Semi-automatic creation of arch dam 3D solid concrete blocks and plan view drawings

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1 INTRODUCTION

Designing and constructing arch dams involves complex analyses, including structural, hydraulic, and geotechnical considerations. ***ArchDam*** is a software based on *Visual Studio*, AutoCAD and *Excel* to assist engineers in the design of arch dams such as

- *Generation of ARCH DAM and ARCH DAM/TERRAIN interface*

  Generation of an arch dam with or without widening the dam towards abutment. Generation of arch dam/terrain interface (shown in Figure 21) is a prerequisite for estimating the arch dam excavation parameters (shown in Figure 22).

  An AutoCAD drawing will be created containing the arch dam as 3DSolid. Please see Figure 19.

- *Generation of EXCAVATION and ARCH DAM/ABUTMENT interface*

  Generation of the excavation according to the parameters defined in the excel input file, including the generation of the ARCH DAM/ABUTMENT interface data (shown in Figure 23), which are displayed in the EXCEL input file, CHART sheet. This chart is intended to help to assess whether the dam abutments are situated sufficiently deeply in the rock.

- *Generation of CONCRETE BLOCKS*

  Generation of the final concrete blocks of the arch dam with horizontal and vertical construction joints as shown in Figure 24.

  There are several computer programs and software tools available to assist engineers in analysis of arch dams. The concrete blocks are deemed to be exported into FEM programs such as ABAQUS or DIANA, for detailed representation of all required static and dynamic load cases.

- *Generation of PLAN VIEW DRAWING*

  Generation of plan views of concrete blocks at numerous elevations. Please see Figure 25.

For use of the ArchDAM program a terrain 3D solid file (e.g. Terrain.dxf as shown in Figure 19) shall exist.

2 NOTATION

2.1 Definition of horizontal arch dam shapes

2.1.1 Parabolic arch dam shape

The shape of the parabolic arch dam is defined by the parameters E and F, shown in Figure 1 below.

$$Y = K + G \cdot (X - S1)^2$$
$$G = \frac{4 \cdot F}{E^2}$$
$$Y = K + \frac{4 \cdot F}{E^2} \cdot (X - S1)^2$$

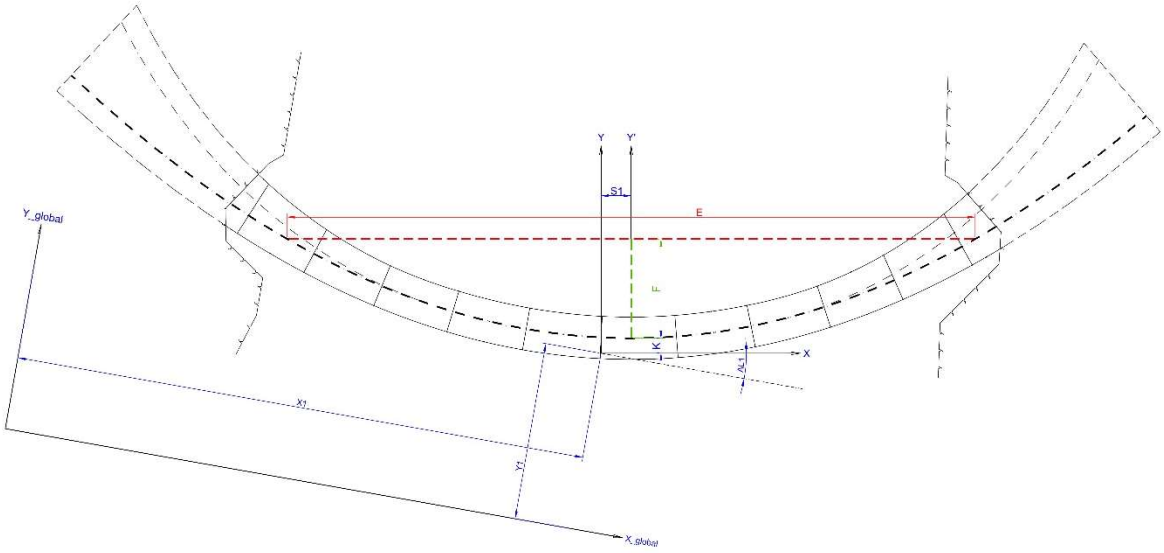


Figure 1: Parabolic arch dam shape

2.1.2 Ellipsoidal arch dam shape

The shape of the ellipsoidal arch dam is defined by the semi-axis lengths A and B shown in Figure 1 below.

$$X = X_E + S1$$
$$Y_E = B \cdot \sqrt{(1 - \frac{X_E^2}{A^2})}$$
$$Y = K + B - Y_E$$
$$Y = K + B - B \cdot \sqrt{(1 - \frac{(X - S1)^2}{A^2})}$$

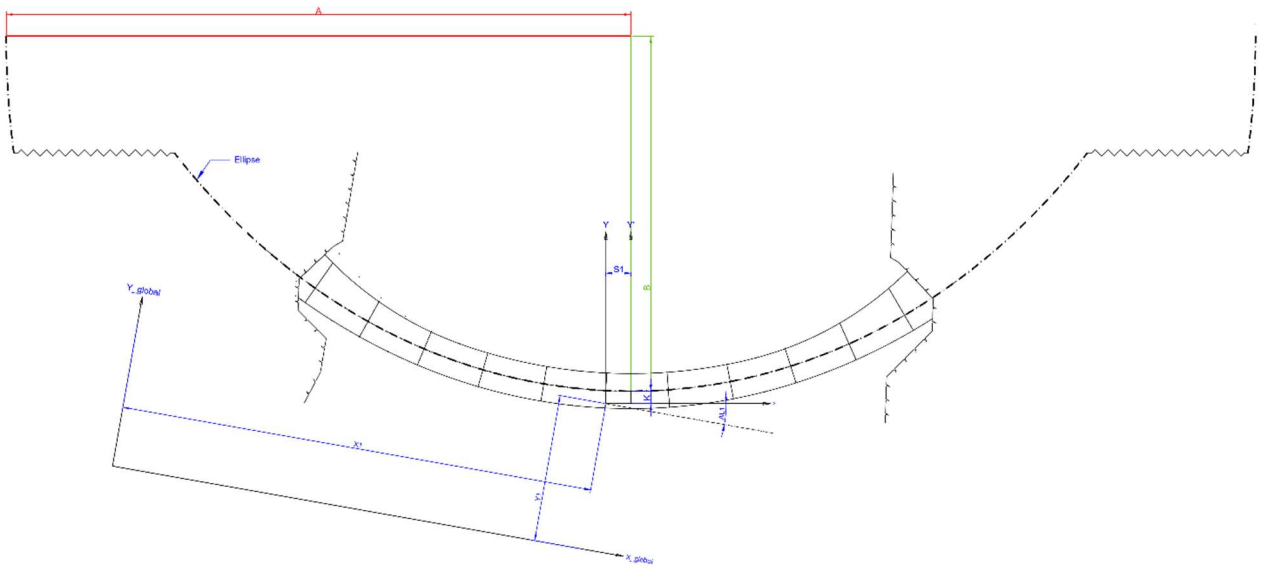


Figure 2: Ellipsoidal arch dam shape

2.2 Maximum horizontal dimension of arch dam

2.2.1 Definition of the maximum horizontal dimension by length along the center line

This definition applies to both parabolic and ellipsoidal arch dam shapes. The value L2_L shall be entered with negative sign.

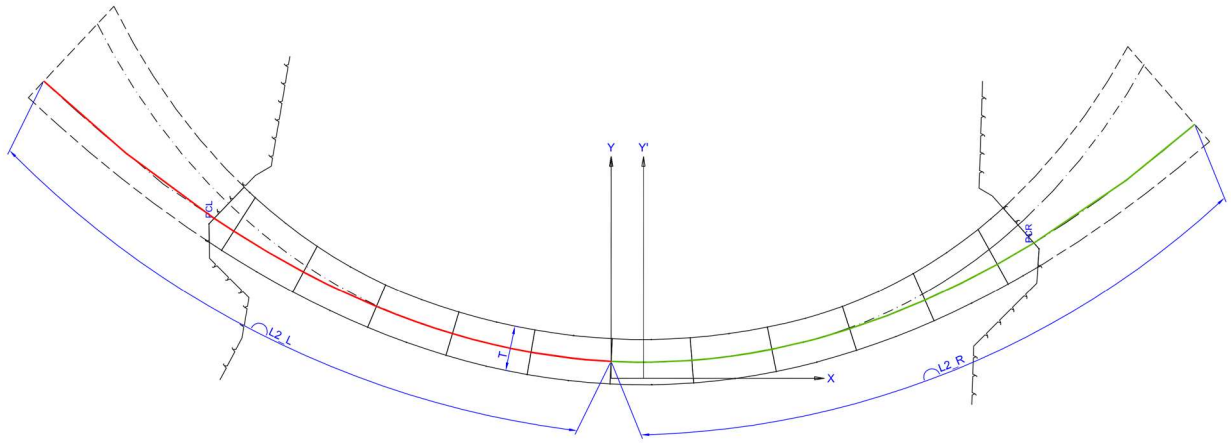


Figure 3: Definition of the maximum horizontal dimension by length along the center line

2.2.2 Definition of the maximum horizontal dimension by reference cylinder and angles PHI_L and PHI_R.

This definition applies to both parabolic and ellipsoidal arch dam shapes. The value PHI_L shall be entered with negative sign.

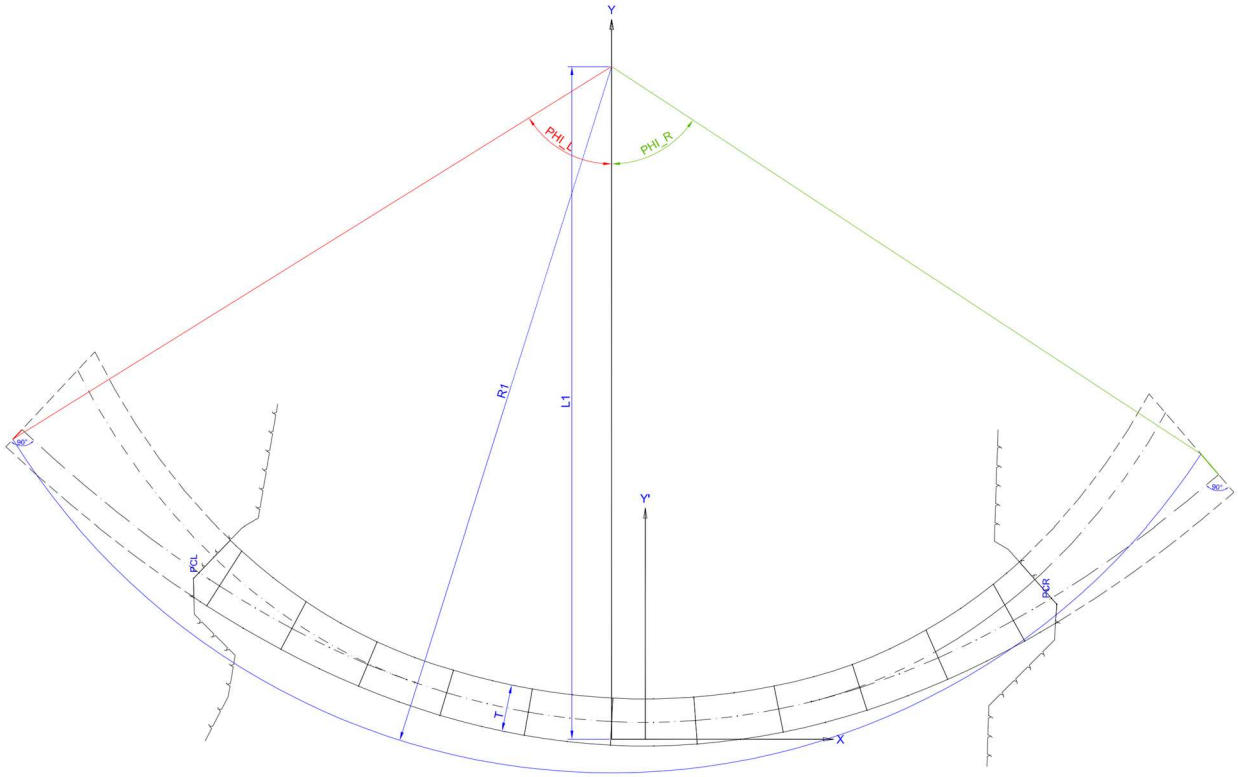


Figure 4: Definition of the maximum horizontal dimension by reference cylinder and angles PHI_L and PHI_R

2.3 Arch dam widening

2.3.1 Start of arch dam widening

2.3.1.1 Definition of start of widening by lengths W_L and W_R along the center line

This definition applies to both parabolic and ellipsoidal arch dam shapes. The value W_L shall be entered with negative sign.

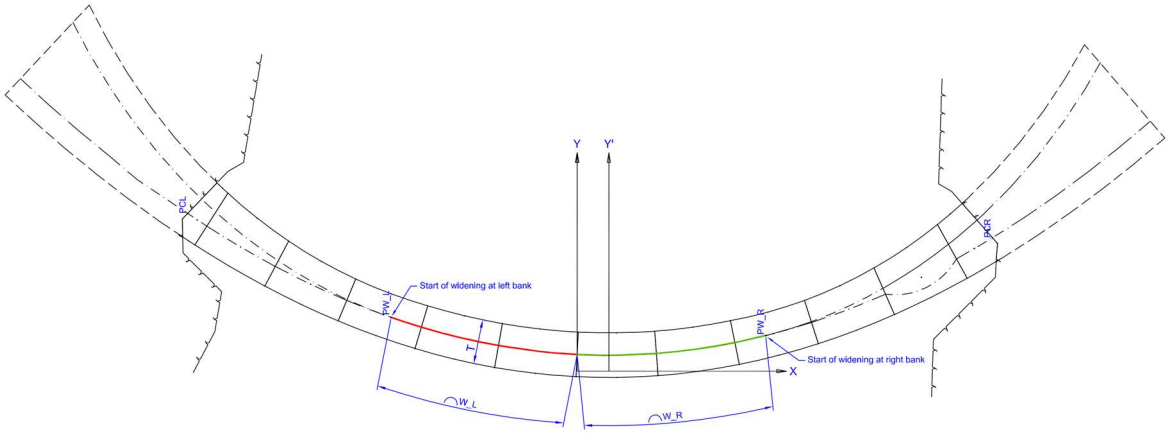


Figure 5: Definition of start of widening by lengths along the center line

2.3.1.2 Definition of start of widening by reference cylinder and angles PSI_L and PSI_R.

This definition applies to both parabolic and ellipsoidal arch dam shapes. The value PSI_L shall be entered with negative sign.

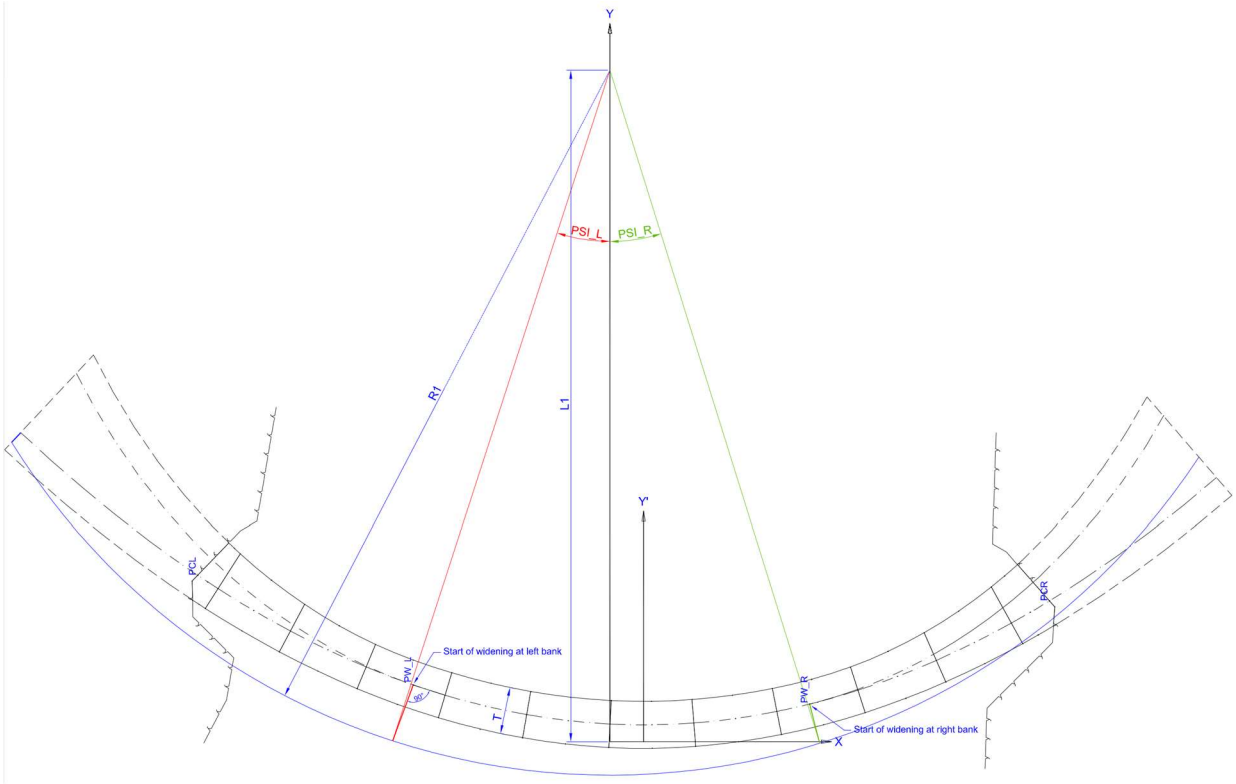


Figure 6: Definition of start of widening by reference cylinder and angles PSI_L and PSI_R

2.3.2 *Arch dam widening factor FW_L and FW_R for parabolic arch dam shapes.*

$G = \frac{4 \cdot F}{E^2}$ see Figure 1

$W = G \cdot (FW\_L - 1) \cdot S^2$

$FW\_L = \frac{E^2 \cdot W}{4 \cdot F \cdot S^2} + 1$

$W = G \cdot (FW\_R - 1) \cdot S^2$

$FW\_R = \frac{E^2 \cdot W}{4 \cdot F \cdot S^2} + 1$

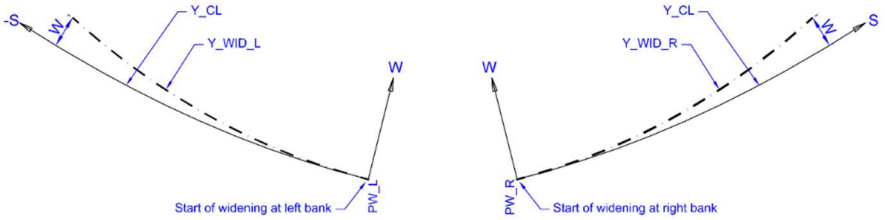


Figure 7: Arch dam widening factor FW_L and FW_R for parabolic arch dam shapes

2.3.3 *Arch dam widening factors FW_L and FW_R for ellipsoidal arch dam shapes.*

There are 2 options for definition of the widening factor.

- Option 1

  Definiton of the widening factor FW_L and FW_R by length S along the arch dam centerline and the arch dam thickness T. In this case the value shall be entered with a positive sign.

  $FW\_L = \frac{W \cdot 2000}{S^2 \cdot \sqrt[4]{T}}$.

  $FW\_R = \frac{W \cdot 2000}{S^2 \cdot \sqrt[4]{T}}$

- Option 2, arch dam thickness T related definition

  Definiton of the widening factor FW_L and FW_R only by length S along the arch dam centerline. In this case the value shall be entered with a negative sign.

  $FW\_L = \frac{-W \cdot 1000}{S^2}$

  $FW\_R = \frac{-W \cdot 1000}{S^2}$

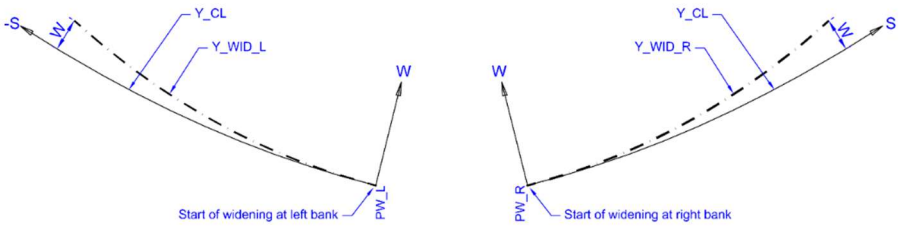


Figure 8: Arch dam widening factor FW_L and FW_R for ellipsoidal arch dam shapes

2.4 Arch dam abutment and excavation

This definition applies to both parabolic and ellipsoidal arch dam shapes.

$U = (T + W) * CW\_L$ CW_L ... contact area width factor for left abutment

$U = (T + W) * CW\_R$ CW_R ... contact area width factor for right abutment

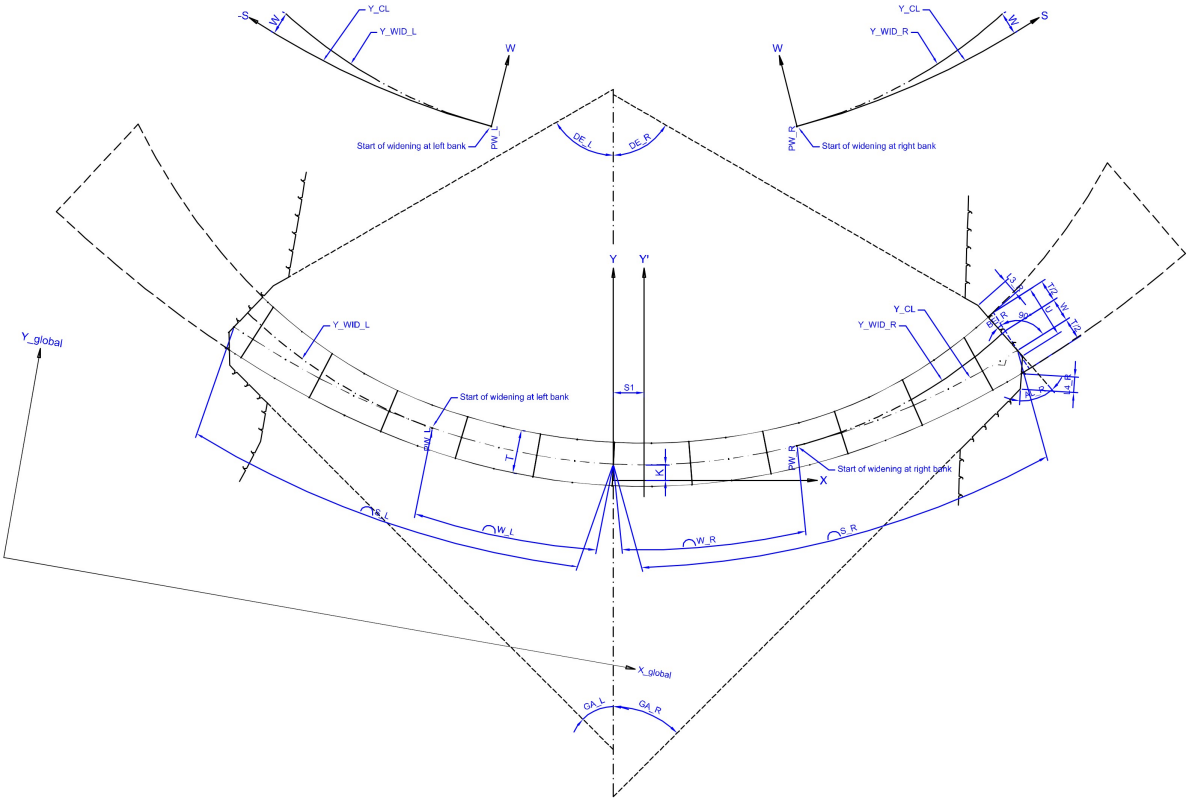


Figure 9: Definiton of abutment and excavation within the widening area

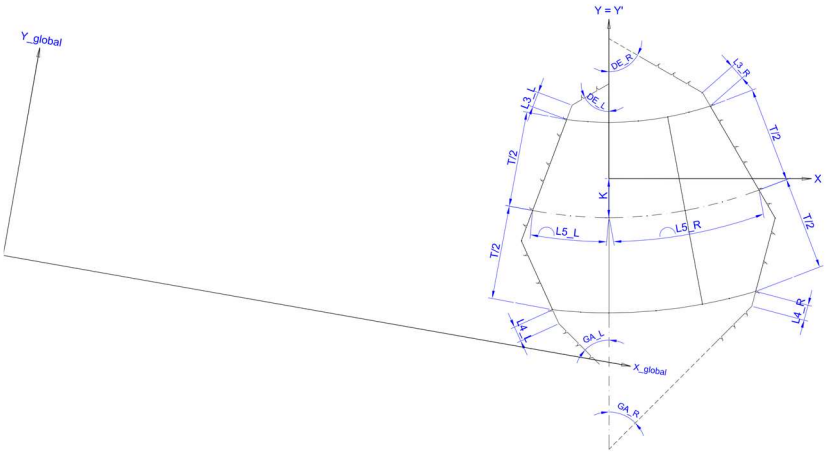


Figure 10: Definiton of abutment and excavation outside of the widening area

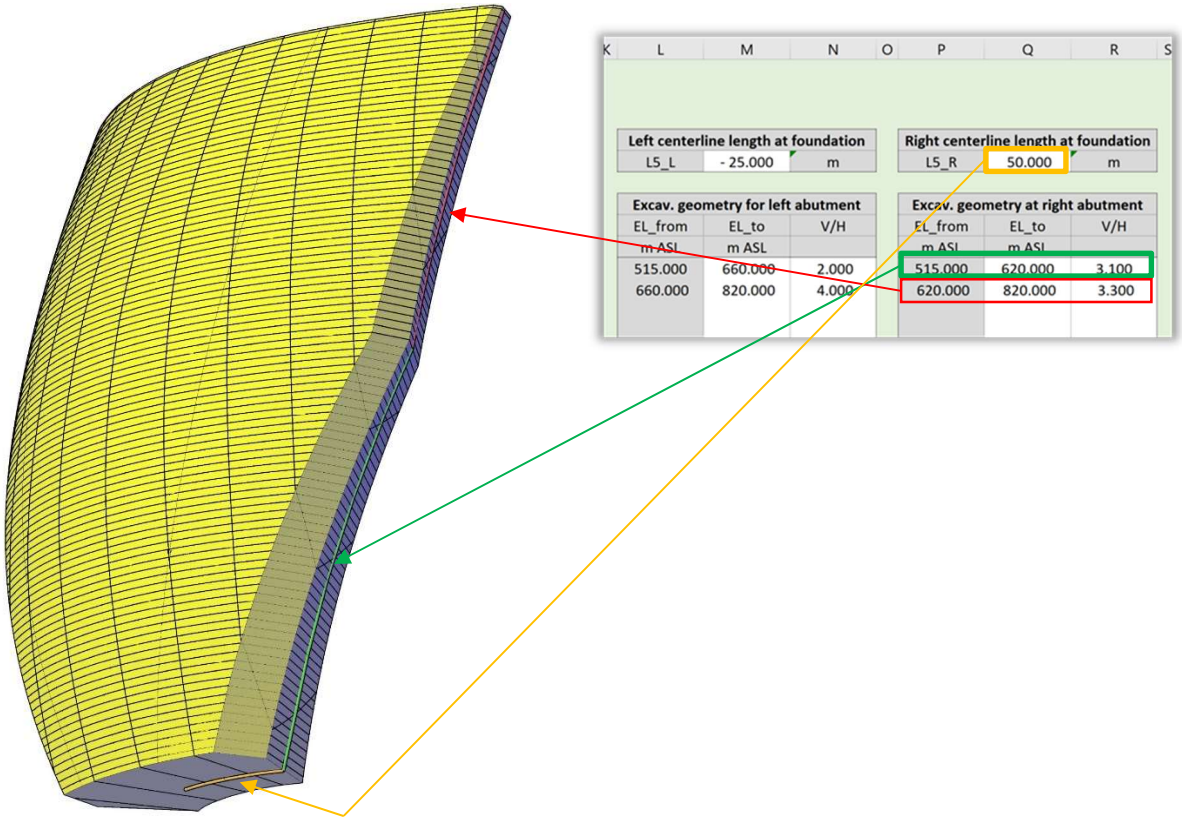
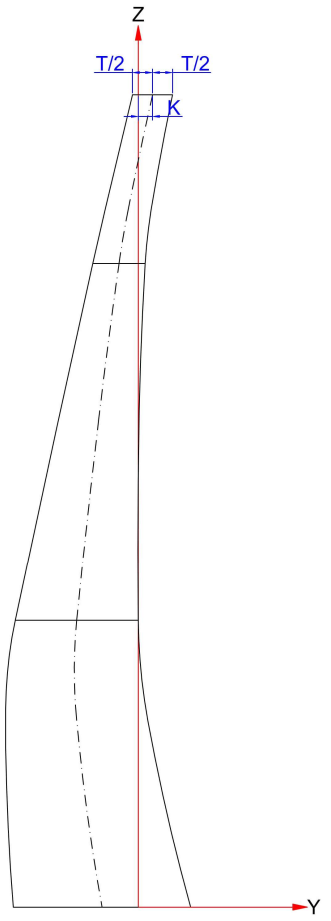
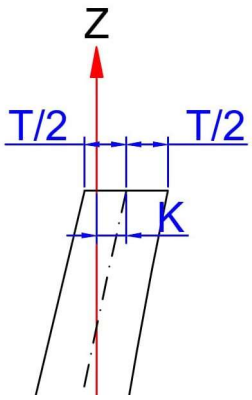


Figure 11: Definition of excavation

2.5 Definition of vertical arch dam shapes





Vertical arch dam parameter		
EL	T	K
m ASL	m	m
799.000	14.000	5.000
775.000	18.340	-2.730
641.900	43.000	-21.500
515.000	62.000	-12.670

2.6 Arch dam concrete block joints

2.6.1 Definition of the vertical arch dam concrete block joints by lengths S_V along the center line

This definition applies to both parabolic and ellipsoidal arch dam shapes. The lengths S_V are entered in EXCEL input file, sheet MAIN, column T.

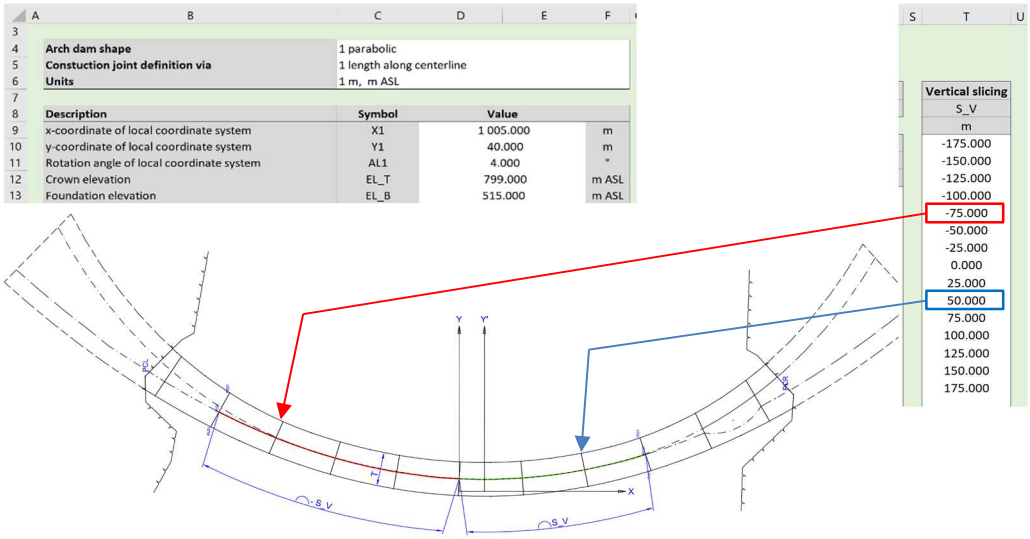
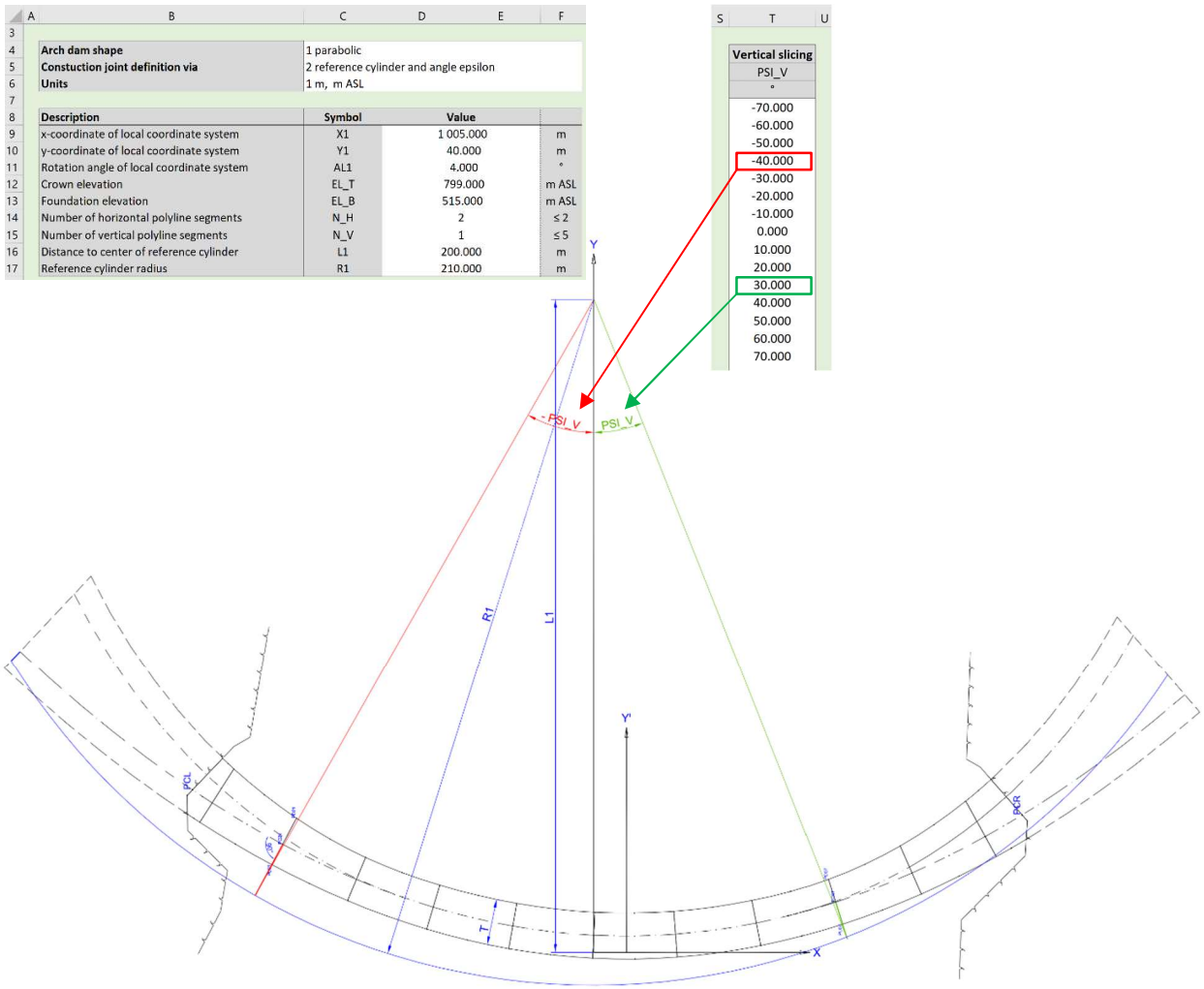


Figure 12: Definition of the arch dam concrete block joints by lengths S_V along the center line

2.6.2 Definition of the vertikal arch dam concrete block joints by reference cylinder and angles PSI_V

This definition applies to both parabolic and ellipsoidal arch dam shapes. The angles PSI_V are entered in EXCEL input file, sheet MAIN, column T.



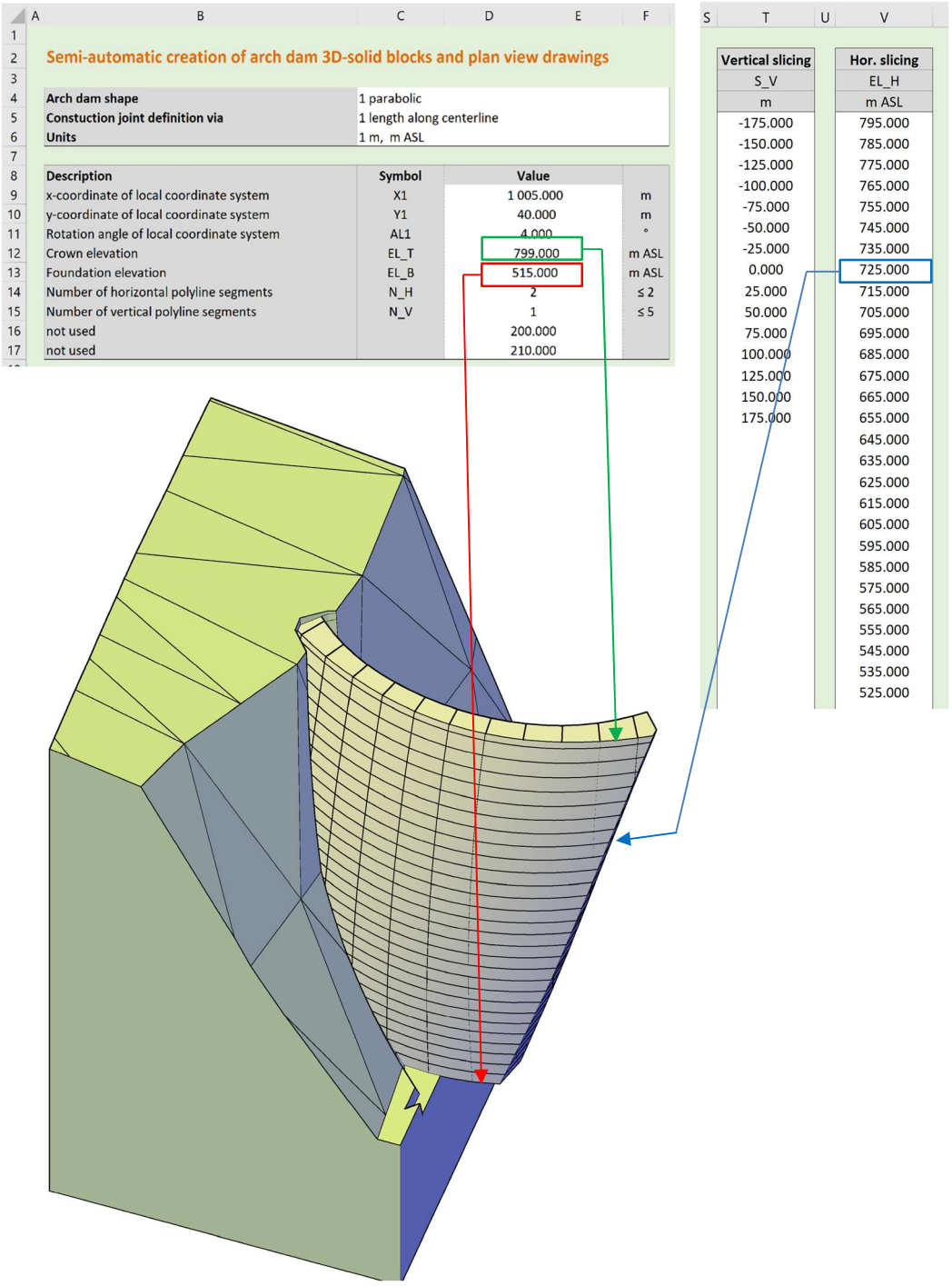
Arch dam shape	1 parabolic	
Constuction joint definition via	2 reference cylinder and angle epsilon	
Units	1 m, m ASL	

Description	**Symbol**	**Value**	
x-coordinate of local coordinate system	X1	1 005.000	m
y-coordinate of local coordinate system	Y1	40.000	m
Rotation angle of local coordinate system	AL1	4.000	°
Crown elevation	EL_T	799.000	m ASL
Foundation elevation	EL_B	515.000	m ASL
Number of horizontal polyline segments	N_H	2	≤ 2
Number of vertical polyline segments	N_V	1	≤ 5
Distance to center of reference cylinder	L1	200.000	m
Reference cylinder radius	R1	210.000	m

Vertical slicing
PSI_V
°
-70.000
-60.000
-50.000
-40.000
-30.000
-20.000
-10.000
0.000
10.000
20.000
30.000
40.000
50.000
60.000
70.000

Figure 13: Definition of the arch dam concrete block joints by reference cylinder and angles PSI_V

2.6.3 *Definition of the horizontal arch dam concrete block joints*



Semi-automatic creation of arch dam 3D-solid blocks and plan view drawings

Arch dam shape	1 parabolic
Constuction joint definition via	1 length along centerline
Units	1 m, m ASL

Description	Symbol	Value	
x-coordinate of local coordinate system	X1	1 005.000	m
y-coordinate of local coordinate system	Y1	40.000	m
Rotation angle of local coordinate system	AL1	4.000	°
Crown elevation	EL_T	799.000	m ASL
Foundation elevation	EL_B	515.000	m ASL
Number of horizontal polyline segments	N_H	2	≤ 2
Number of vertical polyline segments	N_V	1	≤ 5
not used		200.000	
not used		210.000	

Vertical slicing	Hor. slicing
S_V	EL_H
m	m ASL
-175.000	795.000
-150.000	785.000
-125.000	775.000
-100.000	765.000
-75.000	755.000
-50.000	745.000
-25.000	735.000
0.000	725.000
25.000	715.000
50.000	705.000
75.000	695.000
100.000	685.000
125.000	675.000
150.000	665.000
175.000	655.000
	645.000
	635.000
	625.000
	615.000
	605.000
	595.000
	585.000
	575.000
	565.000
	555.000
	545.000
	535.000
	525.000

Figure 14: Definition of the horizontal arch dam concrete block joints

2.6.4 Arch dam concrete block accuracy

N_H is defined in EXCEL sheet MAIN, cell D14
N_V is defined in EXCEL sheet MAIN, Cell D15

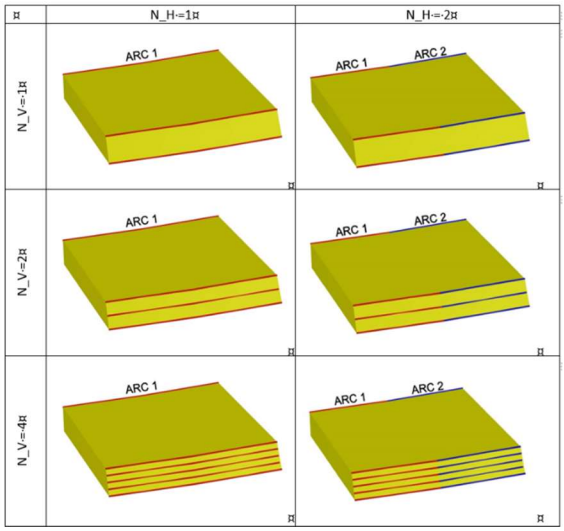


Figure 15: Substitution of parabolic or ellipsoidal shapes by means of arcs

3 INPUT

3.1 ArchDam program - Input mask

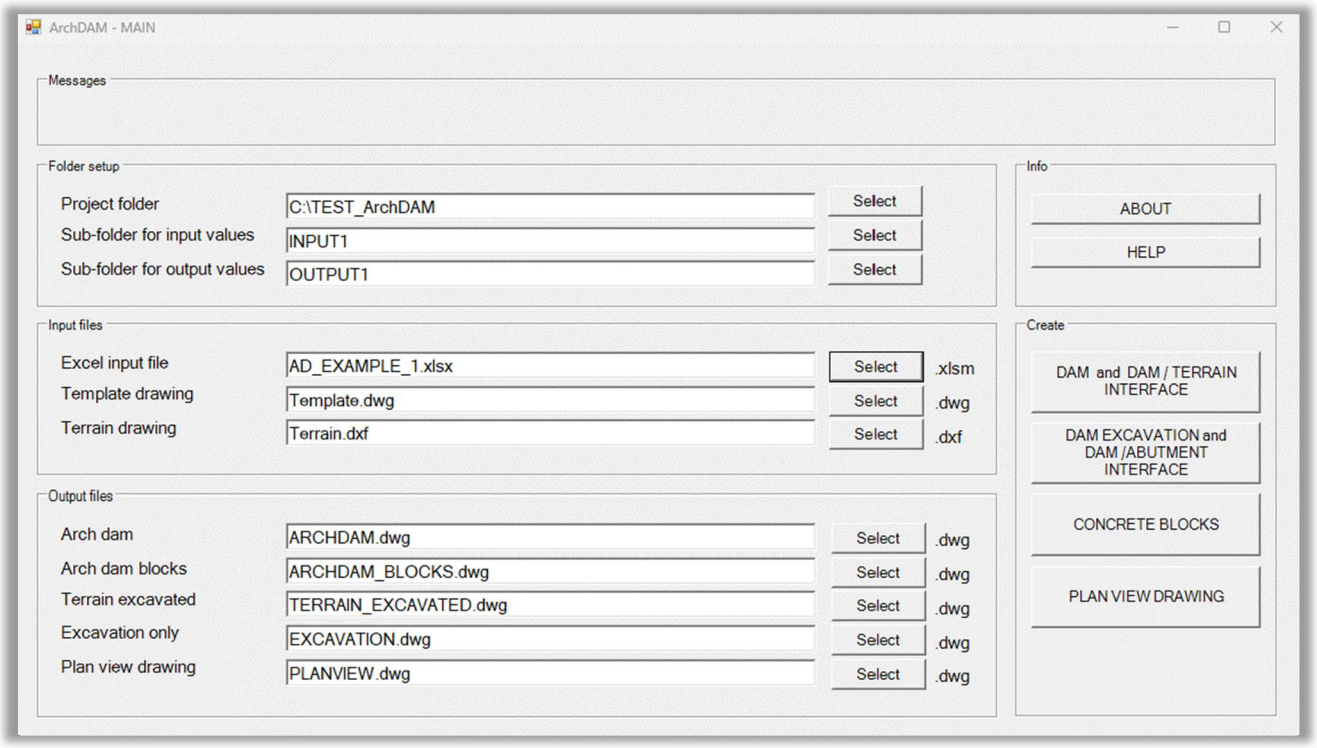
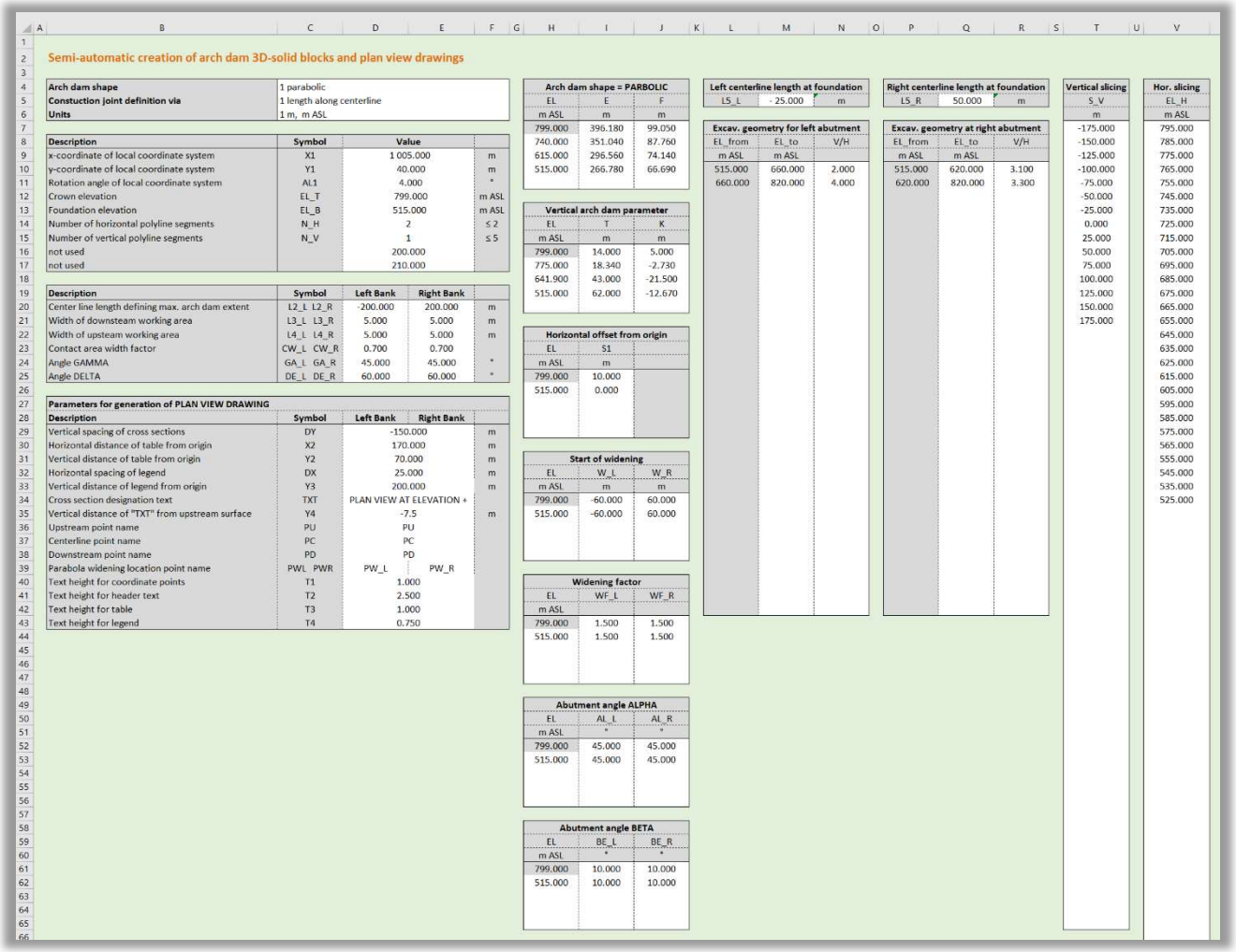


Figure 16: ArchDam program - Input mask

3.2 EXCEL input file – MAIN sheet



Semi-automatic creation of arch dam 3D-solid blocks and plan view drawings

Arch dam shape	1 parabolic
Constuction joint definition via	1 length along centerline
Units	1 m, m ASL

Description	Symbol	Value	
x-coordinate of local coordinate system	X1	1 005.000	m
y-coordinate of local coordinate system	Y1	40.000	m
Rotation angle of local coordinate system	AL1	4.000	°
Crown elevation	EL_T	799.000	m ASL
Foundation elevation	EL_B	515.000	m ASL
Number of horizontal polyline segments	N_H	2	≤ 2
Number of vertical polyline segments	N_V	1	≤ 5
not used		200.000	
not used		210.000	

Description	Symbol	Left Bank	Right Bank	
Center line length defining max. arch dam extent	L2_L L2_R	-200.000	200.000	m
Width of downsteam working area	L3_L L3_R	5.000	5.000	m
Width of upsteam working area	L4_L L4_R	5.000	5.000	m
Contact area width factor	CW_L CW_R	0.700	0.700	
Angle GAMMA	GA_L GA_R	45.000	45.000	°
Angle DELTA	DE_L DE_R	60.000	60.000	°

Parameters for generation of PLAN VIEW DRAWING

Description	Symbol	Left Bank	Right Bank	
Vertical spacing of cross sections	DY	-150.000		m
Horizontal distance of table from origin	X2	170.000		m
Vertical distance of table from origin	Y2	70.000		m
Horizontal spacing of legend	DX	25.000		m
Vertical distance of legend from origin	Y3	200.000		m
Cross section designation text	TXT	PLAN VIEW AT ELEVATION +		
Vertical distance of "TXT" from upstream surface	Y4	-7.5		m
Upstream point name	PU	PU		
Centerline point name	PC	PC		
Downstream point name	PD	PD		
Parabola widening location point name	PWL PWR	PW_L	PW_R	
Text height for coordinate points	T1	1.000		
Text height for header text	T2	2.500		
Text height for table	T3	1.000		
Text height for legend	T4	0.750		

Arch dam shape = PARBOLIC

EL	E	F
m ASL	m	m
799.000	396.180	99.050
740.000	351.040	87.760
615.000	296.560	74.140
515.000	266.780	66.690

Vertical arch dam parameter

EL	T	K
m ASL	m	m
799.000	14.000	5.000
775.000	18.340	-2.730
641.900	43.000	-21.500
515.000	62.000	-12.670

Horizontal offset from origin

EL	S1
m ASL	m
799.000	10.000
515.000	0.000

Start of widening

EL	W_L	W_R
m ASL	m	m
799.000	-60.000	60.000
515.000	-60.000	60.000

Widening factor

EL	WF_L	WF_R
m ASL		
799.000	1.500	1.500
515.000	1.500	1.500

Abutment angle ALPHA

EL	AL_L	AL_R
m ASL	°	°
799.000	45.000	45.000
515.000	45.000	45.000

Abutment angle BETA

EL	BE_L	BE_R
m ASL	°	°
799.000	10.000	10.000
515.000	10.000	10.000

Left centerline length at foundation

L5_L	- 25.000	m

Excav. geometry for left abutment

El_from	El_to	V/H
m ASL	m ASL	
515.000	660.000	2.000
660.000	820.000	4.000

Right centerline length at foundation

L5_R	50.000	m

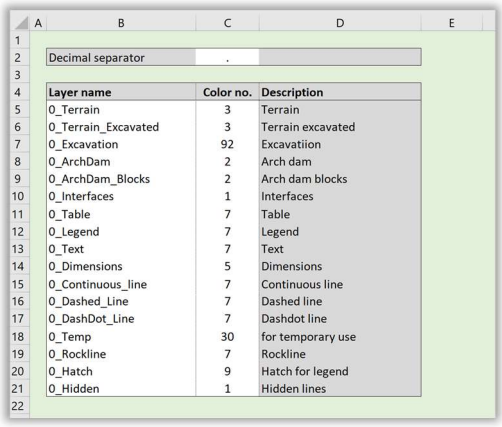
Excav. geometry at right abutment

El_from	El_to	V/H
m ASL	m ASL	
515.000	620.000	3.100
620.000	820.000	3.300

Vertical slicing S_V	Hor. slicing EL_H
m	m ASL
-175.000	795.000
-150.000	785.000
-125.000	775.000
-100.000	765.000
-75.000	755.000
-50.000	745.000
-25.000	735.000
0.000	725.000
25.000	715.000
50.000	705.000
75.000	695.000
100.000	685.000
125.000	675.000
150.000	665.000
175.000	655.000
	645.000
	635.000
	625.000
	615.000
	605.000
	595.000
	585.000
	575.000
	565.000
	555.000
	545.000
	535.000
	525.000

Figure 17: EXCEL input file – MAIN sheet

3.3 EXCEL input file - SETTINGS sheet



Decimal separator	.

Layer name	Color no.	Description
0_Terrain	3	Terrain
0_Terrain_Excavated	3	Terrain excavated
0_Excavation	92	Excavatiion
0_ArchDam	2	Arch dam
0_ArchDam_Blocks	2	Arch dam blocks
0_Interfaces	1	Interfaces
0_Table	7	Table
0_Legend	7	Legend
0_Text	7	Text
0_Dimensions	5	Dimensions
0_Continuous_line	7	Continuous line
0_Dashed_Line	7	Dashed line
0_DashDot_Line	7	Dashdot line
0_Temp	30	for temporary use
0_Rockline	7	Rockline
0_Hatch	9	Hatch for legend
0_Hidden	1	Hidden lines

Figure 18: EXCEL input file – SETTINGS sheet

4 OUTPUT

4.1 Arch dam

In the first step, an 3D arch dam solid is created and displayed in the correct position on the terrain. In addition, the interfaces between the dam and the terrain are displayed on the CHART sheet of the Excel file. Please see Figure 21. This information allows to estimate the excavation parameters as shown in Figure 11. The assumed dam/abutment interface along the centerline is shown as a black dashed line in the CHART.

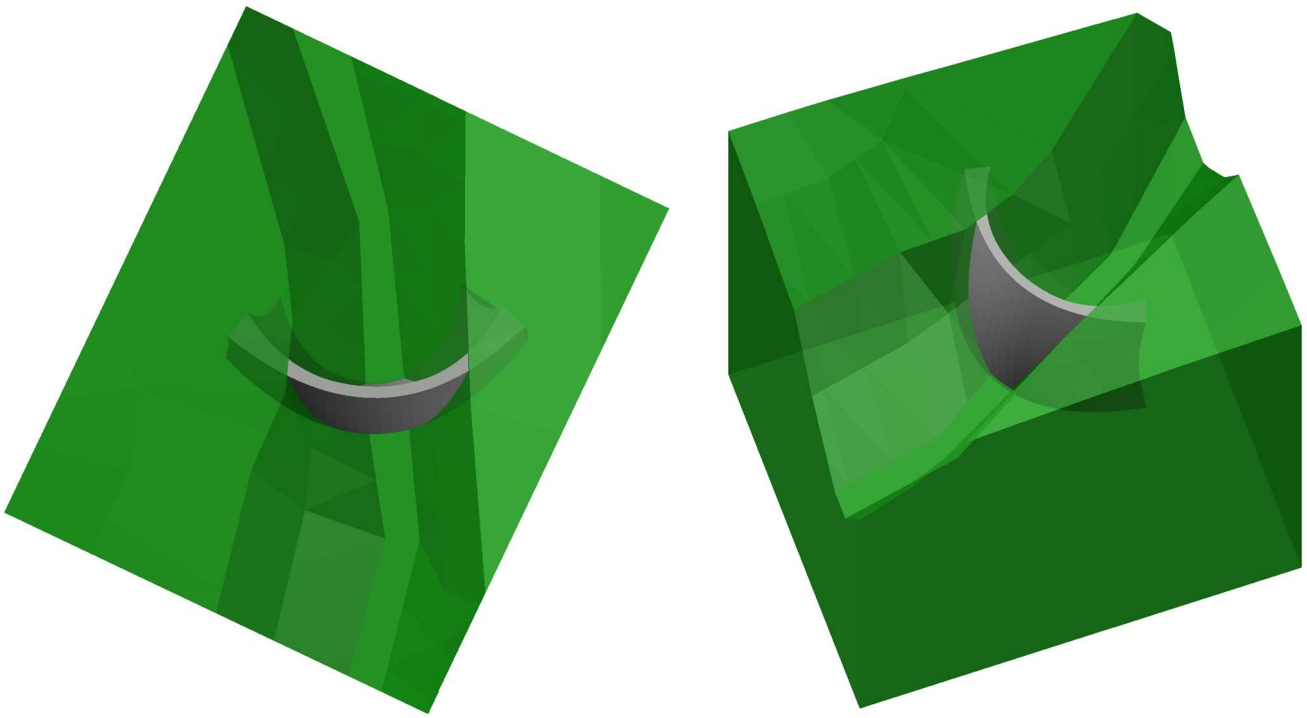


Figure 19: Arch dam without adjustment to excavation

For the display on the CHART page, the interface points of the dam/terrain and dam/abutment are represented by lengths projected onto the center line

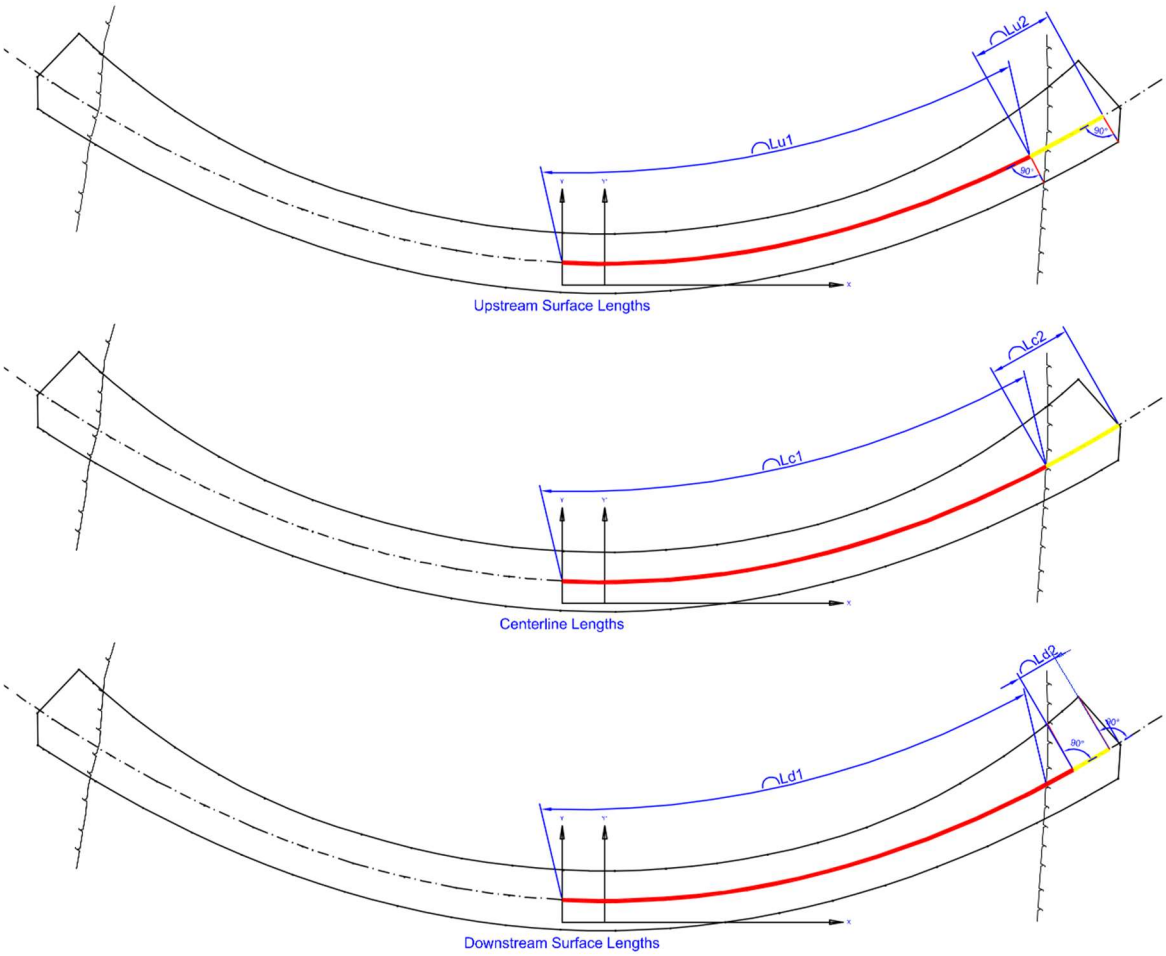


Figure 20: Notation – U/S, D/S and center line length definition used below

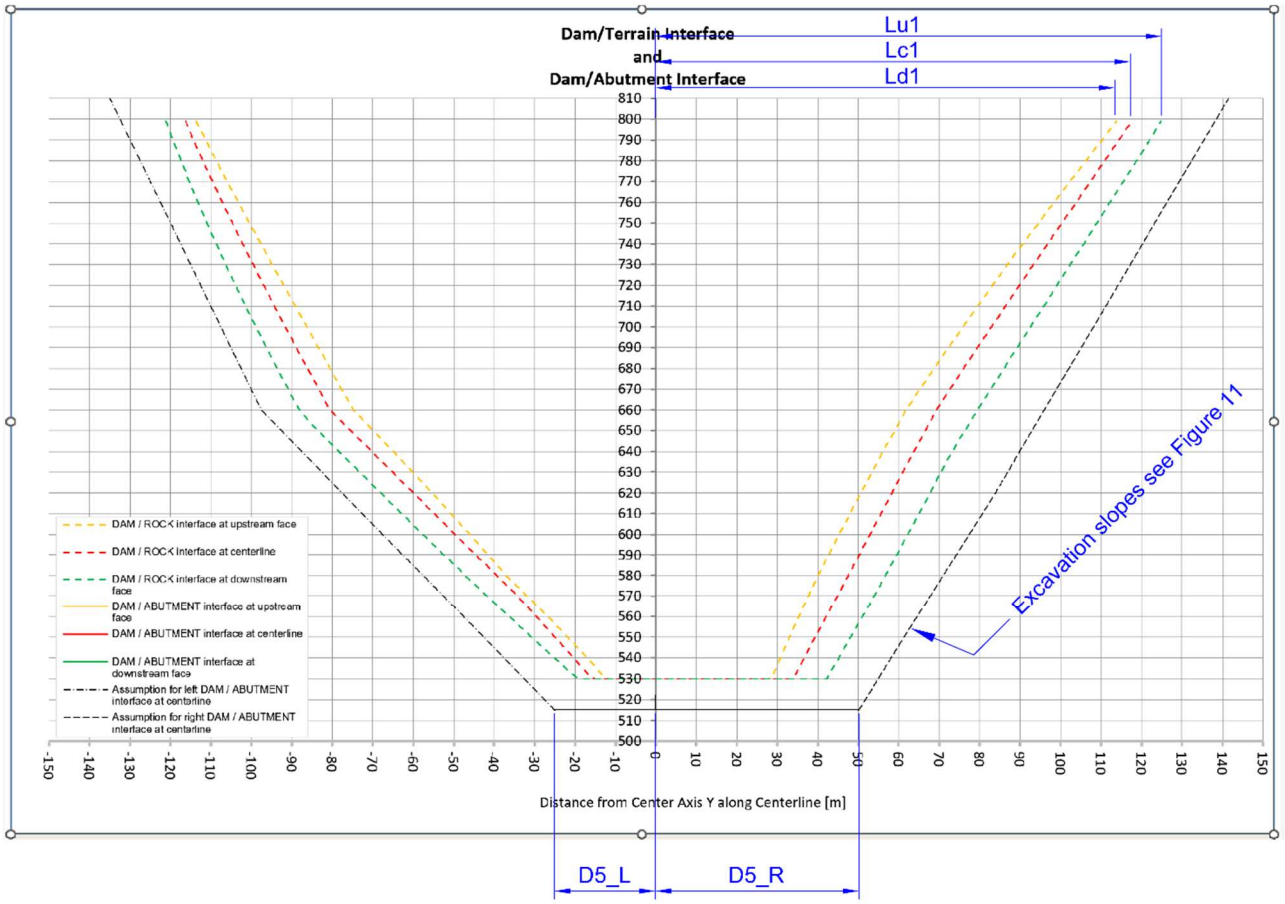


Figure 21: EXCEL output – CHART sheet showing arch dam/terrain interface

4.2 Excavation

A terrain 3D arch dam solid is created showing the excavation and the arch dam. In addition, the interfaces between the dam and the abutments are displayed on the CHART sheet of the Excel file. Please see Figure 23.

Using this CHART, you can estimate whether the dam will be founded deep enough in the rock by reading the lengths Lu2, Lc2 and Ld2.

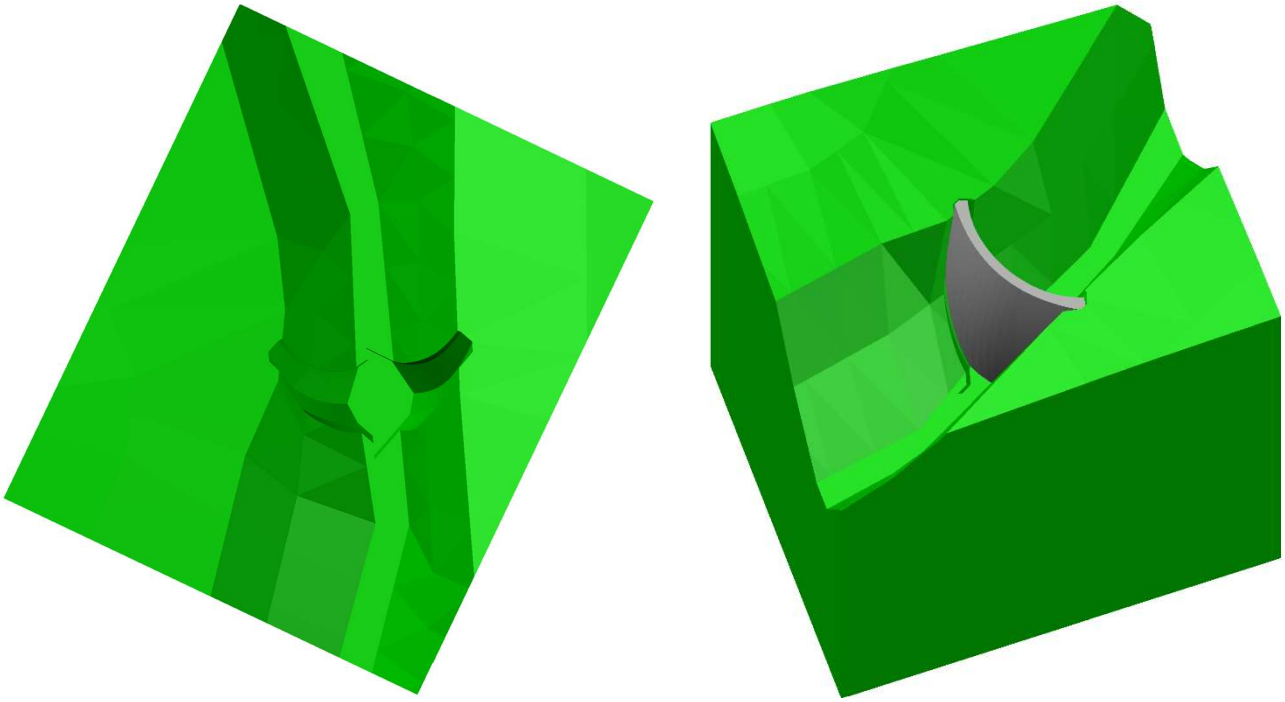


Figure 22: Construction site excavated

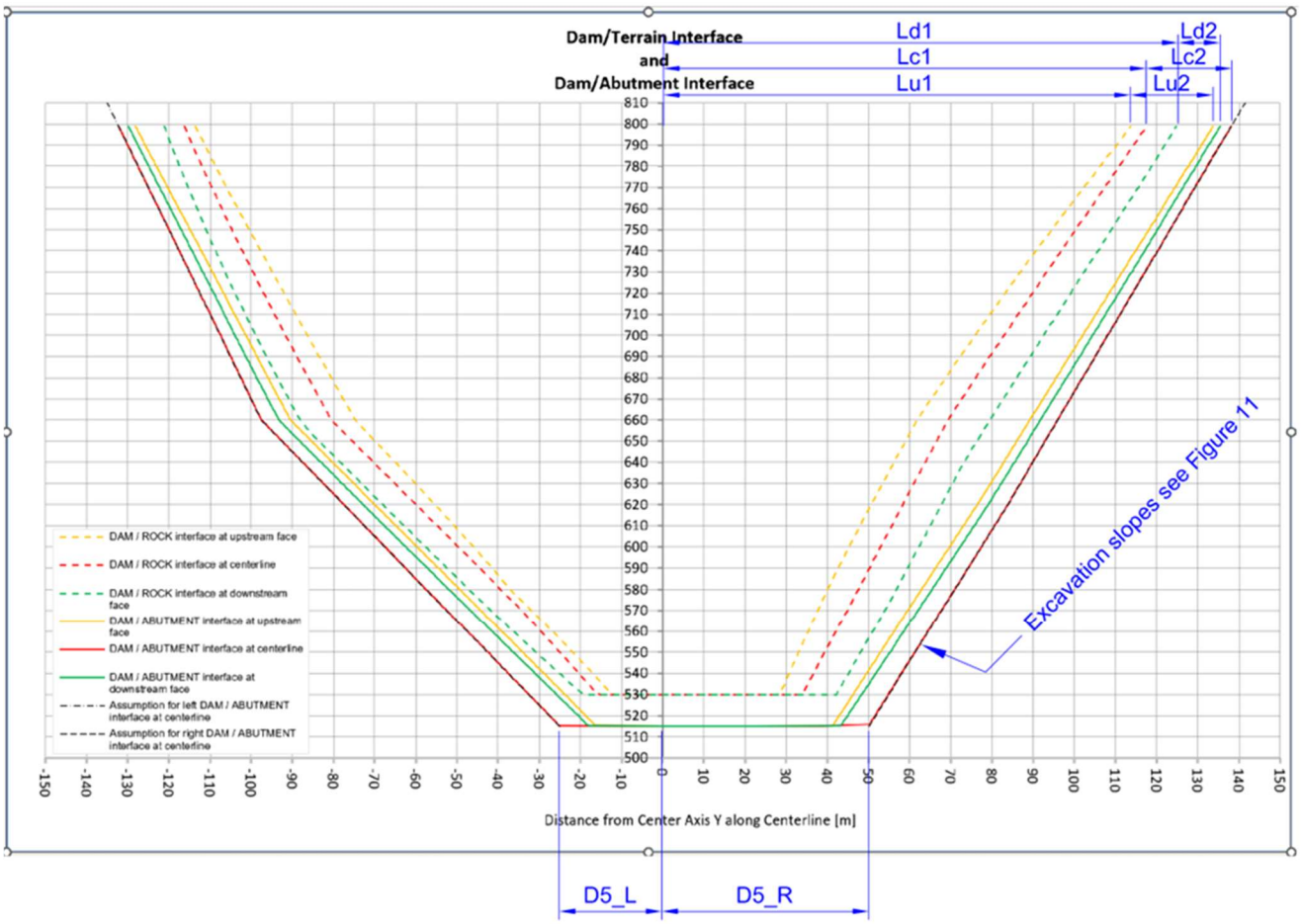


Figure 23: EXCEL output – CHART sheet showing arch dam/abutment interface

4.3 Arch dam concrete blocks

Generation of the final concrete blocks of the arch dam with horizontal and vertical construction joints as shown in Figure 24 below.

These concrete block (3DSolids) are intended to be exported using for example a SAT or IGES file into FEM programs such as Abaqus or Diana, for detailed representation of all required static and dynamic load cases.

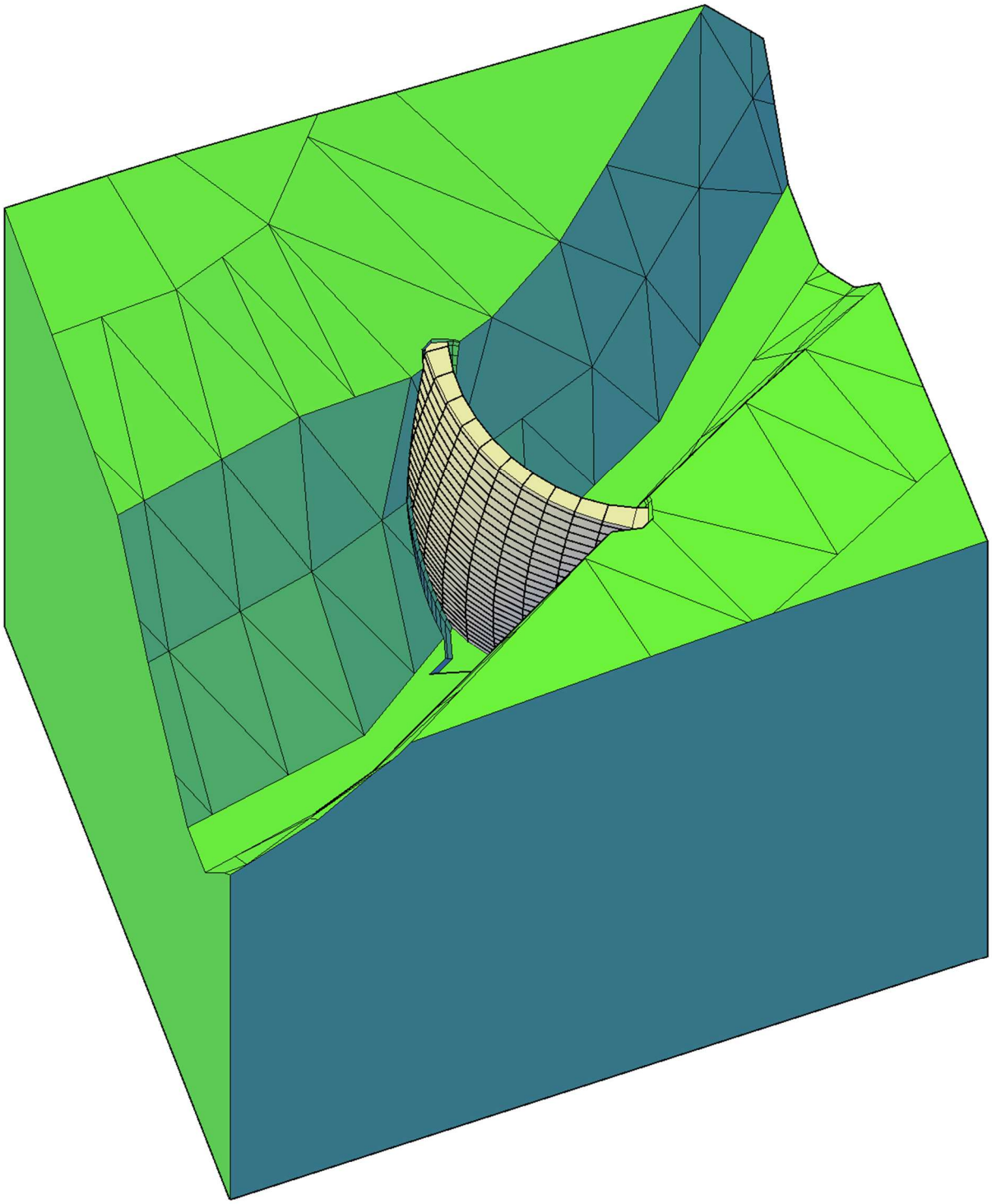


Figure 24: Arch dam concrete blocks

4.4 Plan view drawing

Plan view drawings showing the concrete blocks at elevations EL_T, EL_H and EL_B (please see Figure 12, Figure 13 and Figure 14) will be created.

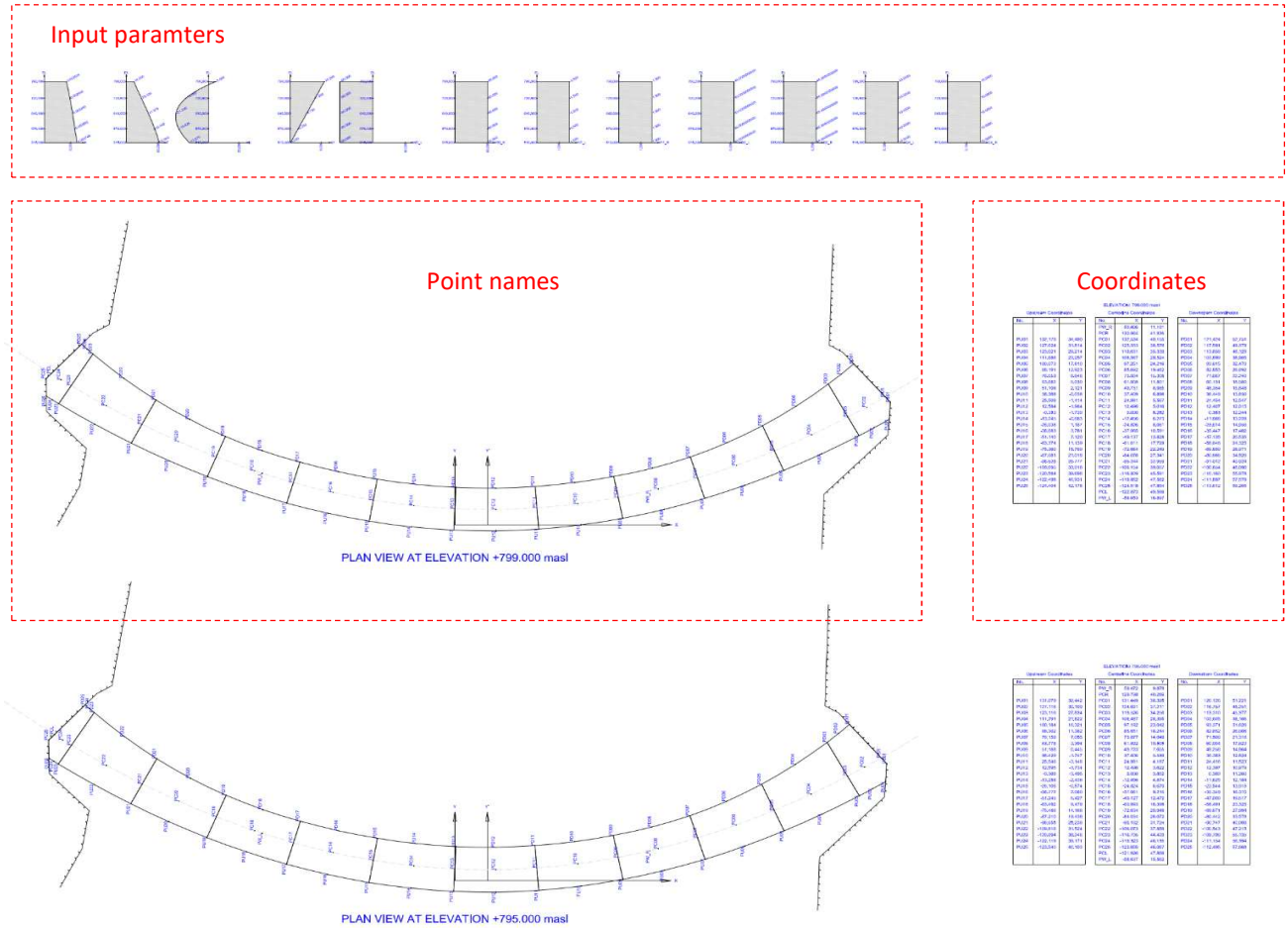


Figure 25: Plan view drawing

5 PROGRAM LIMITATION

If the decimal separator in windows is set to “.” (dot), the list separator in windows should be set to "," (comma).

If the decimal separator in windows is set to “,” (comma), the list separator in windows should be set to ";" (semicolon).

To create the plan view plan drawing, the arch dam shall consist of at least two concrete blocks that reach the full thickness T and widening W.

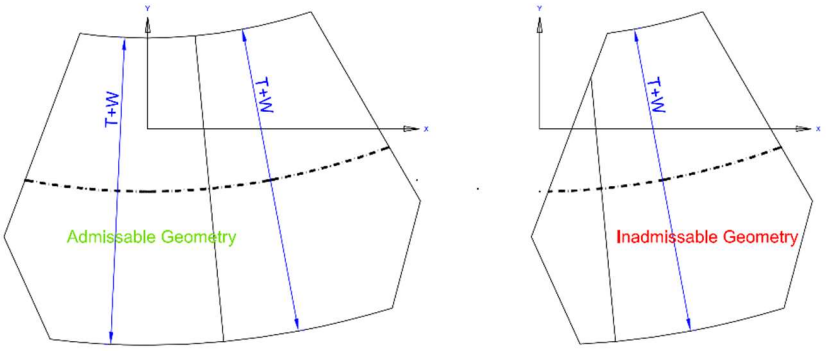


Figure 26: Admissable and inadmissible concrete block geometrie