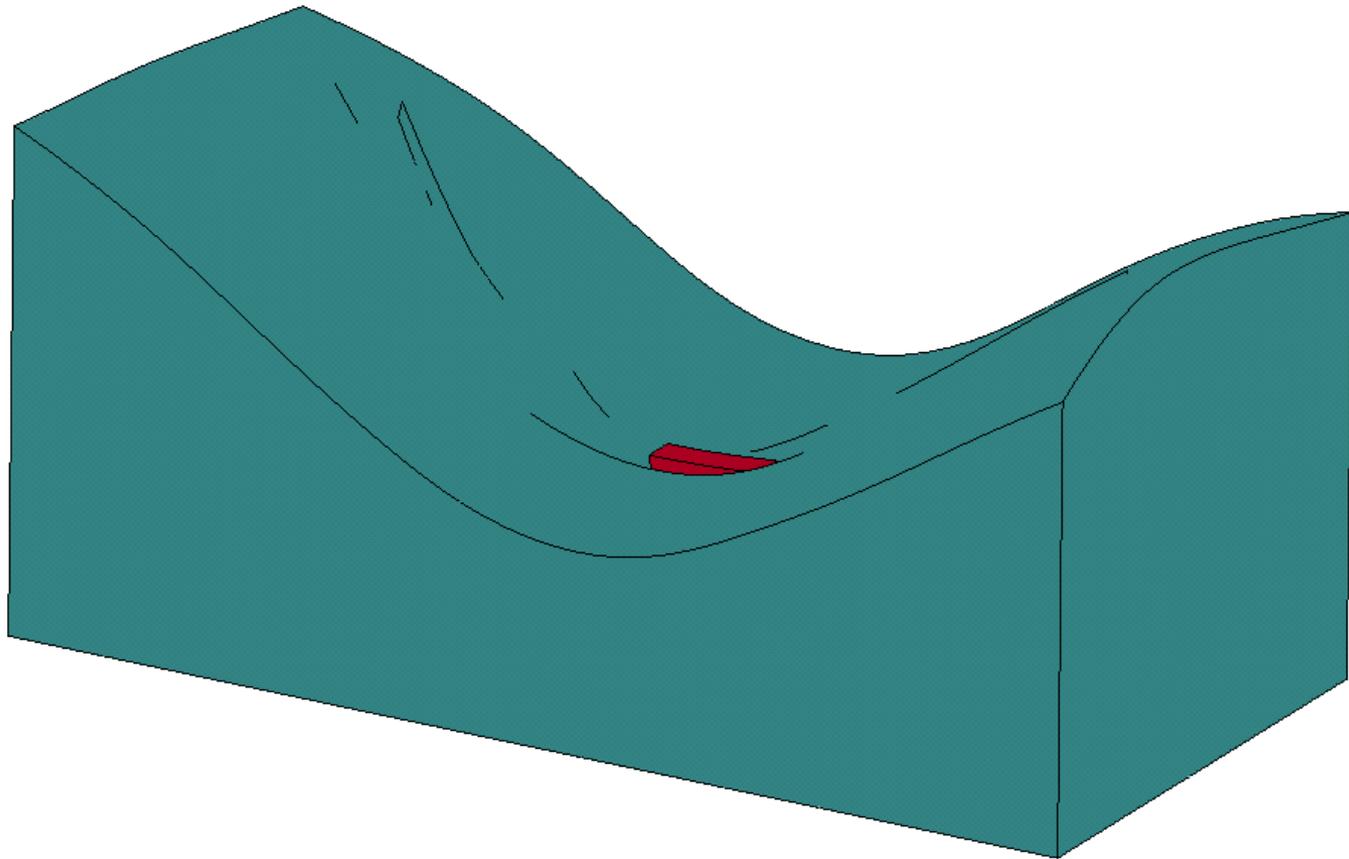
Zillergründl dam, Austria

### Processes and utilities

- Building process: activate parts step by step
- Mechanical: self-weight, stresses during construction
- Thermal: heat source, thermal exchanges dam-air and inside dam (considering free surfaces)

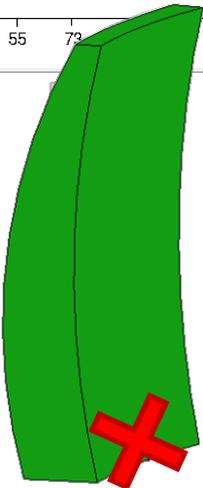
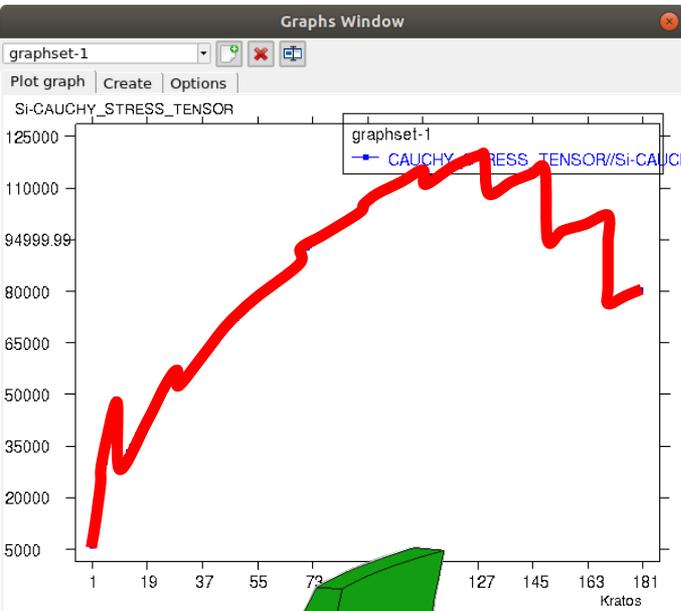
# *Construction phase*

Building process: activate parts step by step

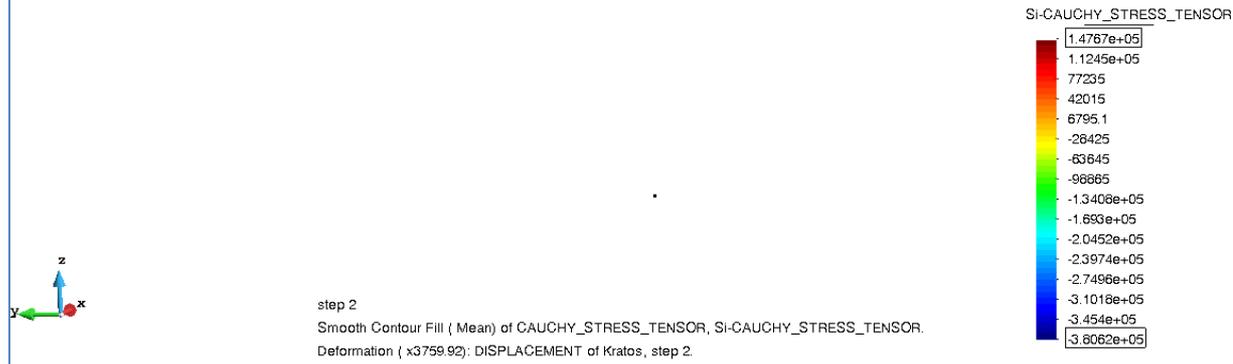


## Construction phase

Mechanical: self-weight during construction (stresses)



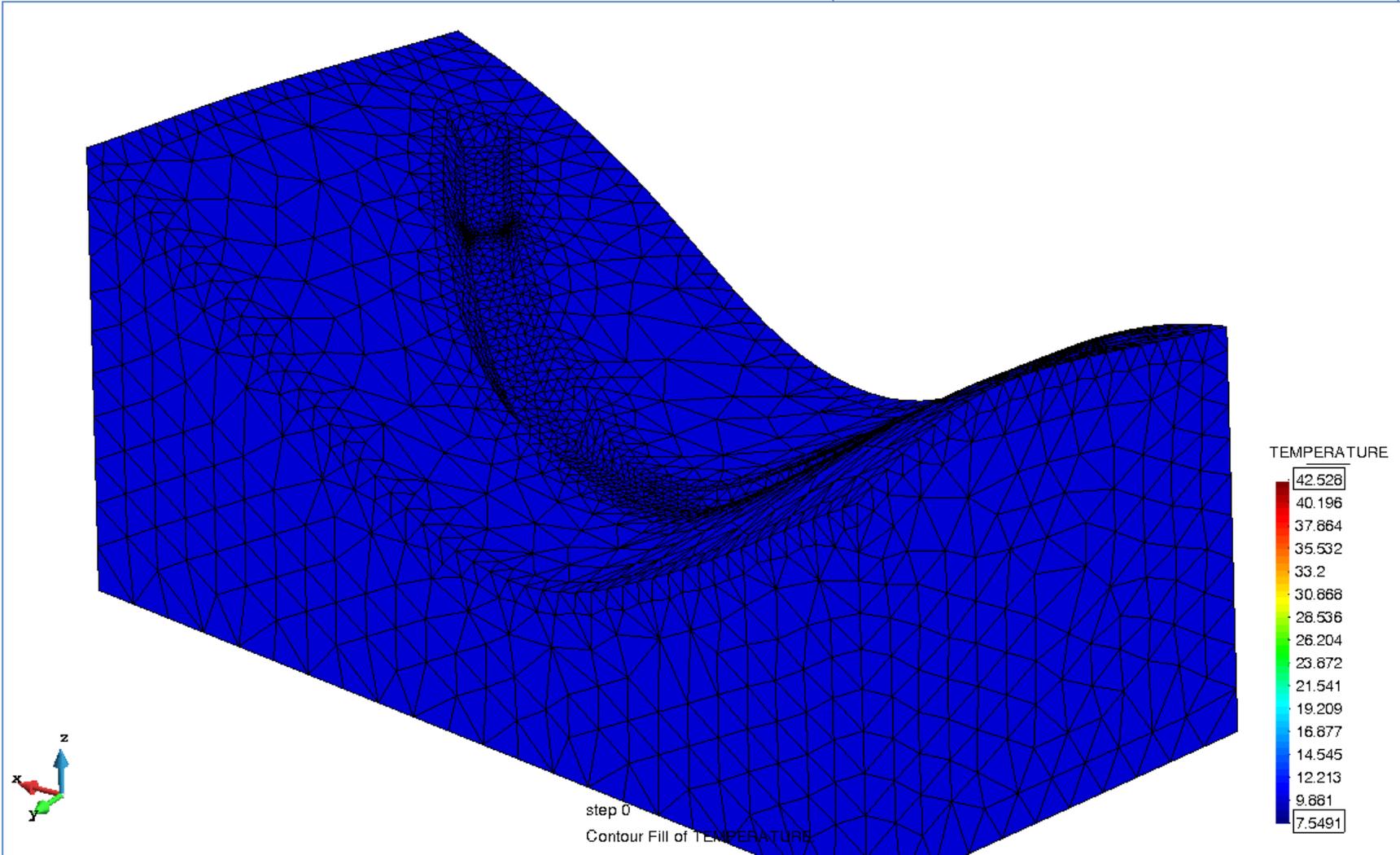
### TENSILE STRESS



# Construction phase

Thermal exchange, heat source

TEMPERATURE



# ***What are the advantages of DamApp?***

- Linked with Dagger (arch-dam generator), both applications cover, with great detail the complete cycle of Dam analysis: design, construction and operation.
- Comprehensive thermo-mechanical analysis of arch-dams. Specific loads and boundary conditions were created. Special focus on transient analysis: variable values (tables) and temporal scales.
- Construction process simulation: step-by-step building progress (parts activation), mechanical stresses (self-weight) and thermal actions (heat source, heat exchange).

## ***In progress work***

- Link construction/operating phases (grouting): self-weight stresses (neglect displacements), transfer temperature field (reference temperat.)
- Calibration of dam behavior with joint elements: during the construction and operation stages.

## ***Acknowledgments***

- Ministry of Economy, for funding AIDA, ACOMBO and NUMA projects (RETOS-COLABORACION calls)
- Lorenzo Gracia... (who laid the foundations of the Dam Application)

# **ARCH DAM GEOMETRY GENERATOR & DAM APPLICATION**

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