

Conceptual design of fill dams for pump-storage reservoirs

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1 INTRODUCTION

Designing a pump storage plant involves several steps, and it requires a multidisciplinary approach that includes civil, electrical, and mechanical engineering, as well as environmental considerations. Increasingly, potential investors for pumped storage power plants expect comprehensive statements in the very first planning phase (feasibility study) regarding the best possible locations, lowest costs, cost comparisons, etc., before they can decide to commission further planning phases.

The *ReservoirDam* program was developed to meet these expectations despite the usually relatively low planning fee, as reservoirs in particular contribute a considerable proportion to the overall construction costs and at the same time the reservoir construction costs are heavily dependent on the shape of the terrain.

ReservoirDam is a software based on Visual Studio and AutoCAD offering an easy and rapid optimization of fill dam reservoirs regarding

- dam crown elevation (mass balance between cut and fill material)
- X and Y coordinates of center of dam crown polyline
- height of live water body
- optimization of shape of dam crown polyline (ratio between major and minor axis length A/B as defined in Figure 2-2 to Figure 2-4 below) and orientation angle AL with the aim of showing alternatives with the lowest possible construction costs for cut stripping, fill stripping, cut, fill, water-proof slope and floor face

Following data are required for optimization of dam elevation only:

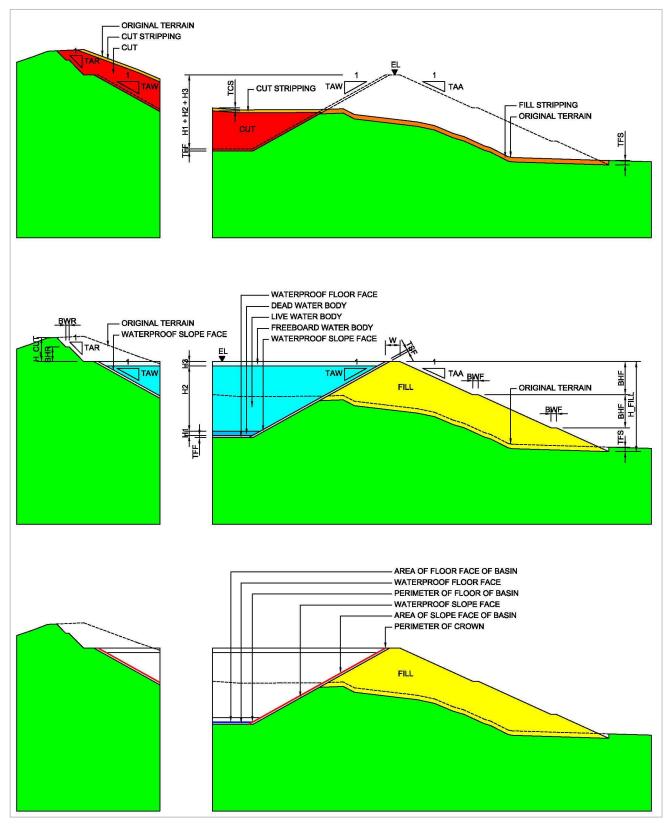
- volume of live water body
- estimated upstream dam slope TAW, downstream dam slope TAA and rock slope TAR (above dam crown)
- estimation of layer thicknesses for cut stripping TCS and fill stripping TFS
- estimation of thickness for waterproof slope face TSF and thickness for waterproof floor face TFF (including filter)
- a terrain 3dSolid drawing (for example derived from contour lines generated by use of the software Civil3D)

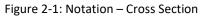
The following additional data are required in order to minimize construction costs:

- estimation of the percentage of excavated material (cut stripping, fill stripping and cut material) that can be re-used (treated or untreated) for fill dam construction
- unit prices for cut stripping, fill stripping, cut, fill (e.g. EUR/m³ each), water-proof slope and floor face (e.g. EUR/m² each)

2 NOTATION

2.1 Cross Section





Legend: W ... Crown width

- ΕL Crown elevation ... Η1 Depth of dead water body ... H2 Depth of live water body Freeboard H3 BWF ... Berm width at fill dam BHF ... Berm height at fill dam BWR ... Berm width at rock (above crown elevation) BHR ... Berm height at rock (above crown elevation) TFS ... Stripping depth below fill dam TCS ... Stripping depth on top of cut ... Thickness of waterproof slope face (including filter) TSF ... Thickness of waterproof floor face (including filter) TFF
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope as water face

2.2 Crown Shape Types

2.2.1 Elliptically Shaped Dam Crown

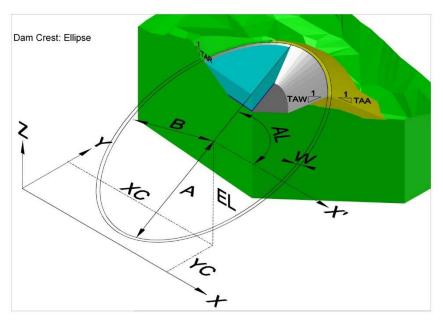


Figure 2-2: Notation - Elliptically Shaped Dam Crown

- A ... Ellipse semi-major axis length at crown
- B ... Ellipse semi-minor axis length at crown
- W ... Crown width
- EL ... Crown elevation
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope as water face
- XC ... X-coordinate of center of ellipse
- YC ... Y-coordinate of center of ellipse
- AL ... Rotation angle of ellipse

2.2.2 Arc Shaped Dam Crown

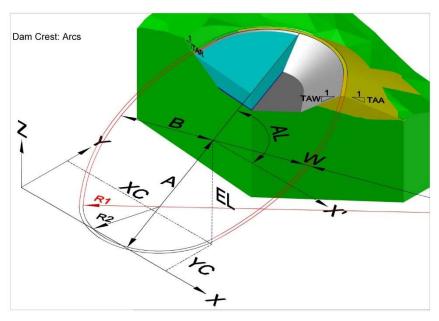


Figure 2-3: Notation - Arc Shaped Dam Crown

- A ... Arc semi-major axis length at crown
- B ... Arc semi-minor axis length at crown
- W ... Crown width
- EL ... Crown elevation
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope at water face
- XC ... X-coordinate of center of arcs
- YC ... Y-coordinate of center of arcs
- AL ... Rotation angle of arcs

2.2.3 Semi-circle Shaped Dam Crown

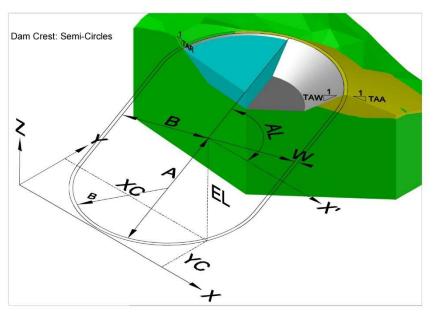


Figure 2-4: Notation - Semi-circle Shaped Dam Crown

- A ... Semi-circle semi-major axis length at crown
- B ... Semi-circle semi-minor axis length at crown
- W ... Crown width
- EL ... Crown elevation
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope at water face
- XC ... X-coordinate of center of semi-circles
- YC ... Y-coordinate of center of semi-circles
- AL ... Rotation angle of semi-circles

2.2.4 Polygonal Shaped Dam Crown – POLYLINE1

For type "POLYLINE1" only the inside crest polyline is defined. The outside crest polyline is at an offset W from inside crest polyline. The inside crest polyline shall consist of lines and/or arcs.

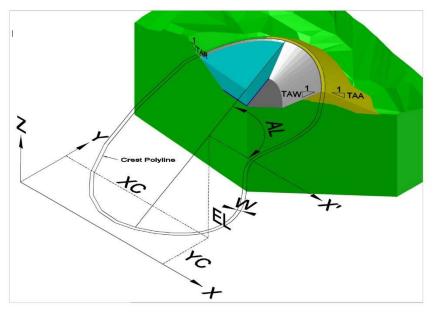
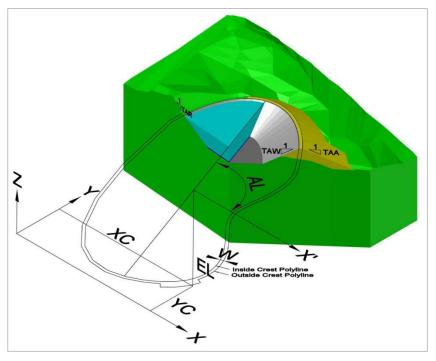


Figure 2-5: Notation - polygonal Shaped Dam Crown – Type POLYLINE1

- W ... Crown width
- EL ... Crown elevation
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope at water face
- XC ... X-coordinate of center of polyline
- YC ... Y-coordinate of center of polyline
- AL ... Rotation angle of polyline

2.2.5 Polygonal Shaped Dam Crown – POLYLINE2

For type "POLYLINE2" 2 polylines inside and outside crest polylines are defined. Inside and outside crest polylines shall consist of lines and/or arcs.





- EL ... Crown elevation
- TAR ... Tangent of rock slope (above crown)
- TAA ... Tangent of dam slope at air face
- TAW ... Tangent of dam slope at water face
- XC ... X-coordinate of center of polyline
- YC ... Y-coordinate of center of polyline
- AL ... Rotation angle of polyline

3 RESERVOIR DAM MODULES

3.1 MAIN

lder setup				Info + Settings
Project folder		C:\PROJECTS\TEST_ReservoirDam	Select	ABOUT
Sub-folder for input values		INPUT	Select	HELP
Sub-folder for output values		OUTPUT	Select	SETTINGS
it files				Create
utoCAD template drawing	.dwg	Template.dwg	Select	TERRAIN CHECK
setup ject folder C:\PROJECTS\TEST_ReservoirDam b-folder for input values INPUT b-folder for output values OUTPUT lies toCAD template drawing .dwg Template dwg	Template.xlsx	Select	WATER BODY	
Project folder C:\PROJECTS\TEST_ReservoirDam Select Attack Sub-folder for input values INPUT Select Select Sub-folder for output values OUTPUT Select Select Imput files AutoCAD template drawing .dwg Template.dwg Select EXECL template file xlsx Template.xlsx Select Select	OPTIMIZATION			
				FINAL

Figure 3-1: MAIN form

In the MAIN form the *input* and *output directory* as well as the *templates* are defined. The *template drawing* is an empty drawing with some settings.

Following files are delivered with the program *ReservoirDam*:

- Template.dwg ... empty AutoCAD drawing with some settings
- Template.xlsx ... Excel file used for graphical presentation of the construction costs
- NORTH_ARROW.dxf ... north indicator shown in the result plot files

3.2 ABOUT

ReservoirDam - ABOUT	- 0
	ОК
Product Name:	ReservoirDam
Version:	2024.0 - for AutoCAD 2019-2020, Microsoft EXCEL, 32 or 64 b
Copyright:	by Dr. Otto Kronberger, 2024
Company Name / Owner:	Software-Kronberger / Otto Kronberger
E-Mail:	otto.kronberger@a1.net
Cell:	+43 664 5459551
Address:	Schmiedingerstrasse 177C, 5020 Salzburg, Austria
Tax Number:	91 162/4732 (Austria) VAT-exempt according to § 6 para. 1 no. 27 sales tax law (small business regulation)

Figure 3-2: ABOUT form

3.3 SETTINGS

lessages					
				CANCEL	ОК
ayer setting			Unit prices		
Layer name C	Color No.	Description	Cut stripping	15	EUR/m³
0_TERR	94	Terrain	Cut	24	EUR/m ³
0_CUT	42	Cut	Fill stripping	15	EUR/m ³
0_FILL	2	Fill	Fill	18	EUR/m ³
0_CUT_STRIPPING	30	Stripping on top of cut	Waterproof slope face (incl. filter)	300	EUR/m ²
0_FILL_STRIPPING			Waterproff floor face (incl. filter)	300	EUR/m ²
0_WB_DEAD	140	Dead water body			
0_WB_LIVE	4	Live water body	Reservoir to be designed		
0_WB_FREEBOARD	140	Freeboard	Reference elevation of center of live	044.05	masl
0_FACE_SLOPE	254	Waterproof slope face	water body Z_LIVE	611.25	IIIdSI
0_FACE_FLOOR	253	Waterproof floor face	Reference XC coordinate of	4850	m
0_NORTH_POINTER	1	North pointer	elevation of center of live water body Reference YC coordinate of		-
0_ERRORS	40	Errors	elevation of center of live water body	3750	m
0_CROWN_POLYLINE	1	Crown Polylines	Cost increase per 1 m extension of the headrace tunnel	17500	EUR/m
Decimal separator shown on output			Turbine cost increase per 1 m live	700000	EUR/m
	· dot		water body elevation decrease		
	C com	ma			
Inits			Power cavern location		
	• mete	r	X coordinate of end of headrace		-
	C yards	3	tunnel	9000	m
Currency			Y coordinate of end of headrace tunnel	6000	m
	E	UR	Z coordinate of end of headrace	300	masl

Figure 3-3: SETTINGS form

In the SETTINGS form following items can by defined:

- color number for layers
- decimal separator, which shall be shown on the output lists
- definition of units to be shown on the output lists
- unit prices and currency, etc.

Currency, unit prices, XC, YC, Z_LIVE, X, Y and Z values are used for POST-PROCESSING only.



Figure 3-4: Notation - Cross section

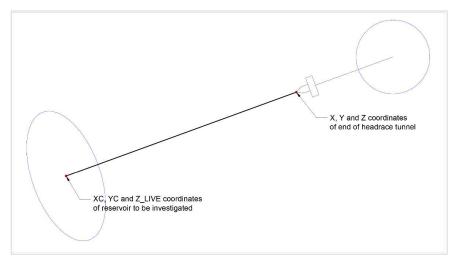


Figure 3-5: Notation - Plan view

3.4 TERRAIN CHECK (optionally)

ReservoirDam - TERRAIN CHEC					
lessages					
			CANCEL	EXEC	CUTE
put and output files					
there may contract mCo					
Headline in result list file	TEXT	Terrain Demo Text			122
	TEXT TERR	Terrain Demo Text Terrain.dxf	Sel	ect	.dxf
Headline in result list file			Sel	ect	dxt

Figure 3-6: TERRAIN CHECK form

A terrain check is recommended in order to prevent AutoCAD from encountering fatal errors (mainly numerical errors) in OPTIMIZATION or FINAL module due to incompatible terrain elements.

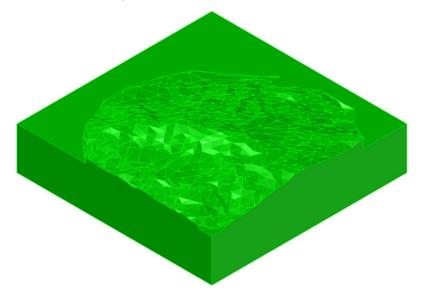


Figure 3-7: TERRAIN file (3D solid)

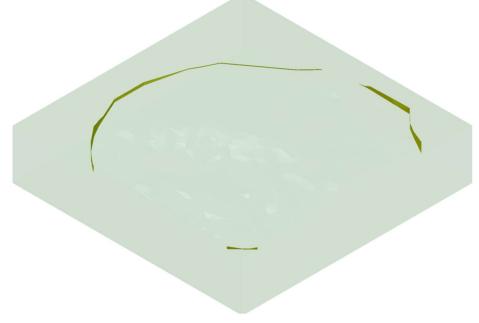


Figure 3-8: TERRAIN drawing file with Errors (red) and Warnings (yellow)

ERRAIN DEMO TEXT			
Terrain file	= C:\T	EST_QuickDAM	NINPUT\TERRAIN.dxf
total number of elements	=	1790	
No. of terrain 3DSolid floor regions	=	1	
No. of terrain 3DSolid vertical boundary regions	=	4	
No. of terrain 3DSolid vertical boundary surfaces	=	0	
No. of terrain regions	=	1759	
No. of terrain surfaces	=	0	
No. of vertical terrain regions	=	26	WARNINGS
No. of vertical terrain surfaces	=	0	
No. of overhanging terrain regions	=	0	
No. of overhanging terrain surfaces	=	0	
No. of regions that form holes in terrain body	=	0	
File showing errors (red) and warnings (yellow) in f	ile = C:\T	EST_QuickDAM	NOUTPUT\TERRAIN_RESULT.dwg
Notation:			
<pre>* regions = plane elements</pre>			
<pre>* surfaces = curved elements</pre>			

Figure 3-9: TERRAIN list file

3.5 WATER BODY (optionally)

essages				CANCEL	ECUTE
					CUIE
nput data					
Find: VOLUME, HEIGHT, SIZE	FIND	SIZE		Select	1
Fill dam crown shape	TYPE	POLYLINE1		Select]
Fill dam crown polyline	POLY	Crown_Approx	dxf	Select	.dxf
Header in result list file	TEXT	Water Demo Te	ext		_
Result list file	LIST	Water_Result.t	xt	.txt	
Result plot file	PLOT	Water_Result.d	lwg	.dwg	
Volume of live water body	V_LIVE	1000000	m³		
Semi-major axis length	A	231.5	m		
Semi-minor axis length	В	92.5	- m		
Ratio A/B	A/B	1	-		
Freeboard	H3	1	m		
Depth of live water body	H2	20	m		
Dead water body	H1	1	m		
Overall thickness of waterproof slope face	TSF	0.5	m		
Overall thickness of waterproof floor face	TFF	0.5	m		
Tangent of dam slope at water face	TAW	0.6	-		

Figure 3-10: WATER BODY form

The WATER BODY module allows an initial estimation of

- volume of live water body V_LIVE
- or depth of live water body H2
- or size of dam crown (A and B, or scale factor for dam crown polyline) without reference to the terrain.

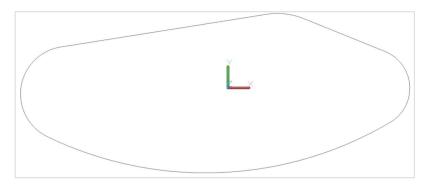


Figure 3-11: Crown Polyline

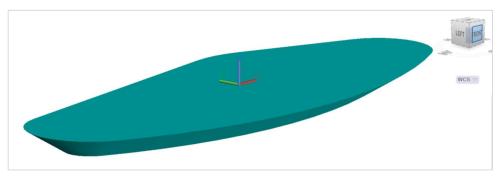


Figure 3-12: WATER BODY result plot file

WATER DEMO TEXT			
INPUT			
File name of dam crest polyline	FILE	= (C:\TEST_QuickDAM\INPUT\CROWN_1_APPROX.dxf
Volume of live water body	V_LIVE	=	100000.000 m ³
Freeboard	H3	=	1.000 m
Depth of live water body	H2	=	20.000 m
Depth of dead water body	H1	=	1.000 m
Thickness of waterproof slope face	TSF	=	0.500 m
Thickness of waterproof floor face	TFF	=	0.500 m
Ratio V/H of dam slope at water face	TAW	=	0.60000
RESULT			
Scale factor for crown polyline	SCALE	=	0.97062874

Figure 3-13: WATER-BODY result list file

3.6 **OPTIMIZATION** (optionally)

ReservoirDam - OPTIMIZATION								-	
Messages								ANCEL	ECUTE
								POST-PROCES	SING
nput data 1					_	Input data 3			
Find: Volume, Height, Size	FIND	SIZE		Selec	t	Maximum cut height	H_CUT [200	m
Fill dam crown shape	TYPE	ARCS		Selec	t	Maximum dam height	H_FILL	200	m
Terrain drawing	TERR	Terrain.dxf		Selec	t .dxf	Live water body	V_LIVE	1000000	m ^a
Fill dam crown polyline	POLY	Crown_Appro:	c.dxf	Selec	t .dxf	Crown width	W	6	m
Post-processing input/output summary file	BATCH	OPTI_Summary.inp OPTI_Summary.xlsx		Selec	t .inp	Semi-major axis length	A [92.5	m
EXCEL summary output file	OUT			.xlsx		Semi-minor axis length	В		m
Detailed result list file	LIST	OPTI_Result.t	ĸt	.txt		Freeboard	нз [1	m
Header in result list file	TEXT	Optimization [omo Text			Dead water body	Н1 [1	m
Re-use of cut excavation for fill dam constr.	RUC	75	%			Tangent of rock slope above crown	TAR [1	-
Re-use of cut strpping for fill dam constr.	RUCST	0	%			Tangent of dam slope at water face	TAW [0.6	_
Re-use of fill strpping for fill dam constr.	RUFST	0	%			Tangent of dam slope at air face	TAA [0.5	-
Fill / Cut balance tolerance	TOL	0.1	%			Fill dam berm width	BWF [3	m
put data 2						Fill dam berm height	BHF [15	m
put data 2		from		increment		Berm width at cut above crown elevation	BWR [3	m
Crown elevation	EL	0.000	to			Berm width at cut above crown elevation	BHR [15	m
		500	700	_	masi	Stripping depth on top of cut	TCS [1	m
X-Cooridnate of center of crown polyline	XC	4800	4900	25	- m	Stripping depth below fill dam	TFS [1	m
Y-Coordinate of center of crown polyline	YC	3700	3900	50	m	Overall thickness of waterproof slope face	TSF [0.5	m
Rotation angle of crown polyline	AL	100	110	5	_	Overall thickness of waterpoof floor face	TFF [0.5	m
Depth of Live water body	H2	15	20	5					
Ratio A/B	A/B	1.5	2.5	0.5		☐ Save each parameter combination to dra	wing file OPT	1 n of nn dwa	1

Figure 3-14: OPTIMIZATION form

For fill dam construction, it is usually necessary to re-use at least some of the excavation material, untreated or treated.

With the OPTIMIZATION EXECUTE module

- volume of live water body V_LIVE
- or depth of live water body H2
- or size of dam crown (A and B, or scale factor for dam crown polyline)
- can be calculated fully automatically for numerous combinations such as
- X-coordinate of center of crown polyline XC
- Y-coordinate of center of crown polyline YC

• rotation angle of crown polyline AL

and the corresponding volumes, areas, lengths and especially crown elevation are calculated. The crown elevation is calculated so that the specified $Ratio = \frac{\text{reusable cut,cut stripping and fill stripping}}{fill}$ is maintained.

A 3D drawing and a corresponding entry in the list files (*Post-processing input/output summary file* and *Detailed result list file*) are created for each combination.

Combination;XC;YC;AL;SCALE;A;B;A/B;H2;EL;V LIVE;Z LIVE;V CSTR;V CUT;V FSTR;V FILL;A SLOPE;A FLOOR;ERROR	
1 of 450;4800.000;3700.000;100.000;100.000;15.679;130.453;1.500;15.000;599.609;99999.041;591.555;75962.164;1463939.311;84914.276;1098672.993;32228.355;53673.39	91;0;
2 of 450;4800.000;3700.000;105.000;1.000;195.679;130.453;1.500;15.000;599.609;999999.041;591.555;76054.135;1472870.740;85746.460;1105371.481;32228.355;53673.39	91;0;
3 of 450;4800.000;3700.000;110.000;100.00;195.679;130.453;1.500;15.000;599.463;999999.041;591.408;76183.035;1486729.018;86191.668;1115147.690;32228.355;53673.39	91;0;
4 of 450;4800.000;3750.000;100.000;100.000;195.679;130.453;1.500;15.000;601.440;999999.041;593.386;76604.340;1386425.388;82076.090;1040524.515;32228.355;53673.39	91;0;
5 of 450;4800.000;3750.000;105.000;105.000;195.679;130.453;1.500;15.000;601.367;999999.041;593.313;76678.134;1396741.497;82281.465;1047860.300;32228.355;53673.39	
6 of 450;4800.000;3750.000;110.000;105.679;130.453;1.500;15.000;601.111;999999.041;593.056;76834.434;1414079.171;82712.693;1059896.900;32228.355;53673.39	
7 of 450;4800.000;3800.000;100.000;1.000;195.679;130.453;1.500;15.000;602.747;999999.041;594.692;74572.822;1304977.023;87505.159;978109.402;32228.355;53673.39	
8 of 450;4800.000;3800.000;105.000;1.000;195.679;130.453;1.500;15.000;602.832;999999.041;594.777;74539.614;1300819.520;86830.637;976316.405;32228.355;53673.39	
9 of 450;4800.000;3800.000;110.000;1.000;195.679;130.453;1.500;15.000;602.734;999999.041;594.680;74617.046;1303986.185;86109.414;978209.180;32228.355;53673.393	1;0;

Figure 3-15: OPTIMIZATION – Post-processing input/output summary file

rameter Combination 1 of 450				
Arc semi-major axis length	A	-	195.679	m
Arc semi-minor axis length	в	-	130,453	
Elevation of crown	EL	=	599,609	
Width of crown	W	-	6,000	
Freeboard	НЗ	-	1.000	
Depth of live water body	H2	=	15,000	
Depth of dead water body	H1	=	1,000	
Berm width at rock cut above crown	BWR	=	3,000	
Berm height at rock cut above crown	BHR	-	15,000	m
Berm width at fill dam	BWF	=	3,000	m
Berm height at fill dam	BHF	=	15,000	m
Ratio V/H of rock slope above dam crown	TAR	=	1,000	
Ratio V/H of dam slope at water face	TAW	=	0.600	
Ratio V/H of dam slope at air face	TAA	=	0.500	
Stripping depth below fill dam	TES	=	1.000	m
Stripping depth on top of cut	TCS	=	1.000	m
Thickness of waterproof slope face	TSF	=	0.500	m
Thickness of waterproof floor face	TFF	=	0.500	m
X-coordinate of center of crest polyline	XC	=	4800.000	m
Y-coordinate of center of crest polyline	YC	=	3700.000	m
Rotation angle of crest polyline	AL	=	100.000	0
Fill versus excavation balance	BAL	=	1.001	
Elevation of floor of basin	Z_FLOOR	=	582.109	ma
Volume of freeboard water body	V_FREE	=	79730.528	m ³
Volume of live water body	V_LIVE	=	999999.041	m ³
Volume of dead water body	V_DEAD	=	54393.893	m ³
Elevation of center of live water body	Z_LIVE	=	591.555	ma
Volume of stripping on top of cut	V_CSTR	=	75962.164	
Volume of cut	V_CUT	=	1463939.311	
Volume of fill	V_FILL	=	1098672.993	
Volume of stripping below fill dam	V_FSTR		84914.276	
Volume of waterproof slope face	V_SLOPE			
Volume of waterproof floor face	V_FLOOR		26657.661	
Area of waterproof slope face	A_SLOPE		32228.355	
Area of waterproof floor face	A_FLOOR	=	53673.391	m²
rameter Combination 2 of 450				
Arc semi-major axis length	A	=	195.679	m
Arc semi-minor axis length	в	=	130.453	m
Elevation of crown	EL	=	599.609	ma
Width of crown	W	=	6.000	m
Freeboard	H3	=	1.000	m
Depth of live water body	H2	=	15.000	m
Depth of dead water body	H1	-	1,000	m

Figure 3-16: OPTIMINZATION - Detailed result list file

With the OPTIMIZATION **POST-PROCESSING** module the most cost-effective parameter combination can be determined.

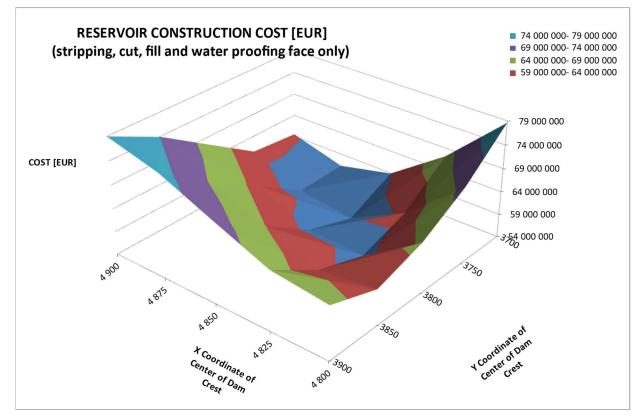


Figure 3-17: OPTIMINZATION – EXCEL summary output file chart

																							De	etail A	A	
			¢	0			6	н	1				м	N	0	,	Q		5	6	U	v	w	. x	Y 7 AA AB AC	40 4
	Combination	×	¥	with	State		0	4/8	2	Ees_Count	A UNE	00472	OUT STRP	01	ant the	114	MOR SOM	AKA_FLOOK	NADE	Perservair construction cost [KUM]	Gesi correction due la appropriate reservoir ste noraaas/decreaas due to eieration loss/galacti	cast corrections due to pervaloch length increase/decrease (CUR)	Cest correction due to buildine cost: increaso(decrease (\$1.84)	Fetal cost [KMI]	INTERPORT	Condean al Cenar al
	1 of 450	4 800	3 700	\$00.000	1.000	195.679	130.453	1.500	15.000	599.609	999 999	591 555	75 962	1 463 939	84 954	1,098 673	32 228	53 673	0	83 094 328	2 791 614	1 187 005	\$ 856 500	93 929 446	Combination 411 of 450 at line 217 shows minimum costs	1 53 747 82
	2 of 450	4.800	3 700	105.000	1.000	195.679	130.453	1.500	15.000	595.609	999 995	501.555	75 054	1 472 871	85 746	1 105 371	32 228	\$3.673	0	83 443 117	2 803 332	1 187 005	6 856 500	94 289 954		
	a of 450	4 800	2 700	110.000	1.000	195.679	130.453	1.500	15.000	599.463	909 999	591.408	75 188	1 486 729	86 192	1 115 148	22 228	53 672	٥	83 960 299	2 864 483	1 187 005	5 939 400	94 971 187		
	5 of 450	4 800	3 700	100.000	1.000	226.279	113.140	2,000	15.000	601.282	1 000 000	593.259	77 310	1410862	86 358	1057794	34 561	52 702	0	81 534 862	2 249 542	1 187 005	5 663 700	90 635 109		
	7 of 450	4.800	3 700	105.000	1.000	226.279	113.140	2.000	15.000	601.318	1 000-000	\$93.296	77 168	1 424 505	87 553	1 064 170	34 561	\$2 702	0	82 064 880	2 253 527	1 187 005	\$ 637 8D0	91 145 212		
	09 of 450	4 850	2750	100.000	1.000	221.366	92,506	2.500	20.000	633.645	999 995	600.715	57 716	\$22.652	77 154	617 423	42 028	23 094	0	25 420 467	116 843	0	443 800	55 981 110		
4;	10 of 450	4 850	3 750	105.000	1.000	231.266	92.506	2.500	20.000	611.237	999 995	601.308	57 466	790 574	09 849	593 048	42 038	33 094	0	54 097 918	7 542	0	29 400	54 134 859		
	11 of 450	4 850	\$ 750	110.000	1.000	281,266	92,509	2,500	20.000	631.279	999 991	601.350	57 174	781.676	6/5 #28	MIS 723	42 0 58	83.094	0	53 747 823	0	a	D	55 747 825		
	7 of 450	4 850	3 800	100.000	1.000	195.679	130.453	1.500	15.000	604.700	999 995	596.645	69 622	1 029 943	88 976	772 992	32 228	53 673	0	66 781 989	1 059 230	413 447	2 293 500	70 721 252		
	8 of 450	4 850	3 800	105.000	1.000	295.679	130.453	1.500	15.000	605.103	399 995	597.068	69 029	999 778	88 341	749 093	32 228	53 673	0	65 609 429	950 189	- 413 447	3 011 400	69 157 571		
	19 of 450	4 850	3 800	110.000	1.000	195.679	130,453	1.500	15.000	605.810	1001 1001	397.755	64 603	575430	88.009	754 460	32 228	\$3.673	0	64 846 304	828 826	418 447	2 866 500	68 192 683		
1	12 of 450	4 850	3 800	100.000	1.000	226.279	113.140	2.000	15.000	605.615	1 000 000	507.593	72 432	1 002 556	71 646	752 145	34 561	52 702	0	\$5,940,004	832 458	- 413 447	2 629 900	68 988 925		

Figure 3-18: OPTIMINZATION – EXCEL summary output file

S	T	U	V	W	х	Y	Z	AA	AB	AC	AD	AE
ERROR	Reservoir construction cost [EUR]	Cost correction due to appropriate reservoir size increase/decrease due to elevation loss/gainXC	Cost correctionn due to penstock length increase/decrease [EUR]	Cost correction due to turbine cost increase/decrease [EUR]	Total cost [EUR]	RUCTIO	REFINITION CUT, THE AND RESERVOIR CONSTRUCTION COST	(stripping, cut, fill and water proofing face only)	[EUR]	X Coordinate of Center of D	Y Coordinate of Center of D	COST [EUR]
0	83 094 328	2 791 614	1 187 005	6 856 500	93 929 446	Combinat	ion 411 of 4	450 at line 2	17 shows i	ninimum co	osts (53 74	7 823)
0	83 443 117	2 803 332	1 187 005	6 856 500	94 289 954							
0	83 960 299	2 864 483	1 187 005	6 959 400	94 971 187							
0	81 534 862	2 249 542	1 187 005	5 663 700	90 635 109							
0	82 064 880	2 253 527	1 187 005	5 637 800	91 143 212							
0	55 420 467	116 843	0	443 800	55 981 110							
0	54 097 918	7 541	0	29 400	54 134 859							
0	53 747 823	0	0	0	53 747 823							
0	66 781 989	1 059 210	- 413 447	3 293 500	70 721 252							
0	65 609 429	950 189	- 413 447	3 011 400	69 157 571							
		893 326	- 413 447	2 866 500	68 192 683							

Figure 3-19: OPTIMINZATION – EXCEL summary output file – Detail A

								CANCEL	EXECUT
nput data 1						Input data 2			
Fill dam crown shape	TYPE	POLYLINE1	-	Select	1	Tangent of rock slope above crown	TAR	1	
Terrain drawing	TERR	Terrain.dxf		Select dxf Tangent of dam slope at water fac		Tangent of dam slope at water face	TAW	0.6	-
Crown polyline	POLY	Crown_Final.d	xf	Select	.dxf	Tangent of dam slope at air face	TAA	0.5	
Result list file	LIST	Final_Result.tx	t	.dxf	_	Fill dam berm width	BWF	3	m
Result plot file	PLOT	Final_Result.dv	vg	.txt		Fill dam berm height	BHF [15	m
Header line in result list file	TEXT	Final Demo Te	xt			Berm width at cut above crown elevation	BWR	3	m
Crown elevation	EL	611.25	masl			Berm width at cut above crown elevation	BHR	15	m
Crown width	W	6	m			Stripping depth on top of cut	TCS	1	m
Semi-major axis length	A	231.3	m			Stripping depth below fill dam	TFS	1	m
Semi-minor axis length	В	92.5	m			Overall thickness of waterproof slope face	TSF [0.5	m
Freeboard	H3	1	m			Overall thickness of waterpoof floor face	TFF [0.5	m
Depth of live water body	H2	20	m			X-Coordinate of center of crown polyline	XC	4850	m
Dead water body	H1	1	m			Y-Coordinate of center of crown polyline	YC [3750	m
Maximum cut height	H_CUT	200	m			Rotation angle of crown polyline	AL [110	•
Maximum dam height	H_FILL	200	m						

Figure 3-20: FINAL form

With the FINAL module, the reservoir dam is created both as a 3D drawing and as a list file according to the values shown in Figure 3-20.

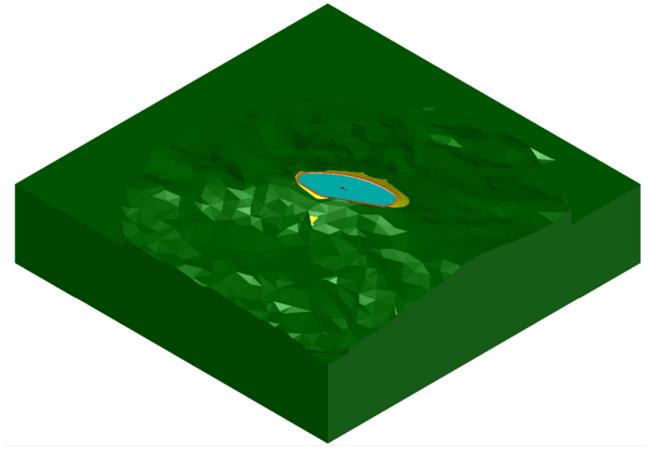


Figure 3-21: FINAL – Result plot file

IPUT				
File name of dam crest polyline	FILE	=	C:\TEST QuickD	AM\INPUT\CROWN 1 FINAL.dx
Elevation of crown	EL	=	610.250	
Width of crown	W	=	6.000	
Freeboard	H3	=	1.000	m
Depth of live water body	H2	=	20.000	
Depth of dead water body	H1	=	1.000	m
Berm width at rock cut above crown	BWR	=	3.000	m
Berm height at rock cut above crown	BHR	=	15.000	m
Berm width at fill dam	BWF	=	3.000	m
Berm height at fill dam	BHF	=	15.000	m
Ratio V/H of rock slope above dam crown	TAR	=	1.000	
Ratio V/H of dam slope at water face	TAW	=	0.600	
Ratio V/H of dam slope at air face	TAA	=	0.500	
Stripping depth below fill dam	TFS	=	1.000	m
Stripping depth on top of cut	TCS	=	1.000	m
Thickness of waterproof slope face	TSF	=	0.500	m
Thickness of waterproof floor face	TFF	=	0.500	m
X-coordinate of center of crest polyline	XC	=	4850.000	m
Y-coordinate of center of crest polyline	YC	=	3750.000	m
Rotation angle of crest polyline	AL	=	110.000	0
SULT				
Elevation of floor of basin	Z FLOOR	=	587.750	masl
Volume of freeboard water body	V FREE	=	67901.452	m ³
Volume of live water body	V LIVE	=	1000000.235	m ³
Volume of dead water body	V DEAD			m ³
Elevation of center of live water body	ZLIVE	=	600.344	masl
Volume of stripping on top of cut	V CSTR	=	58571.514	m ³
Volume of cut	V_CUT	=	776705.367	m ³
Volume of fill	V_FILL	=	585246.351	m ³
Volume of stripping below fill dam	V_FSTR	=	60621.866	m ³
Volume of waterproof slope face	V_SLOPE	=	21533.895	m ³
Volume of waterproof floor face	V_FLOOR	=	16177.009	m ³
Area of waterproof slope face	A_SLOPE	=	42934.363	m ²
Area of waterproof floor face	A_FLOOR	=	32718.230	m ²
Perimeter of waterproof slope face at crown	P_CROWN	=	1099.567	m
Perimeter of waterproof floor face	P_FLOOR	=	869.184	m
Maximum height of fill dam	HFILL	=	67.231	m
Maximum height of rock cut above crown elev.	H CUT	=	8.750	m

Figure 3-22: FINAL – Result list file

CONSTRUCTION STAGES:



Origin Terrain



Excavation of fill stripping



Excavation completed



Excavation of cut-stripping



Excavation of cut



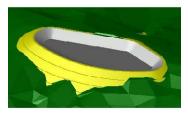
Construction of fill dam



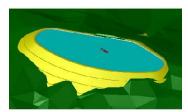
Construction of water-proof slope face



Completed reservoir with dead water body



Construction of water-proof floor face



Completed reservoir with live water body

4.1 General

For verification of the *ReservoirDam* software a circular shaped reservoir as shown in Figure 4-1 below is used. A horizontal terrain surface at elevation +400 is assumed.

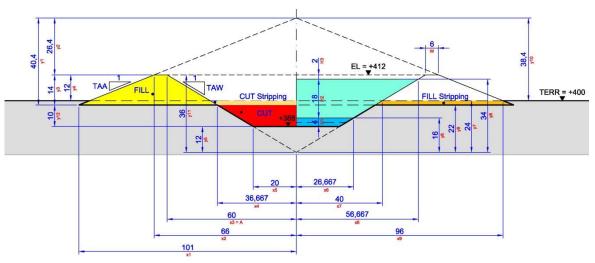


Figure 4-1: Program verification – Notation for circular reservoir

4.2 ReservoirDam Results

INPUT Arc semi-major axis length Arc semi-minor axis length Elevation of crown width of crown Freeboard Depth of live water body Depth of dead water body Berm width at rock cut above crown Berm height at rock cut above crown Berm height at fill dam Berm height at fill dam Ratio V/H of rock slope above dam crown Ratio V/H of dam slope at water face Ratio V/H of dam slope at air face Stripping depth below fill dam	A = B = EL = W = H3 = H2 = H1 = BWR = BHR = BHR = BHF = TAR = TAR = TAR = TAR = TAR = TAS =	60.000 m 60.000 m 412.000 mas1 6.000 m 2.000 m 18.000 m 4.000 m 0.000 m 0.000 m 0.000 m 1.000 m 1.000 0.600 0.400 2.000 m
Stripping depth below fill dam Stripping depth on top of cut Thickness of waterproof slope face Thickness of waterproof floor face X-coordinate of center of crest polyline Y-coordinate of center of crest polyline Rotation angle of crest polyline RESULT Elevation of floor of basin	TCS = TSF = TFF = XC = AL = Z_FLOOR =	2.000 m 0.000 m 0.000 m 0.000 m 0.000 °
Volume of freeboard water body Volume of live water body Elevation of center of live water body Volume of stripping on top of cut Volume of cut Volume of fill Volume of fill Volume of waterproof slope face Volume of waterproof floor face Area of waterproof floor face Area of waterproof floor face Perimeter of waterproof floor face Maximum height of for cut above crown elev.	$V_FREE = V_LIVE = V_DEAD = Z_LIVE = V_CCSTR = V_CCUT = V_FSTR = V_FSTR = V_FLOOR = A_FLOOR = A_FLOOR = P_CROWN = P_FLOOR = H_FTIL = H_CUT = H_CUT = V_FREE = V_FLOR = V_FLOOR = V_FSUC = V_F$	54856.164 m ³ see note 1 0.000 m ³ 11723.824 m ² 1256.637 m ² 376.991 m 125.664 m

Figure 4-2: Program verification – ReservoirDam results

Note 1: The volume V_FSTR shows a slightly higher value in chapter 4.2 than in 4.3. The reason for this is that in chapter 3 the fill stripping ends vertically, but in chapter 4 it is overhanging. Please compare Figure 2-1 and Figure 4-1.

4.3 Analytical Results

For notation, please see Figure 4-1

INPUT							
W := 6	x1 := 101	y1 := 40.4					
H3 := 2	x2 := 66	y2 := 26.4					
H2 := 18	x3 := 60	y3 := 14					
H1 := 4	x4 := 36.666667	y4 := 12					
TAW := 0.6	x5 := 20	y5 := 12					
TAA := 0.4	x6 := 26.6666667	y6 := 16					
	x7 := 40	y7 := 24					
$A \coloneqq x3$	x8 := 56.666667	y8 := 34					
B := x3	x9 := 96	y9 := 22					
		y10 := 38.4					
		y11 := 36					
RESULTS	21 2 240 2						
$V_{fill_str} := x1^2 \cdot \pi$	$\pi \cdot \frac{y_1}{3} - x_2^2 \cdot \pi \cdot \frac{y_{10}}{3} - x_7^2 \cdot \pi$	$\frac{y/3}{3} + x4^2 \cdot \pi \cdot \frac{y9}{3}$	$V_{fill_str} = 51736$	m3			
$V_cut_str := x7^2 \cdot \tau$	$\pi \cdot \frac{y7}{3} - x4^2 \cdot \pi \cdot \frac{y9}{3}$		$V_cut_str = 9239$	m3			
$V_{cut} := x4^2 \cdot \pi \cdot \frac{y^2}{3}$	$\frac{9}{2} - x5^2 \cdot \pi \cdot \frac{y5}{3}$		V_cut = 25947	m3			
V_fill := $x1^2 \cdot \pi \cdot \frac{y1}{3}$	$\frac{1}{2} - x2^2 \cdot \pi \cdot \frac{y2}{3} - x3^2 \cdot \pi \cdot \frac{y11}{3}$	$+x4^2 \cdot \pi \cdot \frac{y9}{3}$	V_fill = 206402	m3			
V_free := $x3^2 \cdot \pi \cdot \frac{y}{2}$	$\frac{11}{3} - x8^2 \cdot \pi \cdot \frac{y8}{3}$		$V_{free} = 21386$	m3			
V_live := $x8^2 \cdot \pi \cdot \frac{y}{2}$	$V_live := x8^2 \cdot \pi \cdot \frac{y8}{3} - x6^2 \cdot \pi \cdot \frac{y6}{3}$						
$V_{dead} := x6^2 \cdot \pi$	$\frac{y6}{3} - x5^2 \cdot \pi \cdot \frac{y5}{3}$		V_dead = 6888	m3			
A_floor := $x5^2 \cdot \pi$			A_floor = 1257	m2			
A_slope := $\frac{x3 + x}{2}$	$\frac{5}{\cdot 2 \cdot \pi} \cdot \frac{\text{H1} + \text{H2} + \text{H3}}{\sin(\text{atan}(\text{TAW}))}$		A_slope = 11724	m2			

Figure 4-3: Program verification – Analytical results

4.4 Conclusion

ReservoirDam results are in accordance with analytical results.