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The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

ENGINEERING FEASIBILITY DESIGN REPORT

SUPPORTING DOCUMENT 4: COST MODEL

FINAL

AUGUST 2014



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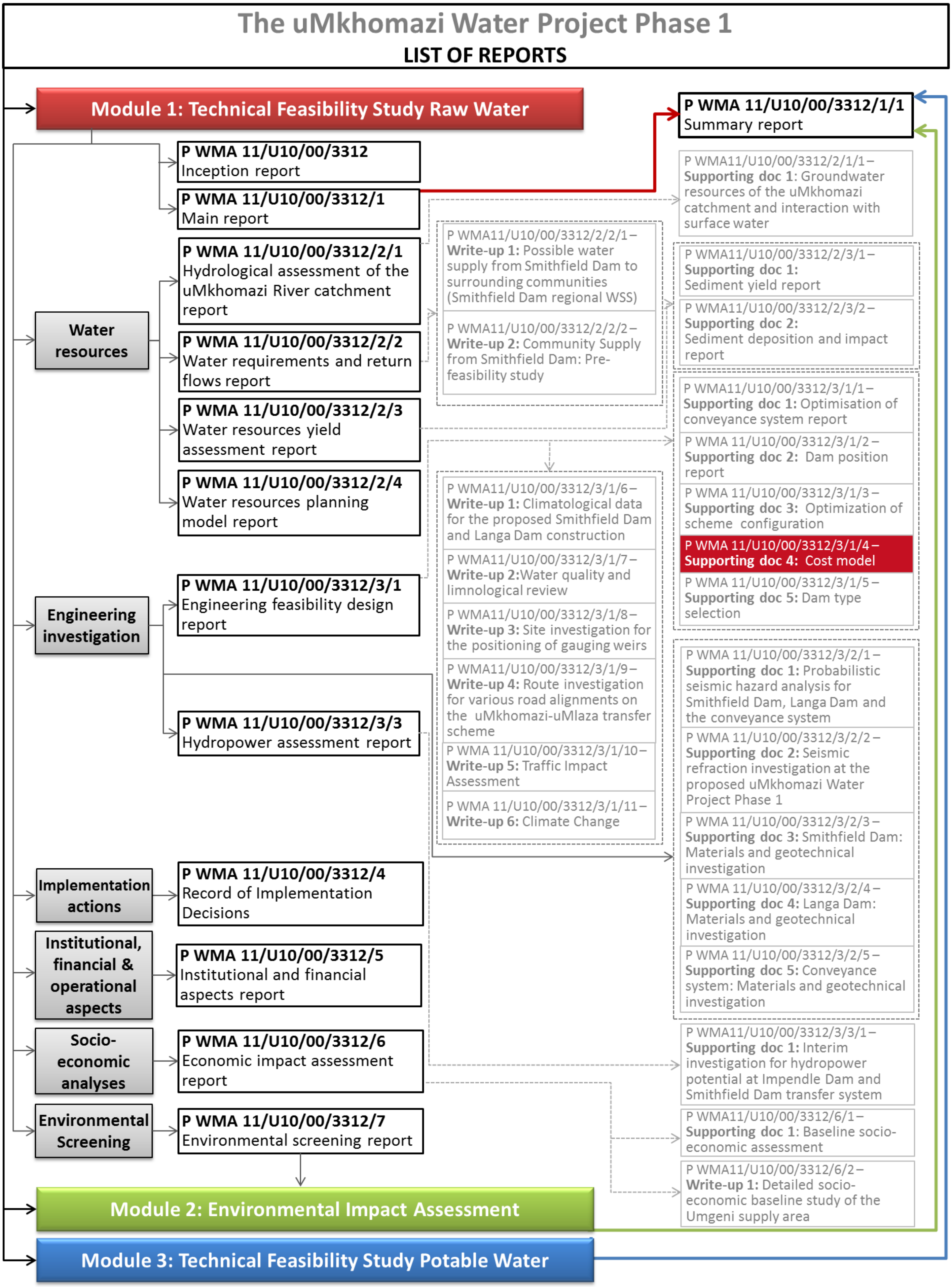
PREAMBLE

In June 2014, two years after the commencement of the uMkhomazi Water Project Phase 1 Feasibility Study, a new Department of Water and Sanitation was formed by Cabinet, including the formerly known Department of Water Affairs.

In order to maintain consistent reporting, all reports emanating from Module 1 of the study will be published under the Department of Water Affairs name.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1 INTRODUCTION TO THE COST MODEL

1.1 BACKGROUND AND OBJECTIVES

A Microsoft Excel spreadsheet-based cost model was developed for the purpose of this study. The objective of the cost model is to provide an interactive, user friendly spreadsheet of cost estimates with interlinked facilities for all raw water components of the uMkhomazi Water Project, including (1) Smithfield Dam (main wall and saddle wall), (2) Langa Balancing Dam, as well as (3) the transfer tunnel and (4) the raw water pipeline to compare construction cost estimates for:

- Selection of the ***optimal dam size*** (i.e. FSL);
- Guidance of the ***geotechnical investigations***;
- Selection of the ***optimal dam type***; and ultimately
- Selection of the ***best scheme***.

The cost model was developed early in the study and was updated as and when new information became available. It was established in close accordance to the *VAPS guidelines* for the preliminary sizing, costing and engineering economic evaluation planning options study for dams (Consult 4, 1994).

The cost model makes provision for various dam sizes in sufficiently small incremental steps within the envelope of required yields to allow for optimization of (1) ***the dam size*** (see report *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, et al., 2014)), as well as, (2) ***the dam type*** (see report *P WMA 11/U10/00/3312/3/1/5: Dam type selection* (AECOM, et al., 2014)). As such, provision is made for full supply levels up to 940 masl (Smithfield Dam) and 923 masl (Langa Balancing Dam) as well as the following dam types:

- Roller compacted concrete (RCC) gravity dam;
- Zoned earthfill embankment dam;
- Earth core rockfill dam (ECRD) **- including various options of zoning depending on availability of material**;
- Concrete faced rockfill dam (CFRD) **- including various options of zoning depending on availability of material**; and
- Composite dam ***- various options***.

1.2 ORGANISATION OF THIS REPORT

This report forms part of the feasibility study on the *uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water*. More specifically, it covers *Task 5.17 (Creating a cost model for the project)* as part of the Engineering Investigations (Task 5). The Engineering Investigation main task consists of the tasks shown in **Table 1.1**:

Table 1.1: Tasks within the Engineering Investigation task

Task number	Task description
5.1	Optimization of conveyance system
5.2	Dam position
5.3	Materials investigation
5.4	Geomorphologic and seismic investigation
5.5	Geotechnical investigation
5.6	Survey
5.7	Dam type selection
5.8	Establish required capacity of dam
5.9	Flood and backwater calculations for the final dam
5.10	Climatological data for the construction site
5.11	Water quality and limnological review
5.12	Sediment yield
5.13	Land requirements and associated costs
5.14	Optimize scheme configuration
5.15	Assessment of the potential for hydropower
5.16	Feasibility design of the selected scheme
5.17	Creating a cost model for the project

The cost model was used in order to assist in the decision making and cost estimation for the following tasks:

- Task 5.1: Optimization of conveyance system;
- Task 5.2: Dam position;
- Task 5.7: Dam type selection;
- Task 5.14: Optimisation of scheme;
- Task 5.15: Assessment for the potential for hydropower;
- Task 7: Institutional, operational and financial aspects; and
- Task 8: Socio-economic analysis.

The report is organised as follows:

- Chapter 1 serves as an ***introduction*** to the report and provides the background and objectives of the cost model.
- Chapter 2 provides ***basic information*** on the cost model pertaining to the rates and costs included in the model.
- Chapter 3 gives an overview on the ***functioning*** of the cost model and presents an overview of what can be expected in the user guide.
- Chapter 4 provides a ***user guide*** explaining how the cost model must be operated. It includes information on the process that needs to be followed in order to ensure that all the required variable parameters are accurately inputted. This chapter also provides an explanation on how to input the dam long section, dimensions of the dam and the rates. In addition, it also provides information on how to view the output results and what should be reviewed in order to provide an accurate output.
- Chapter 5 incorporates ***technical information*** giving a detailed explanation on how the quantities for the various dam types are determined.

2 BASIC INFORMATION ON THE COST MODEL

2.1 COSTS

The cost model takes into account the following ***direct costs*** within each of the major system components as mentioned in **Section 1**:

- Dam(s):
  - Dam forming and excavation;
  - Multi-level intake structure and outlet works;
  - Side channel or ogee spillway(s) with chute; and
  - Diversion works (including cofferdam(s), tunnel(s), intake and outlet portals);
- Transfer tunnel;
  - Intake structure (including intake tower, outlet works, stilling basin, bridge, mechanical and electrical items, etc.);
  - Portals, adits, ventilation shafts and tunnel excavations;
  - Rock support, grouting and concrete linings; and
  - Access roads.
- Raw water pipeline;
  - Excavations;
  - Supply and laying of pipes; and
  - Backfilling.

In addition the following costs are taken into consideration (the percentages shown in brackets are set as a default in the model; they may however be adjusted):

- Landscaping (5% of direct costs)
- Miscellaneous (10% of direct costs)
- Preliminary and general (30%)
- Contingencies (10%)
- Planning design and supervision (15%)
- VAT (14%)

As the main objective of the cost model is to ***compare*** construction cost estimates, and being common costs for all the different scheme-options, the following costs are excluded from the cost model:

- Roads (deviation of roads as well as access roads);
- Electricity supply and deviation;

- Water to site;
- Housing and accommodation;
- Social (relocation) and environmental costs; and
- Flow gauging weirs.

2.2 Bill of Quantities and Rates for Dams

The bill of quantities incorporated in the cost model for each of the different dam types was based on that from the *Vaal Augmentation Planning Study (VAPS)* (Consult 4, 1994) with a level of detail commensurate to a feasibility study.

For this purpose the latest rates from tenders for the various dam components were obtained and incorporated into the cost model. Rates for (1) embankment-forming materials, (2) excavation activities and (3) concrete are explained in detail in the following sections.

2.2.1 Rates for embankment-forming materials

In accordance with the South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams (South African Bureau of Standards, 1984) rates included in the cost model for all ***embankment forming-materials***, i.e. (1) impervious fill, (2) semi pervious fill, (3) rockfill, (4) rip-rap, (5) gravel and sand layer(s), (6) drains, (7) IVRCC, (8) RCC, and (9) CVC sand, consist of the following costs:

- Selection and delivery of material excavated; or
- Excavating and selecting material from borrow pits in the designated borrow areas; as well as
- Haulage;
- Spreading;
- Adding water or drying;
- Placing;
- Compacting;
- Grading in the relevant zones or parts of the embankment;
- Stockpiling or processing, or both, where necessary; and
- Final grading of borrow pits that are in the dam basin.

Rates adopted for embankment forming-materials are summarised in **Table 2.1**.

Table 2.1: 2013 Rates adopted for embankment forming-materials

Item no		Item description	Rate (R/m³)
		Forming embankment	
8.3.5	a)	Core (impervious earthfill)	48.37
	b)	Upstream and downstream shells (semi pervious earthfill)	48.37
	c)	Rockfill (Impervious layer)	91.00
	d)	Rip-rap	438.52
	e)	Gravel layer	97.94
	f)	Sand layer transition zone	97.94
	g)	Blanket and chimney drains	789.45
	h)	IVRCC(1)	45.45
	i)	RCC concrete	1156.71
	j)	CVC concrete	1 981.85

(1) Per square metre of dam surface area

2.2.2 Rates for excavation activities

In accordance with the South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams (South African Bureau of Standards, 1984) rates included for all ***excavation activities*** distinguished between the following:

Material from essential excavations, i.e. the embankment foundation excavations, that is excavated and ***unsuitable for use in the embankments***. This rate covers the cost of excavation in all materials, removal to the ***designated waste disposal site*** that was identified in the dam basin, spreading and trimming.

Material from essential excavations, i.e. the embankment foundation excavations, that is excavated and ***suitable for use in the embankments***. This rate covers the cost of excavation of the hole in all materials and trimming it ready for further construction activity. This material might need to be stockpiled for later use in a ***designated stockpile area***. Provision is also made here for excavation in intermediate and hard rock material.

Rates adopted for excavation activities are summarised in **Table 2.2**.

Table 2.2: 2013 Rates adopted for excavation activities

Item no	Item description	Rate (R/m³)
	Excavation	
8.3.3	a) Material unsuitable for embankment *(excavation, removal to designated waste disposal sites in the dam basin, spreading and trimming)*	31.60
	b) Material suitable for embankment from essential excavations Stockpiled *(excavation , possible removal to stockpile areas, and trimming it ready for further construction activity)*	30.30
	c) Extra over items (b) for excavation in: 1) Intermediate material 2) Hard rock material	 Included in 8.3.3 (a) 36.50

2.2.3 Rates for concrete

In accordance with the South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams (South African Bureau of Standards, 1984) rates adopted for the ***different types of concrete*** used in the dam forming are summarised in **Table 2.3**.

Table 2.3: 2013 Rates adopted for different types of concrete used in the dam forming

Acronym	Item description	Definition	Component of dam	Rate (R/m³)
CVC	Conventional vibrated concrete	• A specific mix-design of concrete that produces a specific range of strengths and is delivered by dump trucks or conveyors, poured and compacted with concrete vibrators. • Two types of conventional vibrated concrete as follows were used: • **Mass concrete:** • Concrete set without structural reinforcement. • Strength: 5 - 10 MPa • **Structural concrete:** • A special type of concrete that is capable of carrying a structural load or forming an integral part of a structure. • Strength: 25 - 30 MPa	• Diversion works; • Intake structure; • Outlet works; • Spillway, i.e. approach, chute and plunge pool; • Measuring weirs.	1 981.85
RCC	Roller compacted concrete	• A special blend of concrete that has essentially the same constituents as conventional concrete but in different ratios, and increasingly with partial substitution of fly ash for Portland cement. • A mix of cement/fly ash, water, sand, aggregate and common additives, but contains much less water. The produced mix is drier and essentially has no slump. • Placed in a manner similar to paving: the material is delivered by dump trucks or conveyors, spread by small bulldozers or specially modified asphalt pavers, and then compacted by vibratory rollers.	• Main dam and spillway forming on a concrete gravity dam	1 156.71
IVRCC	Immersion-vibrated roller compacted concrete	• A special blend of conventional roller compacted concrete that is used as interface concrete to achieve an excellent finish and prevents the ingress of water into the RCC, thus improving the durability of the RCC concrete.	• Facecrete layer on a concrete gravity dam	45.40 / m² of dam surface area

All types sourced from local site processed doleritic materials.

The rate for ***roller compacted concrete (RCC)*** included in **Table 2.3** covers the cost of (1) materials, (2) blasting and processing, (3) mixing, (4) transport, (5) spreading and (6) compacting, as well as (7) other costs i.e. curing, water pressure testing, etc.

The rate for ***conventional vibrated concrete (CVC)*** included in **Table 2.3** covers the cost of (1) materials, (2) blasting and processing, (3) mixing, (4) transport, (5) cooling and (6) vibration, as well as (7) other costs i.e. placing labour, placing plant and joints cleaning, etc.

3 FUNCTIONING OF THE COST MODEL

The cost model consists of a main input table that enables ease of movement between the different input and output tables. The desired input and output tables are opened by selecting the hyperlinks on the main input table.

The general steps that need to be followed with the cost model are as follows:

- Step 1: Insert the long section of the dam;
- Step 2: Select the required dam type(s);
- Step 3: Choose the required components within the cost model;
- Step 4: Change the variable parameters and rates;
- Step 5: Observe the output results: Calculations, bill of quantities and summary sheet.

Figure 3.1 summarises the flow of the input, calculations and output within the cost model.

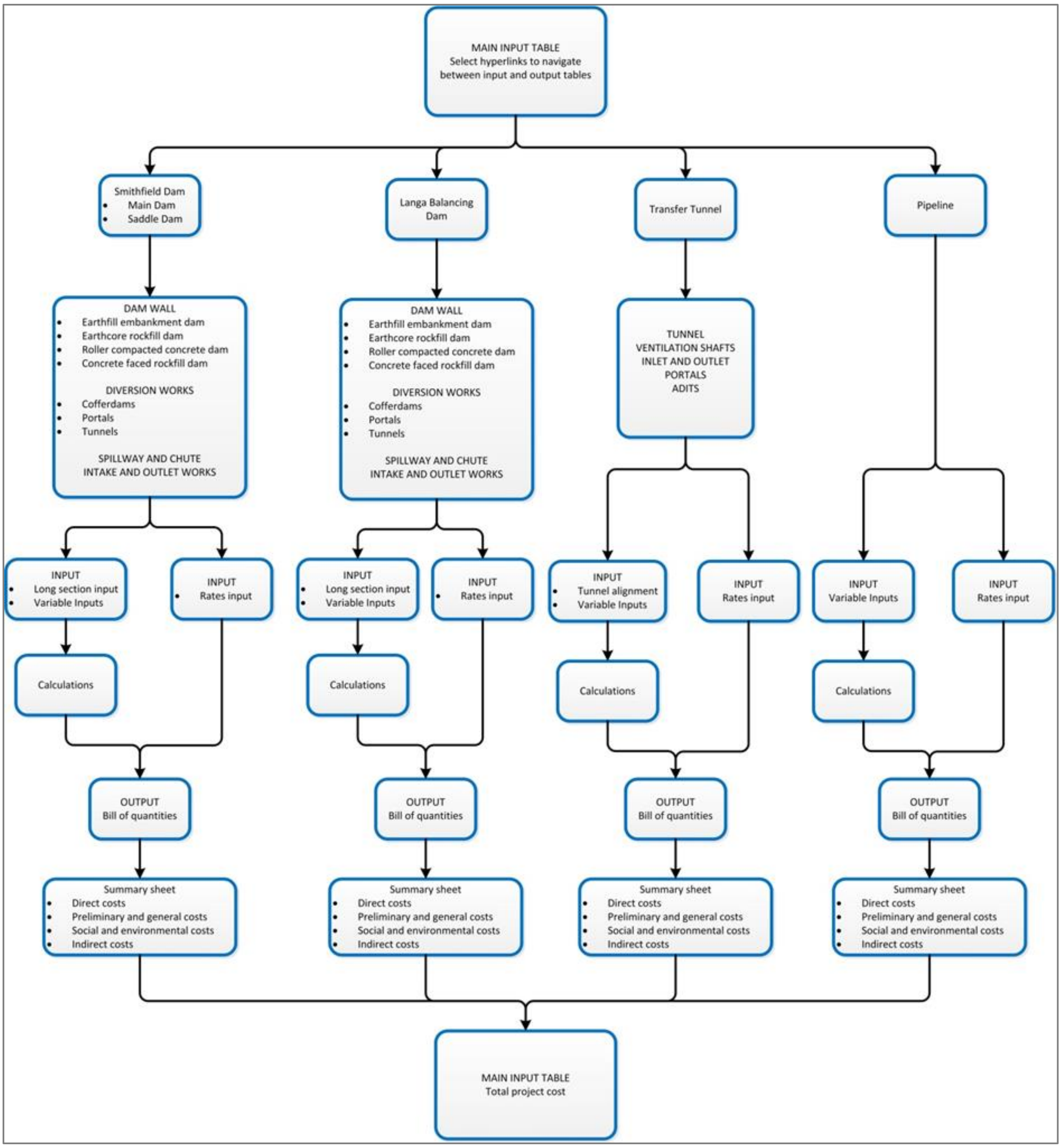


Figure 3.1: Cost model flow diagram

4 COST MODEL USER GUIDE

4.1 MAIN INPUT PANEL

The main input table enables the quick transition between different spreadsheets for input of parameters and the observation of output values. Selecting a hyperlink will take you to the required spreadsheet where data can be inputted or reviewed. As shown in **Figure 4.1**, the information is input from the left to the right by selecting the hyperlinks. In order to return to the main input table, select the AECOM logo. The input occurs in the following order:

- **Step 1:** *Long section input:* Selecting the hyperlink will open the long section input spreadsheet whereby the natural ground level along the long section of the dam is input including the excavation depth for each dam type. The headings provide further explanation.
- **Step 2:** *Select the dam configuration (with the drop down arrows):* The cost model enables the selection of different dam types for the left flank, right flank and river section of the dam. The position of the left and right flank is determined by looking in a downstream direction.
- **Step 3:** *Select the components to be used within the dam model:* Toggling the selection arrow yes/no will either make the hyperlinks for the component visible (therefore requiring input) or make them disappear, which would indicate that this information does not need to be input. However, the exact components to be used within each of the dam type options are further refined within the summary sheet.
- **Step 4:** *Inputs – Variable input parameters and rates input*: Selecting the hyperlinks for each of the options will open the variable inputs table and rates input table. If a hyperlink is selected and opens the same spreadsheet as was opened for a previous option, it indicates that the same input values are used for that option. This can be seen when selecting the rates input hyperlink for each option. The same rates input table is used for each of the dam type options.
- **Step 5:** *Outputs: Calculations, bill of quantities, summary sheet.* Selecting the *calculations* hyperlink will open the calculation spreadsheet for that particular option. This enables the review of the calculations. Selecting the *bill of quantities* hyperlink opens the bill of quantities spreadsheet for that particular option; this enables the review of the bill of quantities. Selecting the *summary* hyperlink for that particular option opens the summary spreadsheet for the dam option; the

summary spreadsheet consists of the cost for each component used within the dam option. The summary spreadsheet enables the selection of what components (intake and outlet works, diversion works, spillway and chute) should be included in the cost for that option. The summary spreadsheet is also where the indirect cost components (preliminary and general, other infrastructure, professional fees, contingencies and VAT percentages) are input.

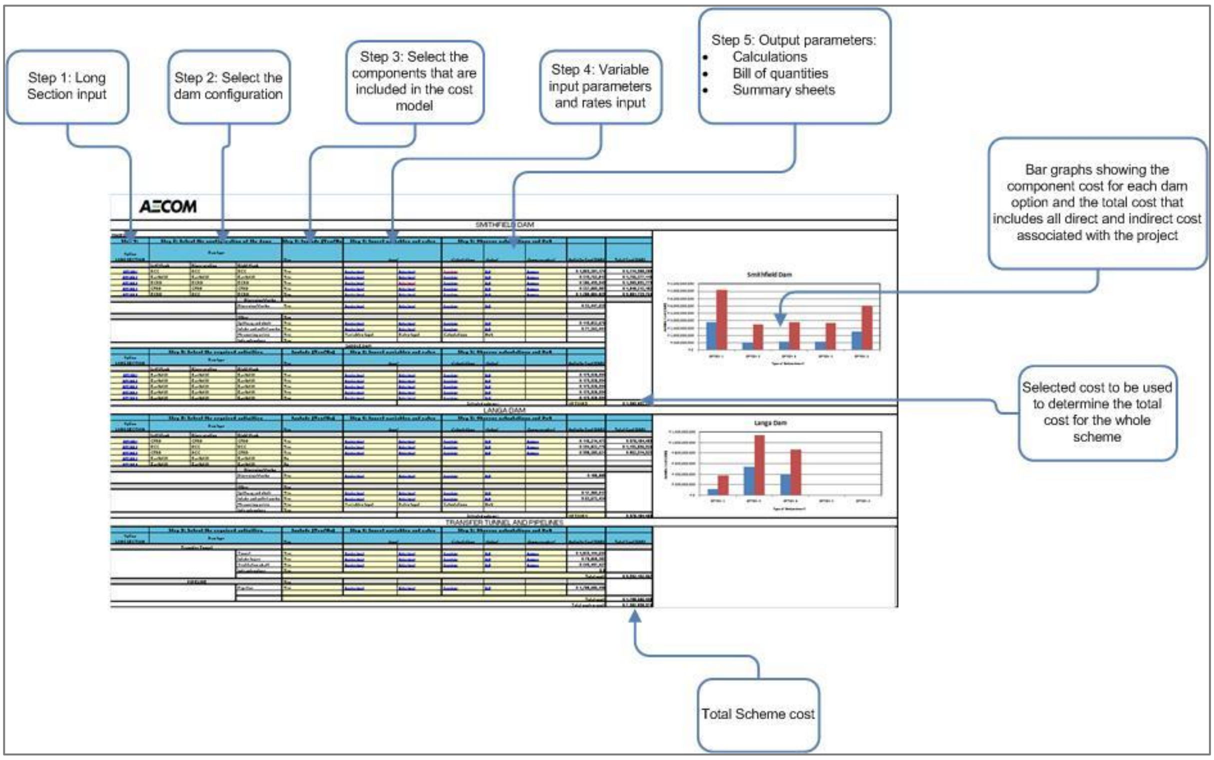


Figure 4.1: Main input table

4.2 DAM LONG SECTION INPUT VALUES

The dam long section input values sheet is opened by selecting the hyperlinks for each dam option as shown in **Figure 4.2**. Selecting the hyperlink will open a spreadsheet as shown in **Figure 4.3**. There are five options, each requiring the input of the natural ground levels along the length of the long section.

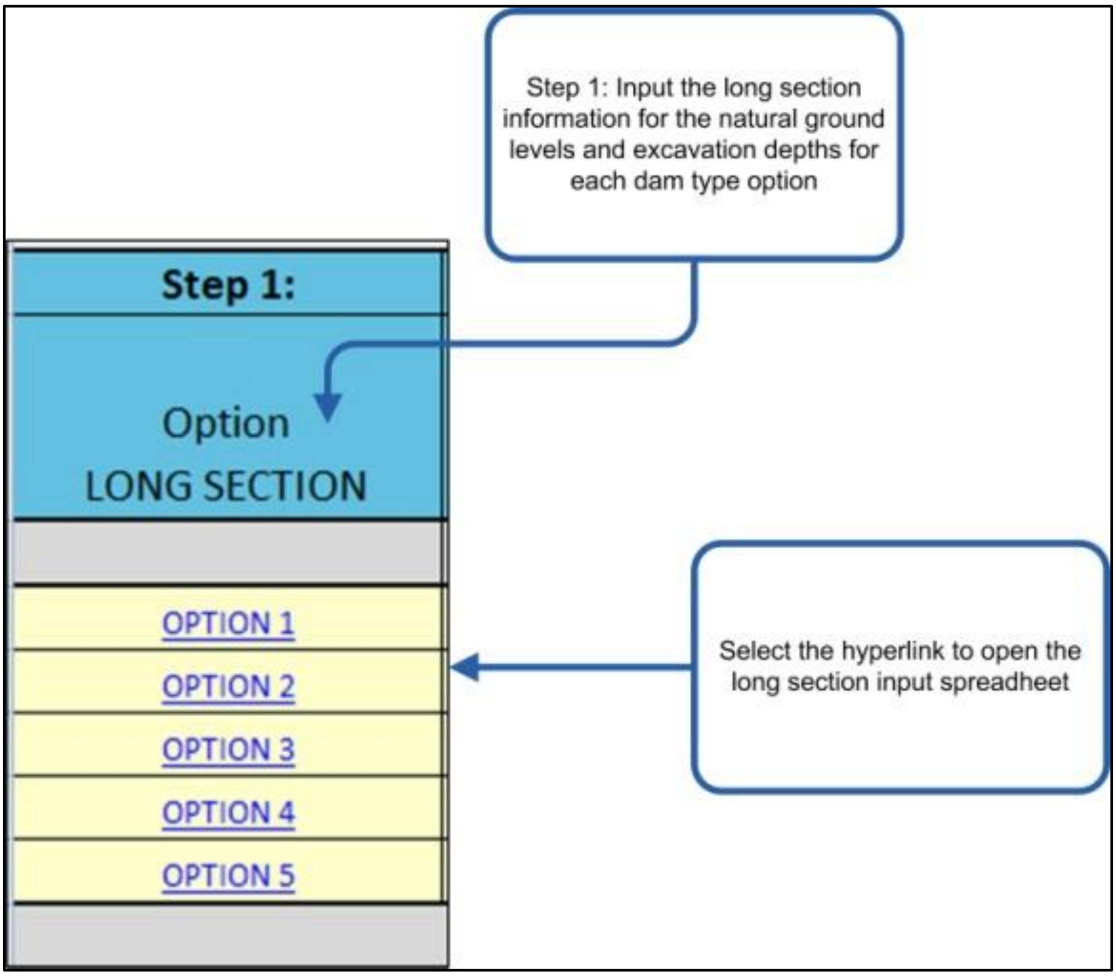


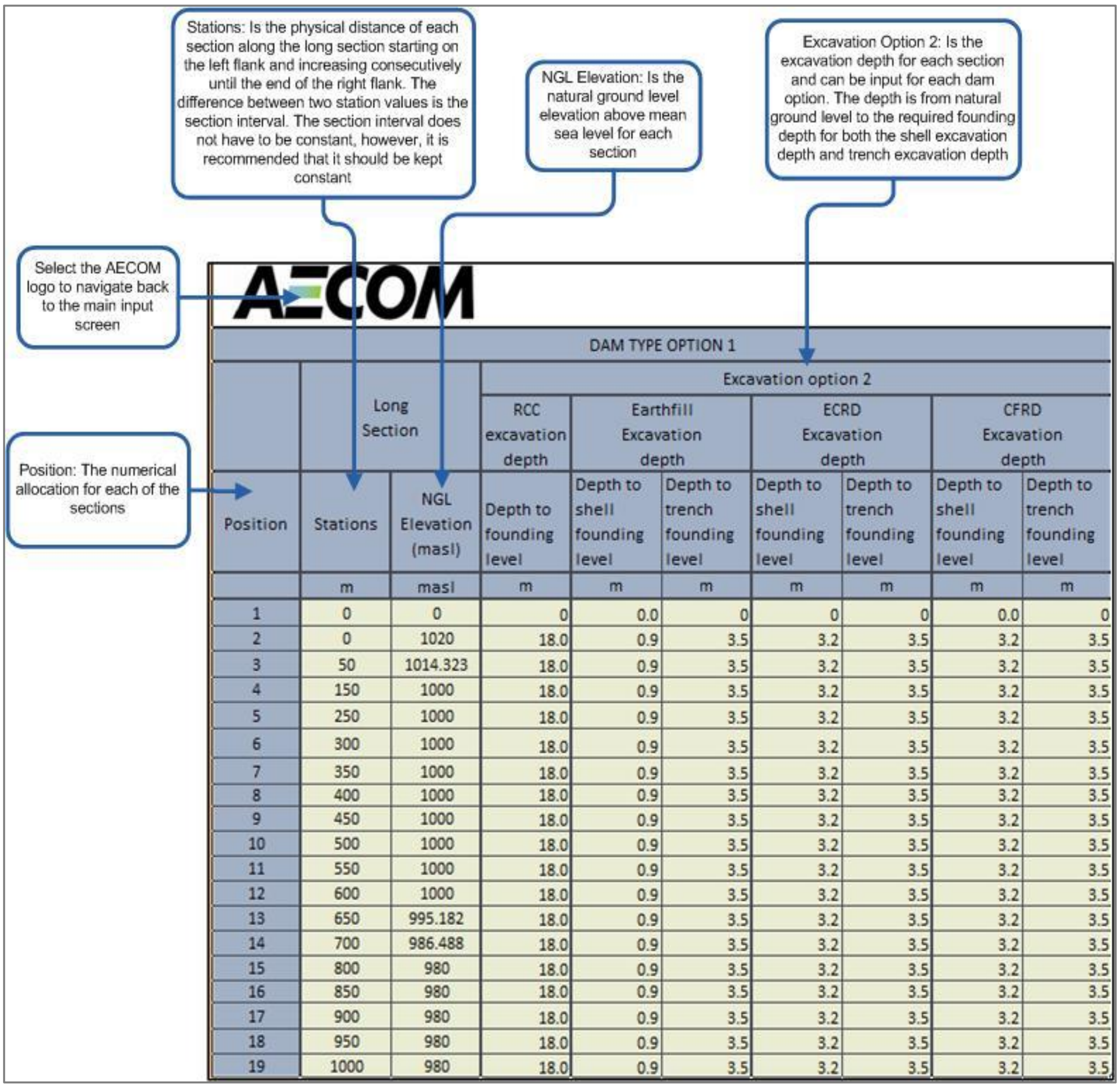
Figure 4.2: Dam long section input

4.2.1 Description of inputs

Note: Ensure that long section data is added to the correct dam type option.

- **Sections of the dam:** The dam is divided into a number of sections at a specified section interval. The smaller the section interval of the dam long section input table, the finer the solution; conversely the larger the section interval, the coarser the final solution. A maximum of 200 sections may be entered.
- **Section interval:** The distance between two adjacent sections. The section interval does not have to be constant, however it is recommended that it is a constant value, as this makes it easier to review the calculations.
- **Stations:** The station values start on the left flank and consecutively increase by the section interval until the end of the right flank. The start value of the stations does not have to begin at position one on the input table but can begin at any position.

- **Excavation option 2:** The excavation depth for each section may be input for both the shell excavation depth and the trench excavation depth. The depth from the natural ground level to the required founding level is determined by means of a geotechnical investigation. If this information is unknown, it may be left blank, however it must be insured that excavation option 1 is selected in the variable inputs table.



DAM TYPE OPTION 1									
	Long Section		Excavation option 2						
			RCC excavation depth	Earthfill Excavation depth		ECRD Excavation depth		CFRD Excavation depth	
Position	Stations	NGL Elevation (masl)	Depth to founding level	Depth to shell founding level	Depth to trench founding level	Depth to shell founding level	Depth to trench founding level	Depth to shell founding level	Depth to trench founding level
	m	masl	m	m	m	m	m	m	m
1	0	0	0	0.0	0	0	0	0.0	0
2	0	1020	18.0	0.9	3.5	3.2	3.5	3.2	3.5
3	50	1014.323	18.0	0.9	3.5	3.2	3.5	3.2	3.5
4	150	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
5	250	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
6	300	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
7	350	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
8	400	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
9	450	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
10	500	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
11	550	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
12	600	1000	18.0	0.9	3.5	3.2	3.5	3.2	3.5
13	650	995.182	18.0	0.9	3.5	3.2	3.5	3.2	3.5
14	700	986.488	18.0	0.9	3.5	3.2	3.5	3.2	3.5
15	800	980	18.0	0.9	3.5	3.2	3.5	3.2	3.5
16	850	980	18.0	0.9	3.5	3.2	3.5	3.2	3.5
17	900	980	18.0	0.9	3.5	3.2	3.5	3.2	3.5
18	950	980	18.0	0.9	3.5	3.2	3.5	3.2	3.5
19	1000	980	18.0	0.9	3.5	3.2	3.5	3.2	3.5

Figure 4.3: Long section input table

4.3 VARIABLE INPUT TABLE

The variable input table, as shown in **Figure 4.4**, is opened by selecting the hyperlink for each particular option or dam component. By selecting the hyperlink the spreadsheet pertaining to the required option will open, allowing easy input of the variables. The variable input parameters include the dimensions of the dam types, intake and outlet works, diversion works and spillway and chute components related to the dam.

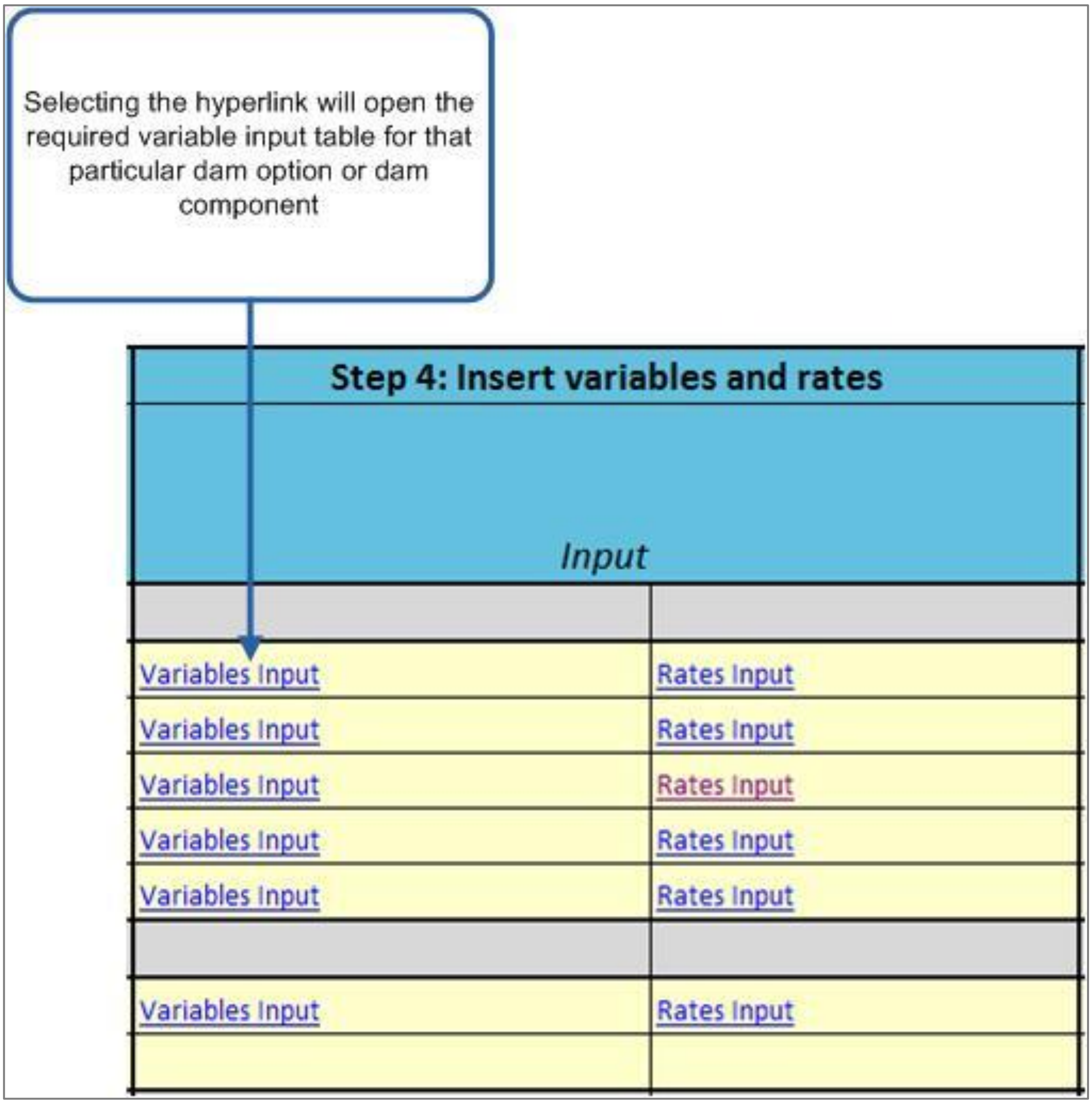


Figure 4.4: Variable input and rates input tables

4.3.1 Dam wall input parameters

The dam wall variable input parameters are accessed by selecting the hyperlink for each dam option. For each dam option a unique set of input variables may be input. This enables the model to be adjusted for various dam design comparisons at different stages of design.

a) Roller compacted concrete dam

Figure 4.5 shows the exact position of each input variable on the dam cross section, with **Figure 4.6** showing the variable input table for the roller compacted dam (RCC) type option.

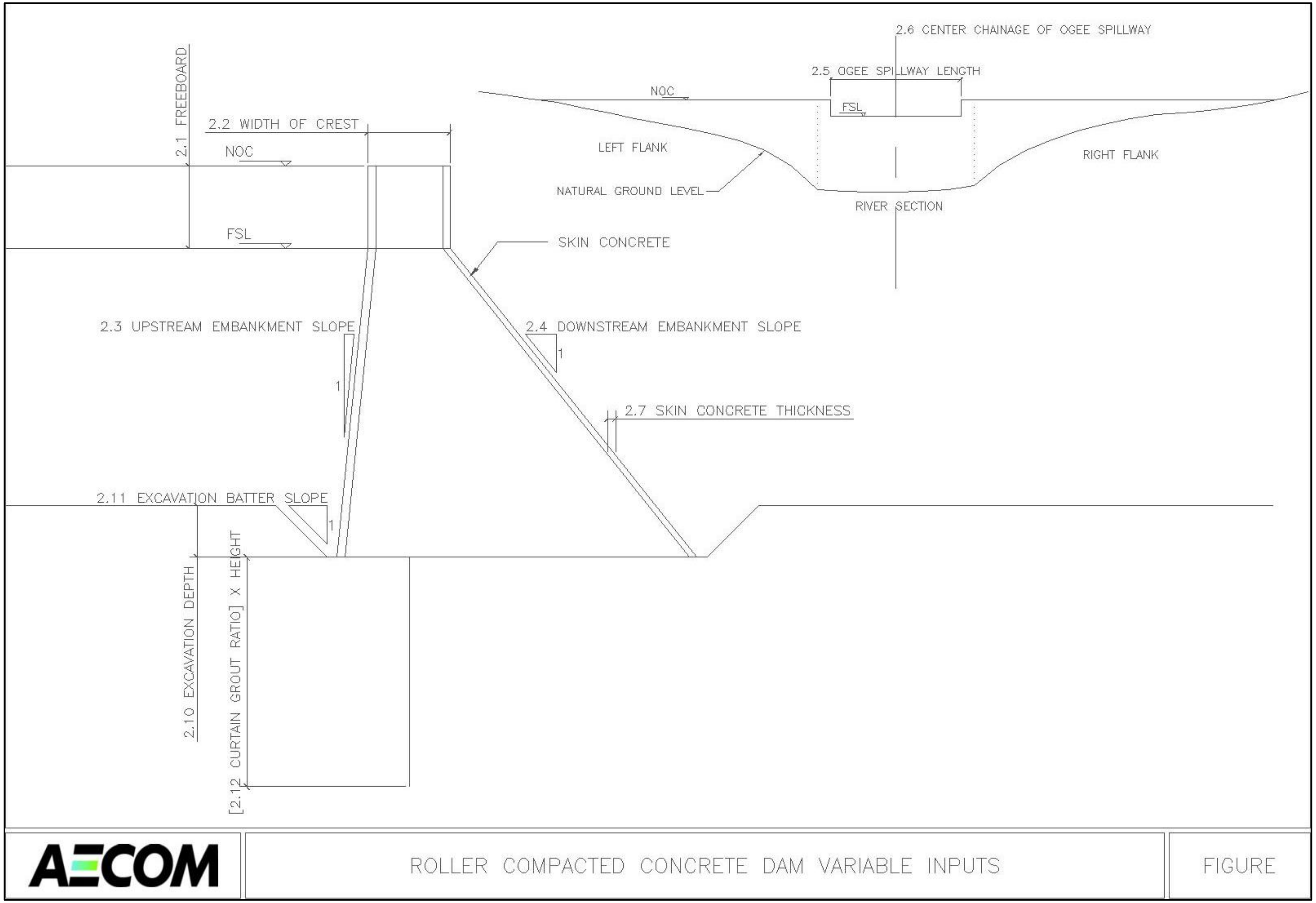


Figure 4.5: Roller compacted concrete dam variable inputs table

Input Variable Components

Variable input values for each of the dam options

	Roller Compacted Concrete Dam (RCC)	Value	Value	Value	Value	Value	Unit
	Outer dimensions						
2.1	Freeboard	5	5	5	5	5	m
2.2	Width of crest	8	8	8	8	8	m
2.3	Upstream embankment slope	0.1	0.1	0.1	0.1	0.1	H:1
2.4	Downstream embankment slope	0.8	0.8	0.8	0.8	0.8	H:1
2.5	Ogee length	160	160	160	160	160	m
2.6	Centre chainage of ogee spillway	3600	3600	3600	3600	3600	
2.7	Skin concrete thickness	0.75	0.75	0.75	0.75	0.75	m
2.8	Waterstop interval	15	15	15	15	15	m
2.9	Crest area (Ogee spillway)	15	15	15	15	15	m^2
	Excavations						
2.10	Depth of topsoil/ Excavation depth (Excavation Option 1)	10	10	10	10	10	m
2.11	Excavation batter slope	1	1	1	1	1	H:1
	Consolidation and curtain grouting						
2.12	Curtain grouting (Ratio of height of dam)	0.75	0.75	0.75	0.75	0.75	
2.13	Curtain grouting spacing	2	2	2	2	2	m
2.14	Blanket grout depth	5	5	5	5	5	m

Figure 4.6: Roller compacted variable input table

Table 4.1 provides an explanation of the variable inputs as given in **Figure 4.5** and **Figure 4.6**.

Table 4.1: Variable inputs comments for a roller compacted concrete dam

Roller Compacted Concrete Dam		
2.1	Freeboard	The vertical distance between the full supply level and the non-overspill crest.
2.2	Width of the crest	The crest width of the dam. The crest width should be sufficiently wide enough to allow access for vehicles.
2.3	Upstream embankment slope	The horizontal component of the slope. If the wall is vertical at the upstream side of the dam a zero (0) is input.
2.4	Downstream embankment slope	The horizontal component of the slope. A zero value is input for a vertical wall.
2.5	Ogee length	The length of the central spillway of the dam.
2.6	Central chainage of the ogee spillway	The position of the ogee spillway on the long section of the dam.
2.7	Skin concrete thickness	The thickness of the conventionally vibrated concrete (CVC) on the upstream and downstream face of the dam wall. Skin concrete provides a more durable surface and reduces the seepage of water into the RCC concrete.
2.8	Waterstop interval	The position of the waterstops along the length of the long section. Waterstops are intended to prevent the passage of water at concrete joints. The waterstop interval is the distance between two consecutive concrete joints.
2.9	Crest area	Represents the area of the ogee spillway that is constructed using conventionally vibrated concrete. The dimensions of the ogee spillway and subsequently the sectional area need to be determined before the variable input table is completed.
2.10	Shell excavation depth (excavation option 1)	The default excavation depth that will be used for all the sections if no geotechnical information has yet being provided.
2.11	Excavation batter slope	The slope to be used for the excavation of the shell.
2.12	Curtain grouting (ratio of height of dam)	The depth of the curtain grouting is often specified as a ratio of the height of the dam.
2.13	Curtain grout spacing	The distance between two consecutive curtain grouting boring holes.
2.14	Blanket grout depth (consolidation grouting)	Is a constant input value used over the entire length of the long section.

b) Earthfill embankment dam

Figure 4.7 shows the exact position of each input variable on the dam cross section and **Figure 4.8** shows the variable input table for the earthfill embankment dam type option.

Table 4.2 provides a description of the variable inputs as shown in **Figure 4.8**.

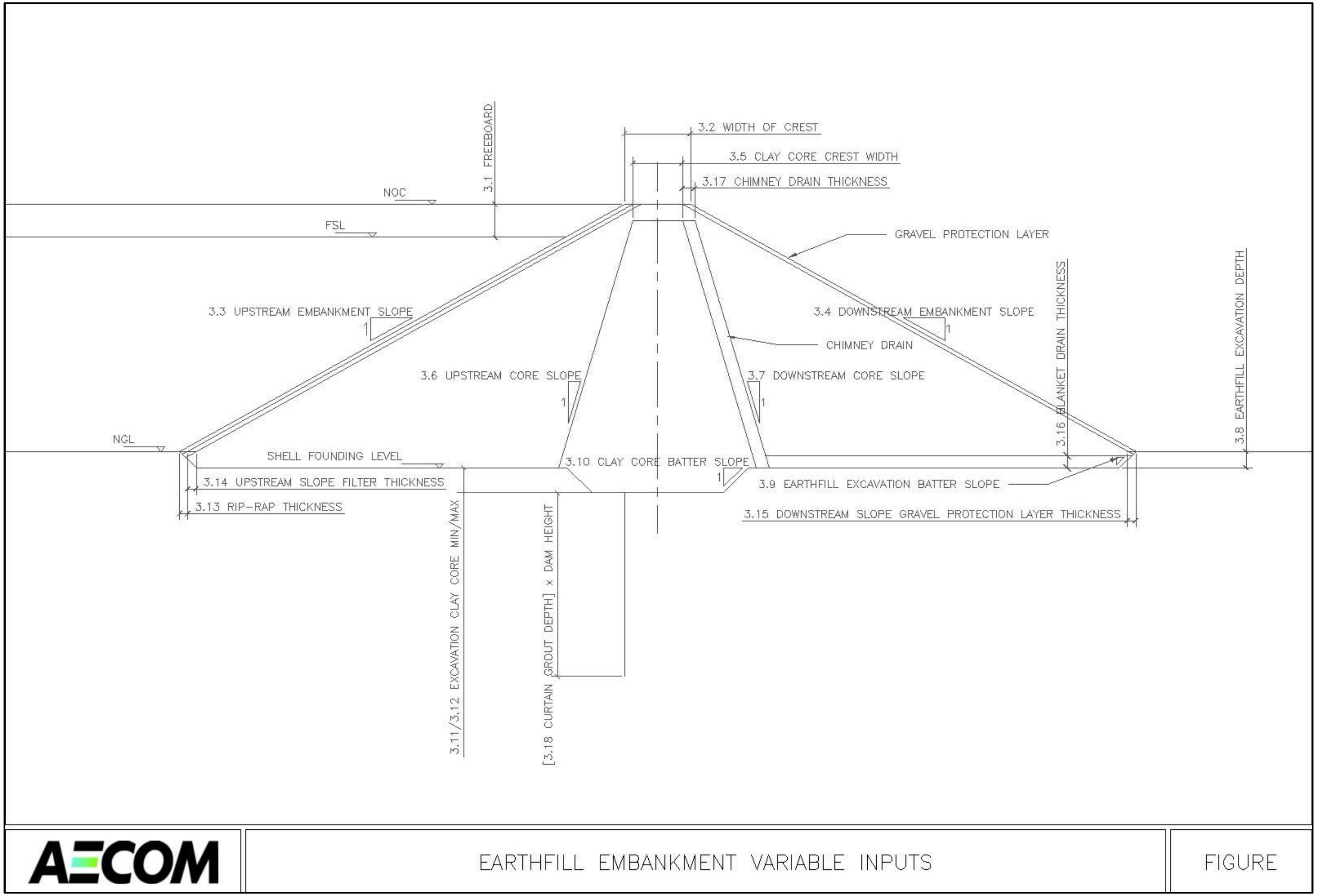


Figure 4.7: Earthfill embankment dam variable inputs diagram

Input Variable Components

Variable input values for each of the dam options

	Earthfill Embankment	Value	Value	Value	Value	Value	Unit
	Outer dimensions						
3.1	Freeboard	8	8	8	8	8	m
3.2	Width of crest	8	8	8	8	8	m
3.3	Upstream embankment slope	3	3	3	3	3	H:1
3.4	Downstream embankment slope	2.5	2.5	2.5	2.5	2.5	H:1
	Clay core dimensions						
3.5	Clay core crest width	7	7	7	7	7	m
3.6	Upstream core slope	0.5	0.5	0.5	0.5	0.5	H:1
3.7	Downstream core slope	0.5	0.5	0.5	0.5	0.5	H:1
	Excavations						
3.8	Earthfill excavation depth (Excavation option 1)	2	2	2	2	2	m
3.9	Earthfill Excavation batter slope	1	1	1	1	1	H:1
3.10	Clay core batter slope	1	1	1	1	1	H:1
3.11	Excavation depth clay core (max)	5	5	5	5	5	m
3.12	Excavation depth clay core (min)	2	2	2	2	2	m
	Filters and Drains						
3.13	Rip-rap thickness	1	1	1	1	1	m
3.14	Upstream slope filter thickness	1	1	1	1	1	m
3.15	Downstream slope gravel protection layer	0.4	0.4	0.4	0.4	0.4	m
3.16	Blanket drain thickness	0.6	0.6	0.6	0.6	0.6	m
3.17	Chimney drain thickness	2	2	2	2	2	m
	Consolidation and curtain grouting						
3.18	Curtain grout depth: Proportion of dam height	0.66	0.66	0.66	0.66	0.66	
3.19	Blanket grout depth	5	5	5	5	5	m
3.20	Grout spacing	2	2	2	2	2	m

Figure 4.8: Earthfill embankment dam variable inputs table

Table 4.2: Variable inputs comments for an earthfill embankment dam

Earthfill Embankment Dam		
3.1	Freeboard	The vertical distance between the non-overspill crest and the full supply level.
3.2	Width of the crest	The crest width of the dam. The crest width should be sufficiently wide enough to allow access for vehicles.
3.3	Upstream embankment slope	The horizontal component of the slope. If the wall is vertical at the upstream side of the dam a zero (0) is input.
3.4	Downstream embankment slope	The horizontal component of the slope. If the wall is vertical at the upstream side of the dam, a zero (0) is input.
3.5	Clay core crest width	The width of the crest of the clay core. The width of the clay core crest should be less than the width of the dam crest.
3.6	Upstream core slope	The horizontal component of the slope of the internal clay core. If the core is vertical at the upstream side of the dam a zero (0) is input.
3.7	Downstream core slope	The horizontal component of the slope of the internal clay core. If the core is vertical at the downstream side of the dam a zero (0) is input.
3.8	Earthfill excavation depth	The default excavation depth that will be used for all of the sections if no geotechnical information has yet being provided. If excavation option 1 is selected.
3.9	Earthfill excavation batter slope	The slope to be used for the excavation of the shell.
3.10	Clay core batter slope	The slope to be used for the excavation of the clay core trench.
3.11	Excavation clay core (max)	The maximum depth the clay core is excavated if excavation option 1 is selected.
3.12	Excavation clay core (min)	The minimum depth the clay core is excavated if excavation option 1 is selected.
3.13	Rip-rap thickness	The horizontal width of the rip-rap layer.
3.14	Upstream slope filter thickness	The horizontal width of the upstream slope filter between the shell earthfill material and the rip-rap layer.
3.15	Downstream slope gravel protection layer	The horizontal width of the downstream gravel protection layer.
3.16	Blanket drain thickness	The vertical thickness of the blanket drain.
3.17	Chimney drain thickness	The horizontal width of the chimney drain on the downstream face of the clay core.
3.18	Curtain grout depth: Proportion of the dam height	The depth of the curtain grouting is specified as a ratio of the height of the dam.
3.19	Blanket grout depth (consolidation grouting)	A constant input value used over the entire length of the long section.
3.20	Grout spacing	The distance between two consecutive curtain grouting boring holes.

c) Earth core rockfill dam

Figure 4.9 displays the exact position of each input variable on the dam cross section, with **Figure 4.10** showing the variable input table for the earth core rockfill embankment dam type option.

Table 4.3 provides a description of the variable inputs as shown in **Figure 4.10.**

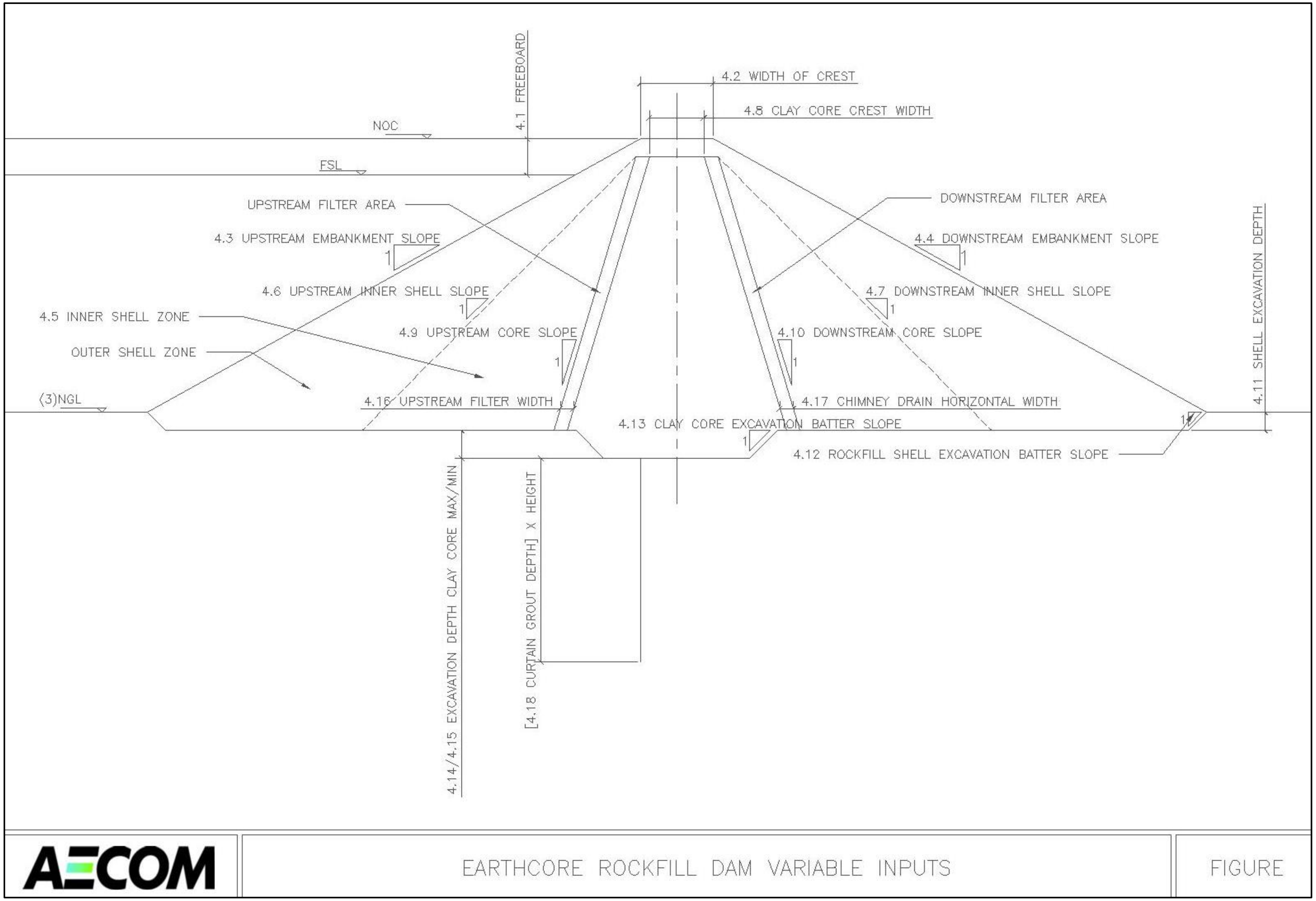
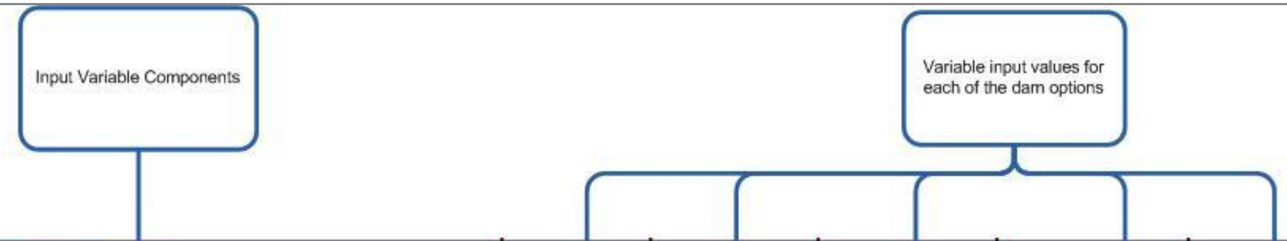


Figure 4.9: Earth core rockfill dam variable input



	Earth core rockfill dam (ECRD)						
	Outer dimensions						
4.1	Freeboard	8	8	8	8	8	m
4.2	Width of crest	6	6	6	6	6	m
4.3	Upstream embankment slope	1.8	1.8	1.8	1.8	1.8	H:1
4.4	Downstream embankment slope	1.75	1.75	1.75	1.75	1.75	H:1
4.5	Inner shell zone	No	No	No	No	No	
4.6	Upstream inner shell slope	0.5	0.5	0.5	0.5	0.5	H:1
4.7	Downstream inner shell slope	0.5	0.5	0.5	0.5	0.5	H:1
	Clay core dimensions						
4.8	Clay core crest width	5	5	5	5	5	m
4.9	Upstream core slope	0.25	0.25	0.25	0.25	0.25	H:1
4.10	Downstream core slope	0.25	0.25	0.25	0.25	0.25	H:1
	Excavations						
4.11	Shell excavation depth	2	2	2	2	2	m
4.12	Rockfill shell excavation batter slope	1	1	1	1	1	H:1
4.13	Clay core excavation batter slope	1	1	1	1	1	H:1
4.14	Excavation depth clay core (max)	3	3	3	3	3	m
4.15	Excavation depth clay core (min)	1	1	1	1	1	m
	Filters and Drains						
4.16	Upstream filter width	1	1	1	1	1	m
4.17	Chimney drain horizontal width	2	2	2	2	2	m
	Consolidation and curtain grouting						
4.18	Curtain grout depth: Proportion of dam height	0.66	0.66	0.66	0.66	0.66	
4.19	Blanket grout depth	5	5	5	5	5	m
4.20	Grout spacing	2	2	2	2	2	m

Figure 4.10: Earth core rockfill dam variable inputs table

Table 4.3: Variable inputs comments for an earth core rockfill dam

Earth core Rockfill Dam		
4.1	Freeboard	The vertical distance between the non-overspill crest and the full supply level.
4.2	Width of crest	The crest width of the dam. The crest width should be sufficiently wide enough to allow access for vehicles.
4.3	Upstream embankment slope	The horizontal component of the slope. If the wall is vertical at the upstream side of the dam a zero (0) is input.
4.4	Downstream embankment slope	The horizontal component of the slope. If the wall is vertical at the downstream side of the dam a zero (0) is input.
4.5	Inner shell zone	Is toggled on/off by selecting the radio button. The inner shell zone, can be used if two material types need to be used within the shell zone. The inner shell zone is located upstream and downstream of the core between the transition layers and the outer shell zones.
4.6	Upstream inner shell slope	The horizontal component of the upstream inner shell slope. If the inner shell zone is vertical at the upstream side of the dam, a zero (0) is input.
4.7	Downstream inner shell slope	The horizontal component of the downstream inner shell slope. If the inner shell zone is vertical at the downstream side of the dam, a zero (0) is input.
4.8	Clay core crest width	The width of the crest of the clay core. The width of the clay core crest should be less than the width of the dam crest.
4.9	Upstream core slope	The horizontal component of the slope of the internal clay core. If the core is vertical at the upstream side of the dam a zero (0) is input.
4.10	Downstream core slope	The horizontal component of the slope of the internal clay core. If the core is vertical at the downstream side of the dam a zero (0) is input.
4.11	Shell excavation depth (excavation option 1)	The default excavation depth that will be used for all of the sections if no geotechnical information has being provided. If excavation option 1 is selected.
4.12	Rockfill shell excavation batter slope	The slope to be used for the excavation of the rockfill shell.
4.13	Clay core excavation batter slope	The slope to be used for the excavation of the clay core trench.
4.14	Excavation depth clay core (max)	The maximum depth the clay core is excavated if excavation option 1 is selected.
4.15	Excavation depth clay core (min)	The minimum depth the clay core is excavated if excavation option 1 is selected.
4.16	Upstream filter width:	The horizontal width of the upstream filter located between the clay core and the upstream rockfill shell.
4.17	Chimney drain horizontal width	The horizontal width of the chimney drain on the downstream face of the clay core.
4.18	Curtain grout depth	Proportion of the dam height: The depth of the curtain grouting is specified as a ratio of the height of the dam
4.19	Blanket grout depth (consolidation grouting):	A constant input value used for the entire length of the long section.
4.20	Grout spacing:	The distance between two consecutive curtain grouting boring holes.

d) Concrete faced rockfill dam

Figure 4.11 shows the variable input table for the concrete faced rockfill embankment type option, with **Figure 4.12** showing the exact position of each input variable on the dam cross section.

Table 4.4 provides a description of the variable inputs as shown in **Figure 4.12**.

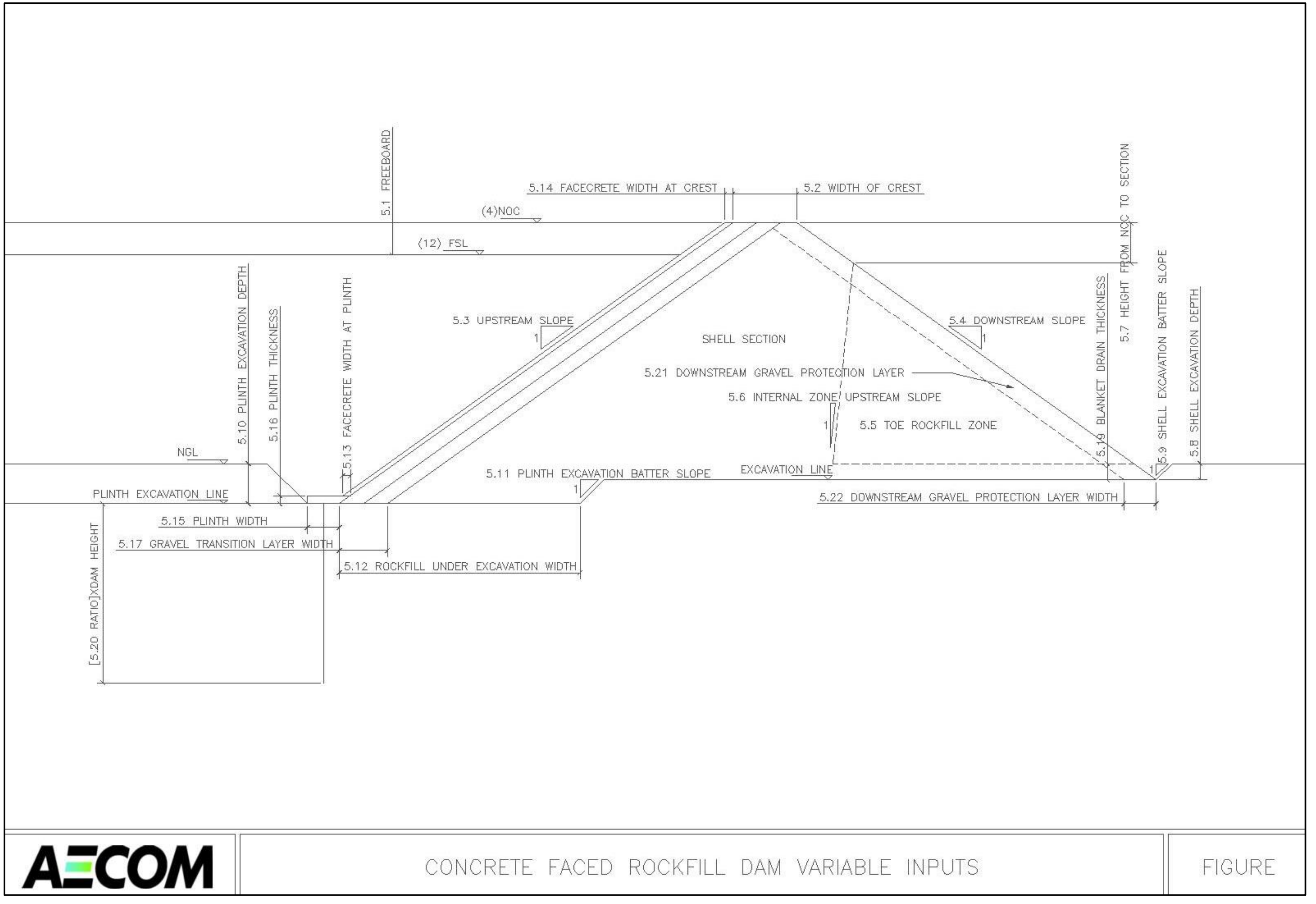


Figure 4.11: Concrete faced rockfill dam diagram

Input Variable Components

Variable input values for each of the dam options

	CFRD						
	Outer dimensions						
5.1	Freeboard	8	8	8	8	8	mamsl
5.2	Width of crest	6.00	6.00	6.00	6.00	6.00	m
5.3	Upstream slope	1.80	1.80	1.80	1.80	1.80	H:1
5.4	Downstream slope	1.75	1.75	1.75	1.75	1.75	H:1
5.5	Toe rockfill zone	Yes	Yes	Yes	Yes	Yes	
5.6	Internal zone upstream slope	0.1	0.1	0.1	0.1	0.1	H:1
5.7	Distance between NOC crest and the top of the toe section	0	0	0	0	0	m
	Excavation						
5.8	Shell excavation depth	2.00	2.00	2.00	2.00	2.00	m
5.9	Shell excavation batter slope	1.00	1.00	1.00	1.00	1.00	H:1
5.10	Plinth excavation depth from NGL	3.00	3.00	3.00	3.00	3.00	m
5.11	Plinth excavation batter slope	1.00	1.00	1.00	1.00	1.00	H:1
5.12	Rockfill under excavation_Width	30.00	30.00	30.00	30.00	30.00	m
	Concrete Face						
5.13	Facecrete width at plinth	0.45	0.45	0.45	0.45	0.45	m
5.14	Facecrete width at crest	0.30	0.30	0.30	0.30	0.30	m
5.15	Plinth width	4.00	4.00	4.00	4.00	4.00	m
5.16	Plinth thickness	0.40	0.40	0.40	0.40	0.40	m
	Filters and drains						
5.17	Gravel transition layer width	8.00	8.00	8.00	8.00	8.00	m
5.18	Curtain grouting spacing	2.00	2.00	2.00	2.00	2.00	m
5.19	Bottom blanket drain thickness	2	2	2	2	2	m
5.20	Ratio of height to grout depth	0.66	0.66	0.66	0.66	0.66	
5.21	Downstream gravel protection layer	No	No	No	No	No	
5.22	Downstream gravel protection layer width	4.00	4.00	4.00	4.00	4.00	m

Figure 4.12: Concrete faced rockfill dam variable input table

Table 4.4: Variable inputs comments for a concrete faced rockfill dam

Concrete Faced Rockfill Dam		
5.1	Freeboard	The vertical distance between the non-overspill crest and the full supply level.
5.2	Width of crest	The crest width of the dam. The crest width should be sufficiently wide enough to allow access for vehicles.
5.3	Upstream slope	The horizontal component of the slope. If the wall is vertical at the upstream side of the dam a zero (0) is input.
5.4	Downstream slope	The horizontal component of the slope. If the wall is vertical at the downstream side of the dam a zero (0) is input.
5.5	Toe rockfill zone	Is toggled on/off by selecting the radio button. If two different materials need to be used in the dam shell, a triangular toe section may be included in the dam.
5.6	Internal zone upstream slope	The slope of the upstream side of the toe rockfill zone.
5.7	Distance between NOC and the top of the toe section	The vertical distance between the non-overspill crest and the top of the toe rockfill zone.
5.8	Shell excavation depth	The default excavation depth that will be used for all of the sections if no geotechnical information has being provided. If excavation option 1 is selected.
5.9	Shell excavation batter slope	The slope to be used for the excavation of the rockfill shell.
5.11	Plinth excavation batter slope	The slope to be used for the excavation of the plinth.
5.12	Rockfill under excavation width	The length of the plinth excavation trench extension into the dam wall. The length starts at the upstream toe of the concrete slab and continues downstream of the upstream toe.
5.13	Facecrete width at plinth	The horizontal width of the facecrete slab at the plinth of the dam.
5.14	Facecrete width at crest	The horizontal width of the facecrete slab at the crest of the dam.
5.15	Plinth width	The horizontal width of the plinth.
5.16	Plinth thickness	The vertical thickness of the plinth.
5.17	Gravel transition layer thickness	The total horizontal width of the two gravel transition layers located between the rockfill shell and the facecrete concrete slab.
5.18	Curtain grout spacing	The distance between two consecutive curtain grouting boring holes.
5.19	Bottom blanket drain thickness	The vertical thickness of the blanket drain. This input only relates to the use of a toe rockfill zone.
5.20	Ratio of height to grout depth	The depth of the curtain grouting is specified as a ratio of the height of the dam.
5.21	Downstream gravel protection layer	Is toggled on/off by selecting the radio button. If a downstream rockfill layer is required.
5.22	Downstream gravel protection layer width	The horizontal width of the downstream gravel protection layer.

e) Composite dam

The cost model also enables the input of composite dam designs. The most common composite dam structure is one that consists of a concrete gravity central spillway section with an earth core rockfill embankment, earthfill embankment or concrete faced rockfill left and right flank (see **Figure 4.13** and **Figure 4.14**). For this reason the cost model has been set up for the input of only this type of composite structure. Other combinations may be used; however there may be inconsistences in the transitions from one dam type to another.

In the cost model the position of the spillway is input and the lengths of transition and overlap lengths may be input. The transition and overlap zones extend into the left and right earthfill embankment sections.

The variables as described previously will be applicable to this section.

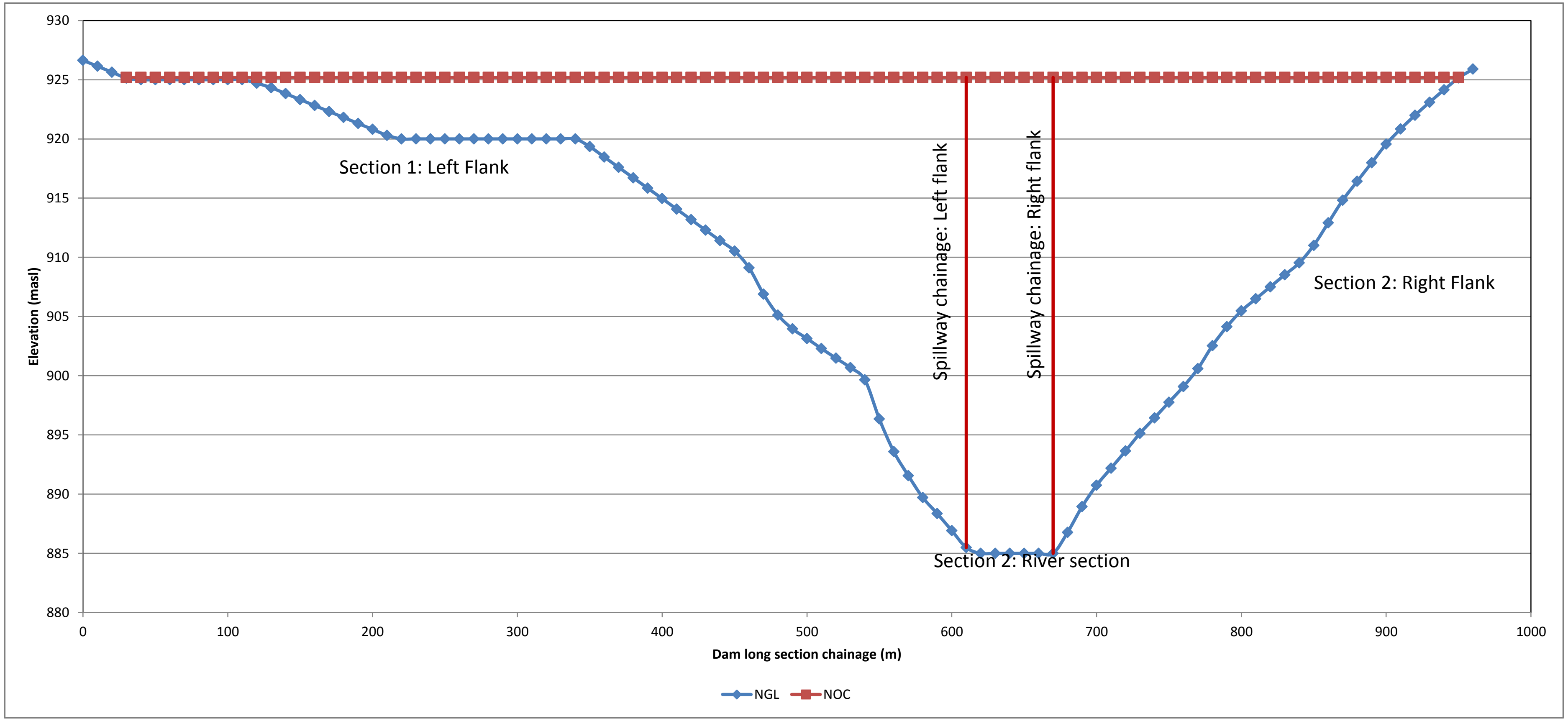


Figure 4.13: Composite dam longitudinal section

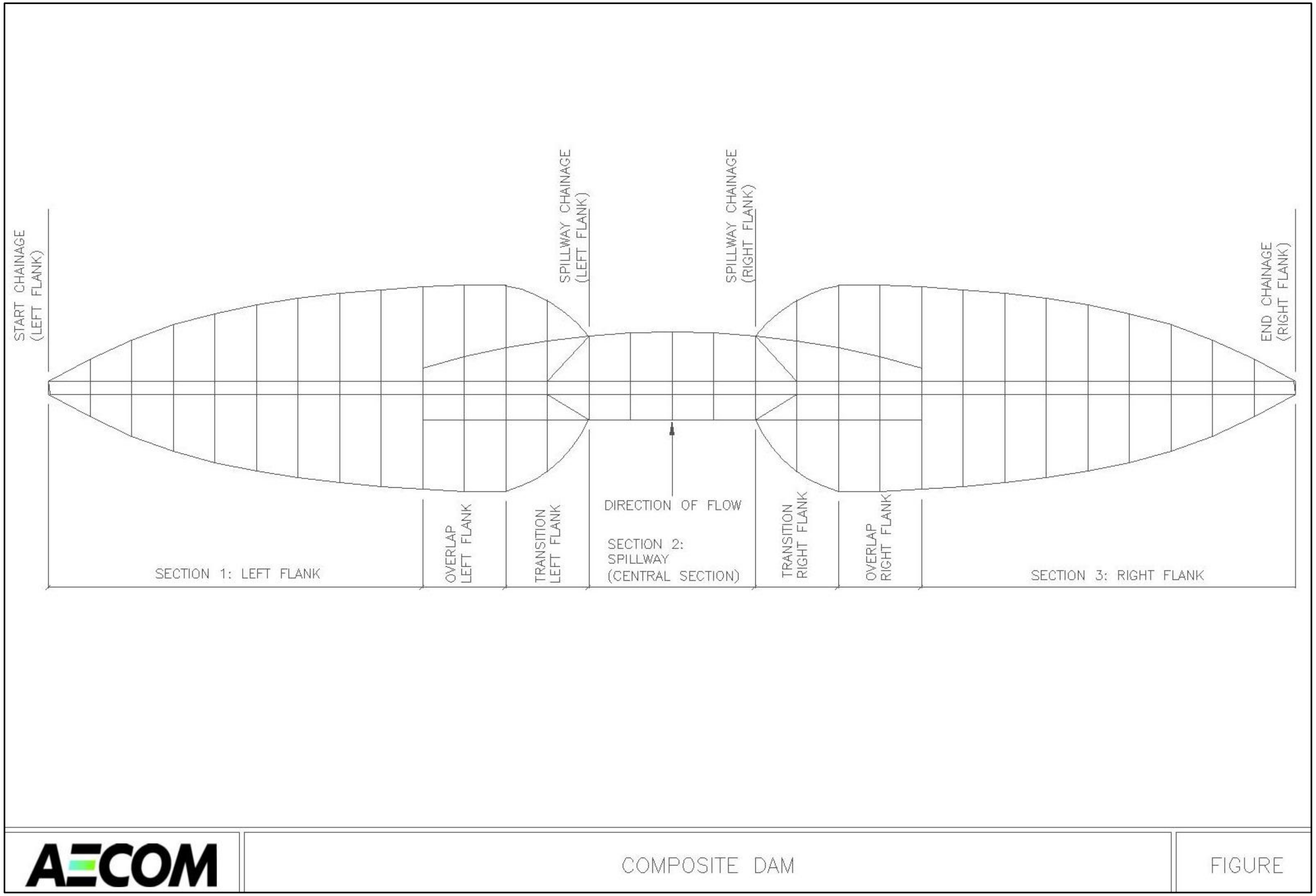


Figure 4.14: Composite dam layout

4.3.2 Diversion works

This provision is necessary to permit construction to proceed in dry conditions. An outlet tunnel or culvert may be temporarily adapted for this purpose during construction, and subsequently employed as a discharge facility for the completed dam. In order to transfer the flow into the tunnel, the construction of temporary upstream and downstream cofferdams will need to be constructed as shown in **Figure 4.15** *(Novak, Moffat et. Al, 2007)*.

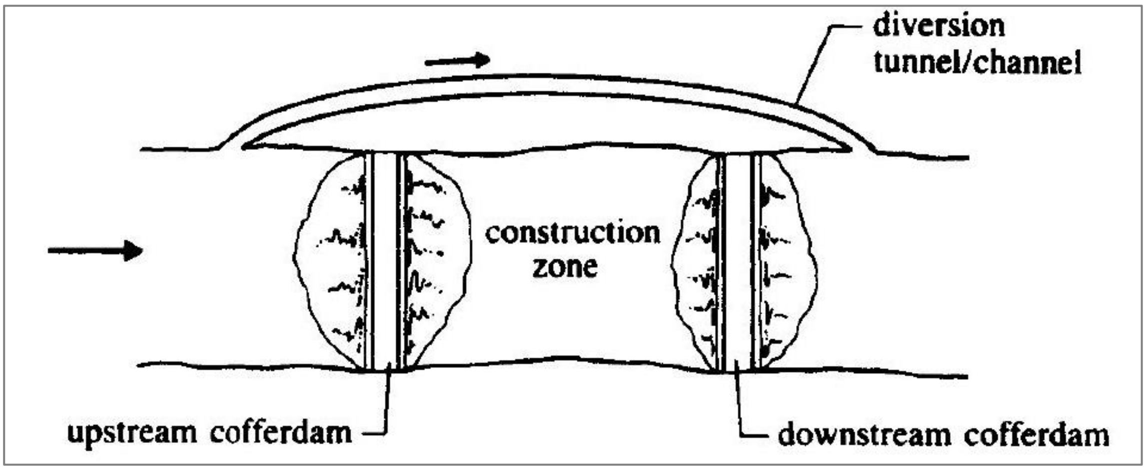


Figure 4.15: Layout of diversion works (Novak, Moffat et. Al, 2007).

a) Cofferdam

Cofferdams are temporary structures used to divert water from an area where a permanent structure has to be constructed. They must be as water tight as practicable, relatively cheap and, if possible, constructed of locally available materials *(Novak, Moffat et. Al, 2007)*.

The cost model makes provision for the input of two soilcrete cofferdams, an upstream and a downstream cofferdam. For both the upstream and downstream cofferdams, a long section of station values and their corresponding natural ground level elevations is required as input. The station input and the station interval (the difference between two station values) does not have to be the same but it is recommended to ensure consistency and ease of calculations. Therefore the station values should increment by a constant station value.

b) Diversion tunnel variable input

Figure 4.16 shows the long section input and variable inputs table for the diversion works at Smithfield dam. The diversion works entails the construction of soilcrete cofferdams at the upstream and downstream sides of the main dam. Tunnels are bored through the left or right flank in order to divert the water to provide a dry area for the construction of the main dam wall.

Figure 4.17 and **Figure 4.18** provide schemetic presentations of the dam inlet portal and diversion tunnels.

DIVERSION WORKS

VARIABLE INPUTS

COFFER DAM -SOILCRETE

Upstream			Downstream		
Position	Station	Elevation	Position	Station	Elevation
1	0	0	1	0	0
2	0	0	2	0	0
3	0	1049.8803	3	0	1049.8803
4	20	1049.7338	4	20	1049.7338
5	40	1049.1203	5	40	1049.1203
6	60	1047.7813	6	60	1047.7813
7	80	1040.6249	7	80	1040.6249
8	100	1031.0876	8	100	1031.0876
9	120	1026.4478	9	120	1026.4478
10	140	1025.08	10	140	1025.08
11	160	1023.7739	11	160	1023.7739
12	180	1022.7346	12	180	1022.7346
13	200	1021.4424	13	200	1021.4424
14	220	1019.3523	14	220	1019.3523
15	240	1014.2243	15	240	1014.2243
16	260	1011.9783	16	260	1011.9783
17	280	1019.0331	17	280	1019.0331
18	300	1020.5084	18	300	1020.5084
19	320	1022.0871	19	320	1022.0871
20	340	1026.3428	20	340	1026.3428
21	360	1030.1905	21	360	1030.1905
22	380	1032.6923	22	380	1032.6923
23	400	1034.5565	23	400	1034.5565
24	420	1036.4452	24	420	1036.4452
25	440	1040.2727	25	440	1040.2727
26	460	1044.6787	26	460	1044.6787
27	480	1050.1121	27	480	1050.1121
28	500	1055.9729	28	500	1055.9729
29	520	1059.0808	29	520	1059.0808
30	540	1061.8179	30	540	1061.8179
31	560	1064.4933	31	560	1064.4933
32	580	1067.1978	32	580	1067.1978
33	600	1070.6162	33	600	1070.6162
34	620	1074.8651	34	620	1074.8651
35	640	1079.4215	35	640	1079.4215
36	660	1082.8655	36	660	1082.8655
37	680	1085.6499	37	680	1085.6499
38	700	1086.1845	38	700	1086.1845
39	0	0	39	0	0
40	0	0	40	0	0
41	0	0	41	0	0
42	0	0	42	0	0
43	0	0	43	0	0
44	0	0	44	0	0
45	0	0	45	0	0
46	0	0	46	0	0
47	0	0	47	0	0
48	0	0	48	0	0
49	0	0	49	0	0
50	0	0	50	0	0
51	0	0	51	0	0
52	0	0	52	0	0
53	0	0	53	0	0
54	0	0	54	0	0
55	0	0	55	0	0
56	0	0	56	0	0
57	0	0	57	0	0
58	0	0	58	0	0
59	0	0	59	0	0
60	0	0	60	0	0

1.0	Diversion Tunnel	Value	Unit
1.1	Diversion tunnel diameter	6	m
1.2	Number of tunnels	2	
1.3	Invert of tunnels at the inlet portal	1011.978	masl
1.4	Slope of the tunnel	13.16428	H:1
1.5	Invert of tunnels at the outlet portal	992	masl
1.6	Space between tunnel (m)	5	m
1.7	Average length of excavation to tunnel inlet	25	m
1.8	Average length of excavation to tunnel outlet	25	m
1.9	Minimum cover on tunnels	5	m
1.10	Length of tunnel	263	m
1.11	Number of bolts per metre	4	bolts/m
1.12	Length of rockbolts	2	m
1.13	Thickness of shotcrete	0.05	m
1.14	Thirds of shotcrete in tunnel	0.333333	
1.15	Thirds of mesh in tunnel	0.333333	
1.16	Dewatering	Yes	Yes/No
1.17	Remove and grub large trees	0	No
2.0	Upstream and downstream cofferdams	Value	Unit
2.1	Height of the cofferdam	10	m
2.2	Non-overspill crest (NOC)	1021.978	masl
2.3	Crest width	4	m
2.4	Upstream and downstream slopes	1.5	H:1
2.5	Soilcrete slab width	2.0	m
2.6	Excavation depth	2	m
2.7	Excavation batter slopes	1	H:1
2.8	Dewatering	Yes	Yes/No

3.0	INLET PORTAL		
3.1	Diameter	6	m
3.2	Number of tunnels	2	No.
3.3	Invert level	1011.978	masl
3.4	Tunnel top	1017.978	masl
3.5	Cover on tunnels	5	m
3.6	Top of NGL	1022.978	masl
3.7	Height required	11	m
3.8	Length of excavtion	25	m
3.9	Excavation area parallel to tunnel direction	138	m^2
3.10	Volume per tunnel	1513	m^3
3.11	Excavation for the specified number of tunnels	3025	m^3
3.12	Footprint	601	m^2

4.0	OUTLET PORTAL		
4.1	Diameter	6	m
4.2	Number of tunnels	2	No.
4.3	Invert level	992	masl
4.4	Tunnel top	998	masl
4.5	Cover on tunnels	5	m
4.6	Top of natural ground level	1003	masl
4.7	Height required	11	m
4.8	Length	25	m
4.9	Excavation area parallel to tunnel direction	138	m^2
4.10	Volume per tunnel	1513	m^3
4.11	Excav all tunnels	3025	m^3
4.12	Footprint	601	m^2

Figure 4.16: Diversion works variable input table

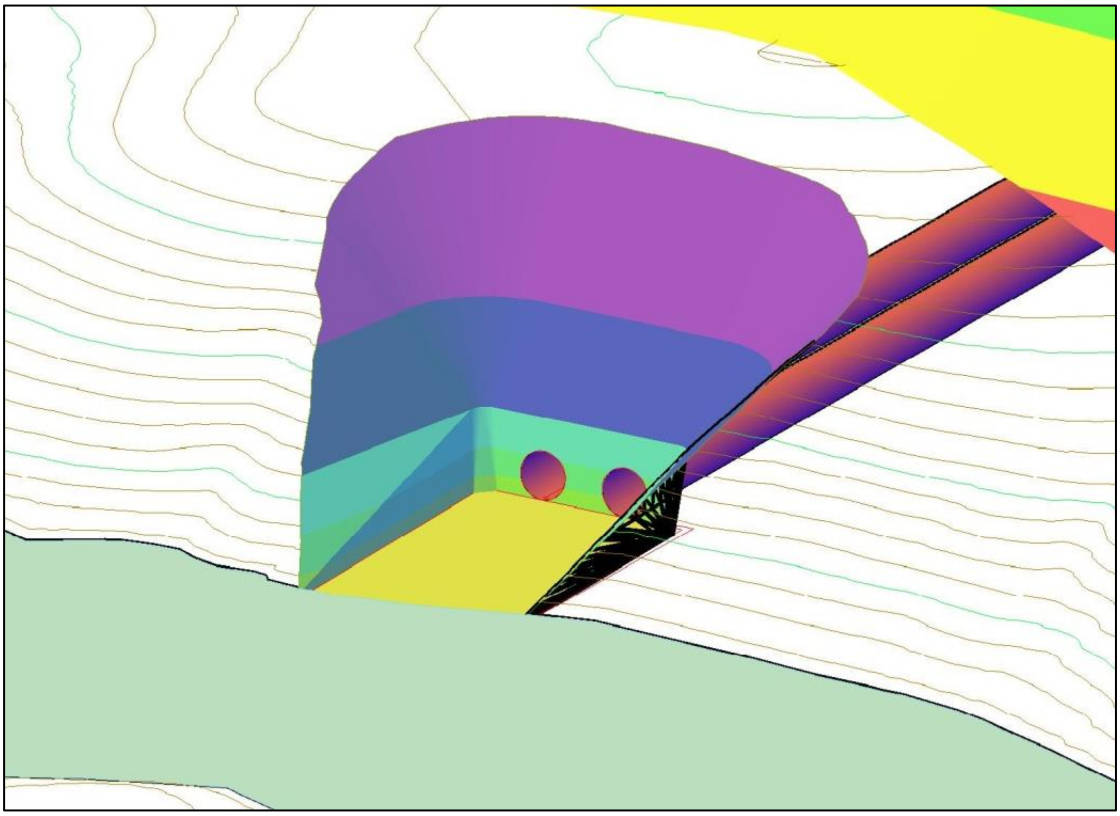


Figure 4.17: Inlet portal and diversion tunnels

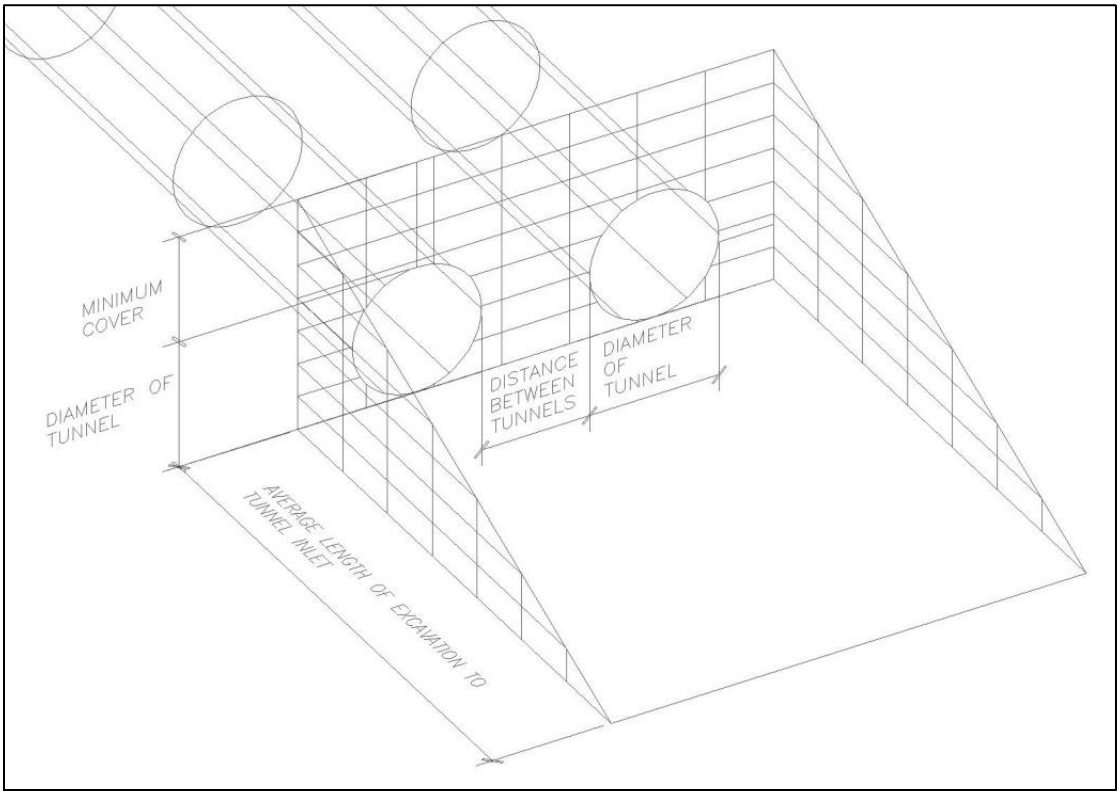


Figure 4.18: Schematic representation of dam inlet and diversion tunnels

Table 4.5 and **Table 4.6** provide descriptions of the variable inputs, as shown in **Figure 4.16**, for the diversion tunnels and the upstream and downstream cofferdams respectively.

Table 4.5: Diversion tunnels variable input

Diversion tunnels		
1.1	Diversion tunnel diameter	The diameter of the diversion tunnels that will be running from the inlet portal to the outlet portal.
1.2	Number of tunnels	The number of tunnels required to pass the required design flood.
1.3	Invert of tunnels at the inlet portal	The invert level of the tunnel that also refers to the bottom level of the tunnel and inlet portal.
1.4	Slope of the tunnel	The required downward slope of the tunnel. Entered as a positive value and the horizontal component of the slope is an input.
1.5	Invert of tunnels at the outlet portal	(Calculated or read only) The invert level of the tunnel at the outward portal that is calculated using the slope of the tunnel and the invert level of the inlet portal.
1.6	Space between the tunnels	The space required between the tunnels.
1.7	Average length of excavation to tunnel inlet	The distance from the daylight point at the invert level to the point at which the excavation of the tunnel will commence.
1.8	Average length of excavation to tunnel outlet	The distance from the daylight point at the invert level to the point at which the excavation of the tunnel will stop.
1.9	Minimum cover on tunnels	The minimum cover required for the tunnel or the distance between the top of the tunnel and the natural ground level.
1.10	Length of tunnel:	The distance between the inlet portal of the tunnel and the outlet portal.
1.11	Number of bolts per metre of tunnel	The number of 25mm diameter bolts required per linear metre of tunnel that depends on the tunnel diameter and rock support class. Refer to **Table 4.19**.
1.12	Length of rockbolts	The lengths of the bolts used to secure the tunnel lining.
1.13	Thickness of shotcrete	The thickness perpendicular to the tunnel surface.
1.14	Thirds of shotcrete in tunnel	Depending on the class of bolting, only certain sections of the tunnel circumference require shotcrete (refer to **Table 4.18** and **Table 4.19**). Class I and II – zero shotcrete is required; Class III and IV – top 120 degress require shotcrete; Class V – the top 180 degrees require shotcrete; Class VI – entire circumference requires shotcrete.
1.15	Thirds of mesh in tunnel	As in 1.14 above; the sections being grouted require mesh.
1.16	Dewatering	Select Yes/No by clicking on the radio button. Indicate whether dewatering needs to be included in the final cost or not. Dewatering is input as a sum in the rates input table.
1.17	Remove and grub large trees	The number of trees that need to be removed and grubbed.

Table 4.6: Upstream and downstream cofferdams variable input

Upstream and downstream cofferdams		
2.1	Height of the cofferdam	The difference in height between the NOC of the cofferdam and the natural ground level in the centre of the river.
2.2	Non-overspill crest (NOC) (calculated or read only)	Calculated by taking the lowest natural ground level in the centre of the river bank and adding the height of the cofferdam.
2.3	Crest width	The width of the crest of the cofferdam.
2.4	Upstream and downstream slopes	The upstream and downstream slopes of the cofferdam. The horizontal component of the slopes is the input parameter.
2.5	Soilcrete slab width	The horizontal section width of the soilcrete slab within the upstream and downstream cofferdams.
2.6	Excavation depth	The depth of excavation required in order to reach the required founding level. The same excavation depth is used for all the sections.
2.7	Excavation batter slopes	The batter slopes required for the excavation of the cofferdam foundations. The horizontal component of the slope is input.
2.8	Dewatering	Indicate, by selecting the Yes/No radio button, whether dewatering is required for the upstream and downstream cofferdams.

4.3.3 Spillway and chute input parameters

Dams require certain ancillary structures and facilities to enable them to discharge their operational function safely and effectively. In particular, adequate provision must be made for the safe passage of extreme floods and for the controlled draw-off and discharge of water in fulfilment of the purpose of the reservoir. Spillways and outlet works are therefore essential features *(Novak, Moffat et al., 2007)*.

The purpose of the spillway is to pass flood water, and in particular the design flood, safely downstream when the reservoir is overflowing. It has two principal components: the controlling spill weir and the spillway channel. The purpose of the latter being is to conduct flood flows safely downstream of the dam. The latter must incorporate a stilling basin or other energy-dissipating device. The spillway capacity must safely accommodate the safety evaluation flood, with the spillway level dictating the maximum retention level of the dam, i.e. the full supply level (FSL) *(Novak, Moffat et al., 2007)*. **Figure 4.19** shows the position of the spillway and chute in relation to the dam wall and **Figure 4.20** the plan and profile view thereof.

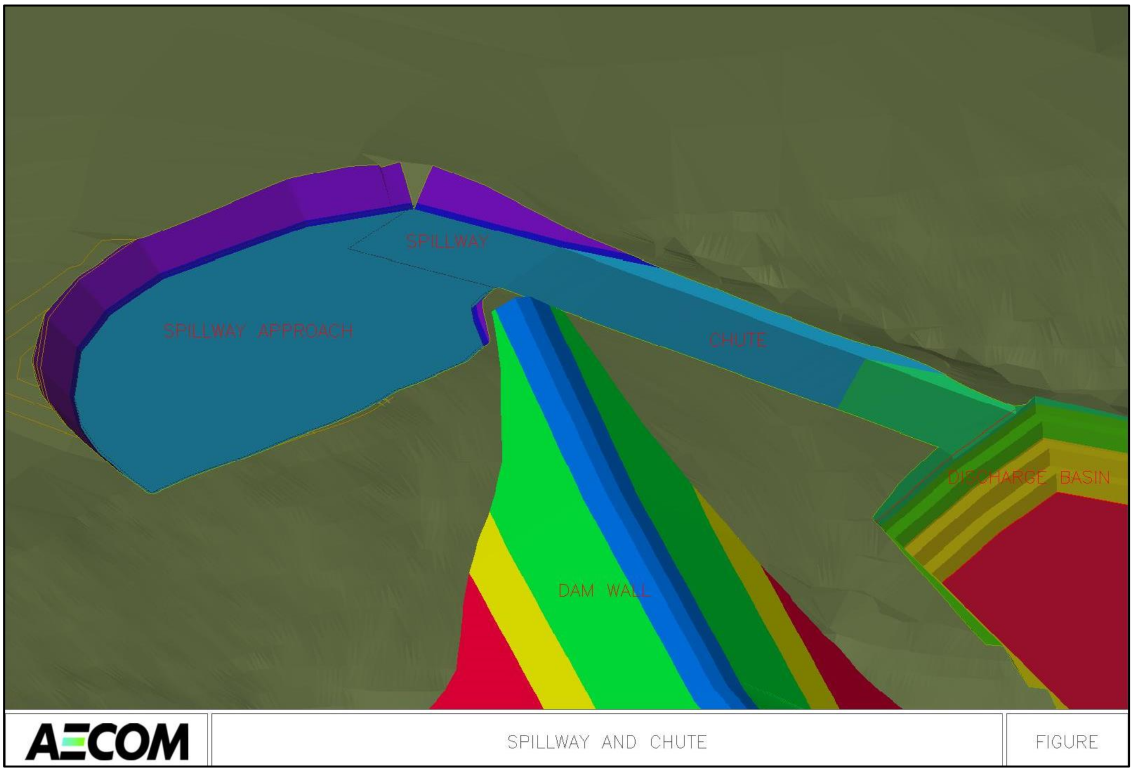


Figure 4.19: Graphical layout of spillway and chute

Figure 4.21 shows the variable input table for the layout of the spillway and chute.

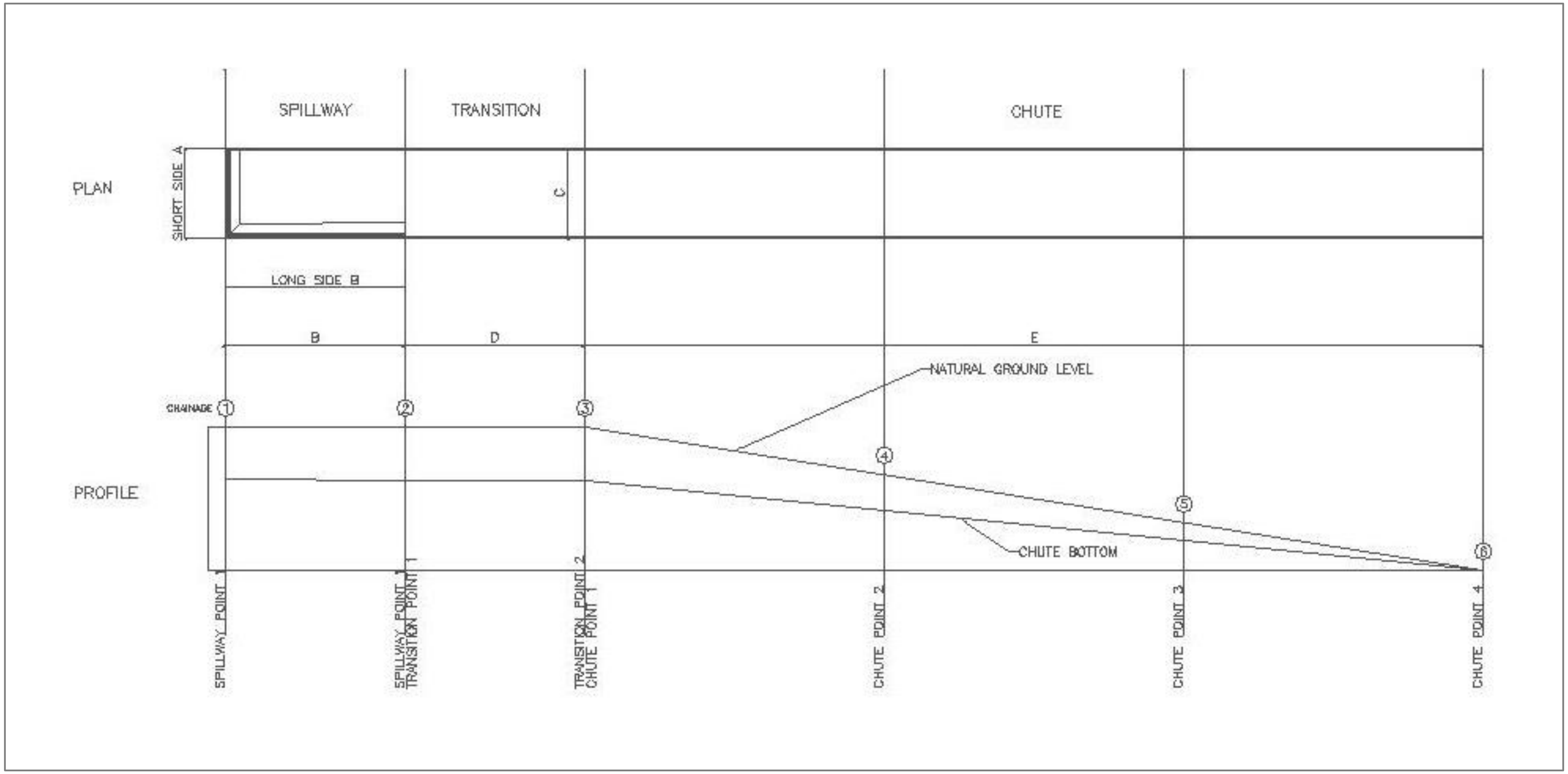


Figure 4.20: Plan and profile view of the spillway and chute

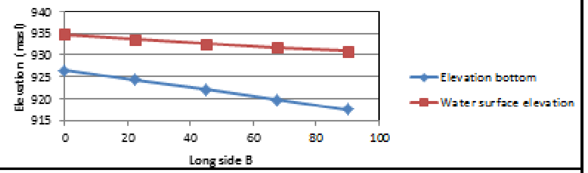
AECOM

SPILLWAY AND CHUTE

VARIABLE INPUT

1.0	Spillway and Chute		Unit
1.1	FSL	930	masl
1.2	Q_{ref}:	6960	m^3/s
1.3	Spillway and chute excavation slope	1	H:1
2.0	Spillway		
2.1	Co	2.14	
2.2	Ogee length	160	m
2.3	Ogee slope	0.7	m/m
2.4	Upstream slope	0.1	m/m
2.5	Spillway and chute wall thickness	0.5	m
2.6	Spillway floor thickness	0.5	m
2.7	Ogee reinforcement	10	kg/m^3
2.8	Manning n-value:	0.015	
2.9	Ho:	7.45	m
2.10	Short side A	70	m
2.11	Long side B	90	m
2.12	Transition inlet	70	
3.0	Transition		
3.1	Transition length	100	m
3.2	Transition loss	0.2	
4.0	Chute		
4.1	Joint spacing in chute	20	m
4.2	Anchor spacing (mxm)	5	m
4.3	Anchor length	2	m
4.4	Drainage spacing	20	m
4.5	Drainage pipe diameter	160	mm
4.6	Chute reinforcement	100	kg/m^3
4.7	Stilling basin blocks	33	No
4.8	Steel density	7850	kg/m^3

5.0	Ogee design		Left	Right	Unit
5.1	Depth of chute inlet	13.44	15.61	15.61	m
5.2	Ogee design, start elevation	917.5	OK		m
5.3	Station:	Left (Input)	Right (Output)		
5.3.1		0.716404047	0.716436919		m
5.3.2		0.898234784	0.898248344		m
5.3.3		1.070568689	1.070595058		m
5.3.4		1.178826004	1.178832242		m



6.0	Chute design	1	2	3			
6.1		Stretch (m)	Elevation	Depth (m)	Left	Right	
6.2	Point 1 (At chute inlet)	0	917.5	13.44	0.00	0.00	OK
6.3	Point 2	177	897	4.07	36.73	36.74	OK
6.4	Point 3	177	869.7	3.12	61.86	61.94	OK
6.5	Point 4	210	856	3.07	68.55	68.64	OK
6.6	Total length	564		3			

Insert the NGL from the level of the Ogee design, start elevation, until the bottom of the chute. Iterate the depth until the Left is equal to the right

Figure 4.21: Spillway and chute variable input table

Table 4.7 to **Table 4.12** provides descriptions of the variable inputs, as shown in **Figure 4.21**, for the spillway and chute, ogee design and the chute design.

Table 4.7: Spillway and chute variable input components

Spillway and chute		
1.1	FSL	Full supply level of the dam.
1.2	Q_{sef}	The safety evaluation flood for the dam.
1.3	Spillway and chute excavation slope	The batter slopes for the spillway and chute excavations.

Table 4.8: Spillway variable input components

Spillway		
2.1	C_o	Discharge coefficient for the ogee design.
2.2	Ogee length	The length of the spillway ($Q = C.\boldsymbol{L}.H^{\frac{3}{2}}$) .
2.3	Ogee slope	The downstream slope of the ogee spillway.
2.4	Upstream slope	The spillway slope.
2.5	Spillway and chute wall thickness	The thickness of the spillway and chute walls.
2.6	Spillway floor thickness	The thickness of the spillway and chute base.
2.7	Ogee reinforcement	The proportion of steel placed in the ogee spillway.
2.8	Mannings n-value	The roughness parameter used to calculate local and friction losses within the system.
2.9	H_o	(Not an input parameter or read only) The water head above the crest of the spillway.
2.10	Short side A (calculated parameter or read only)	Is assumed that the width of the chute is equal to the Q_{sef}/100 (see **Figure 4.22**).
2.11	Long side B (calculated parameter or read only)	The length of the chute calculated normal to the short side B and parallel to the direction of flow.
2.12	Transition inlet (calculated or read only)	For the initial calculations and cost, the width of the transition inlet is equal to the short side A.

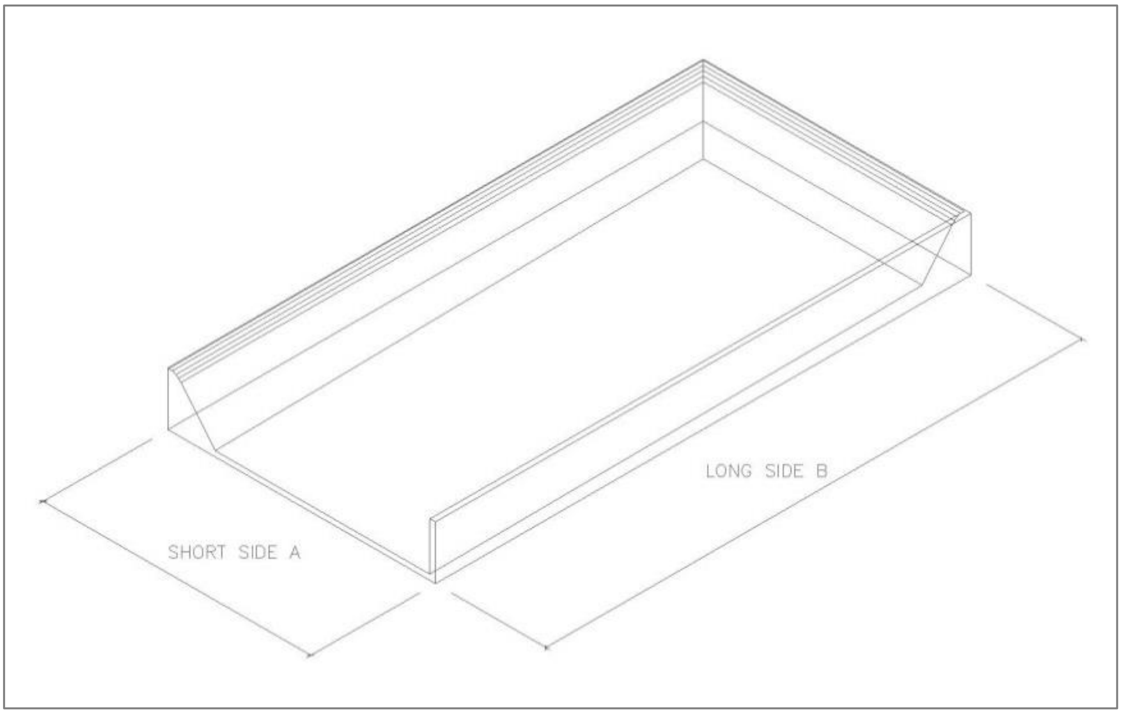


Figure 4.22: Layout of the spillway

Table 4.9: Transition variable input components

Transition		
3.1	Transition length	The transition length is the horizontal section that follows the spillway and aids in transition from turbulent flow to laminar flow down the chute.
3.2	Transition loss	This is 0.2 of the difference in the velocity head between the ends of the transition *[United States Department of the Interior (1987)]*.

Table 4.10: Chute variable input components

Chute		
4.1	Joint spacing in the chute	The spacing of the joints along the length of the chute.
4.2	Anchor spacing	The spacing of the anchors on a square grid (m x m).
4.3	Anchor length	The length of the anchors used to secure the chute.
4.4	Drainage spacing	The spacing of the drains.
4.5	Drainage pipe diameter	The diameter of the drainage pipes.
4.6	Chute reinforcement	The steel reinforcement used in the chute. Input as a mass per unit volume of concrete.
4.7	Stilling basin blocks	The number of blocks used in the stilling basin.
4.8	Steel density	The density of the steel reinforcement (Assume: 7 850 kg/m^3).

Table 4.11: Ogee design variable input components

Ogee design		
5.1	Depth of the chute inlet	The depth must be input such that the left column must be equal to the right.
5.2	Start elevation	The elevation at the end of the spillway section; at the start of the transition zone. The design of the spillway section starts at the end of the spillway and continues upstream towards the short side A.

With reference to **Table 4.12**, the left value is input. Iterate the left value with the depth of the chute such that the left value is equal to the right (Enter the right column's value in the left column until they are equal). The what-if function in Microsoft Excel can be used.

Table 4.12: Chute design variable input table

6.0	Chute design	1	2	3	4		5
6.1		Stretch (m)	Elevation	Depth (m)	Left		Right
6.2	Point 1 At chute inlet	Zero, start of the spillway section	Chute floor elevation of point 1 (meters above sea level)	Equal to the depth of the chute inlet	[Calculated value]	=	[Calculated value]
6.3	Point 2	[Input] Distance between point 1 and point 2	[Input] Chute floor elevation of point 2 (meters above sea level)	[Input] Depth of the water in the chute at point 2. Enter value such that the left column is equal to the right column	[Calculated value]	=	[Calculated value]
6.4	Point 3	[Input] Distance between point 2 and point 3	[Input] Chute floor elevation of point 3 (meters above sea level)	[Input] Depth of the water in the chute at point 3. Enter value such that the left column is equal to the right column	[Calculated value]	=	[Calculated value]
6.5	Point 4	[Input] Distance between point 3 and point 4	[Input] Chute floor elevation of point 4 (meters above sea level)	[Input] Depth of the water in the chute at point 4. Enter value such that the left column is equal to the right column	[Calculated value]	=	[Calculated value]
6.6	Total length	The total length between point 1 and point 4					

** Grey shaded cells require input*

4.3.4 Intake and outlet input parameters

Controlled outlet facilities are required to permit water to be drawn off as operationally necessary. Provision must be made to accommodate the required penstocks and pipework with their associated control gates or valves. For concrete dams, it is common practice to incorporate the intake structure within the dam. For embankment dams it is normal practice to provide an external control structure or valve tower, which is separate from the dam, controlling entry to an outlet tunnel or culvert *(Novak, Moffat et. al, 2007)*.

A bottom discharge facility is provided in most dams to provide an additional measure of drawdown control and, where reasonable, to allow emptying of the reservoir. In most cases it is necessary to use special outlet valves and/or structures to avoid scouring and damage to the stream bed and banks downstream of the dam *(Novak, Moffat et. al, 2007)*.

Figure 4.23 shows the layout of the water intake structure used within the cost model. **Figure 4.24** shows the variable input table for inlet and outlet works.

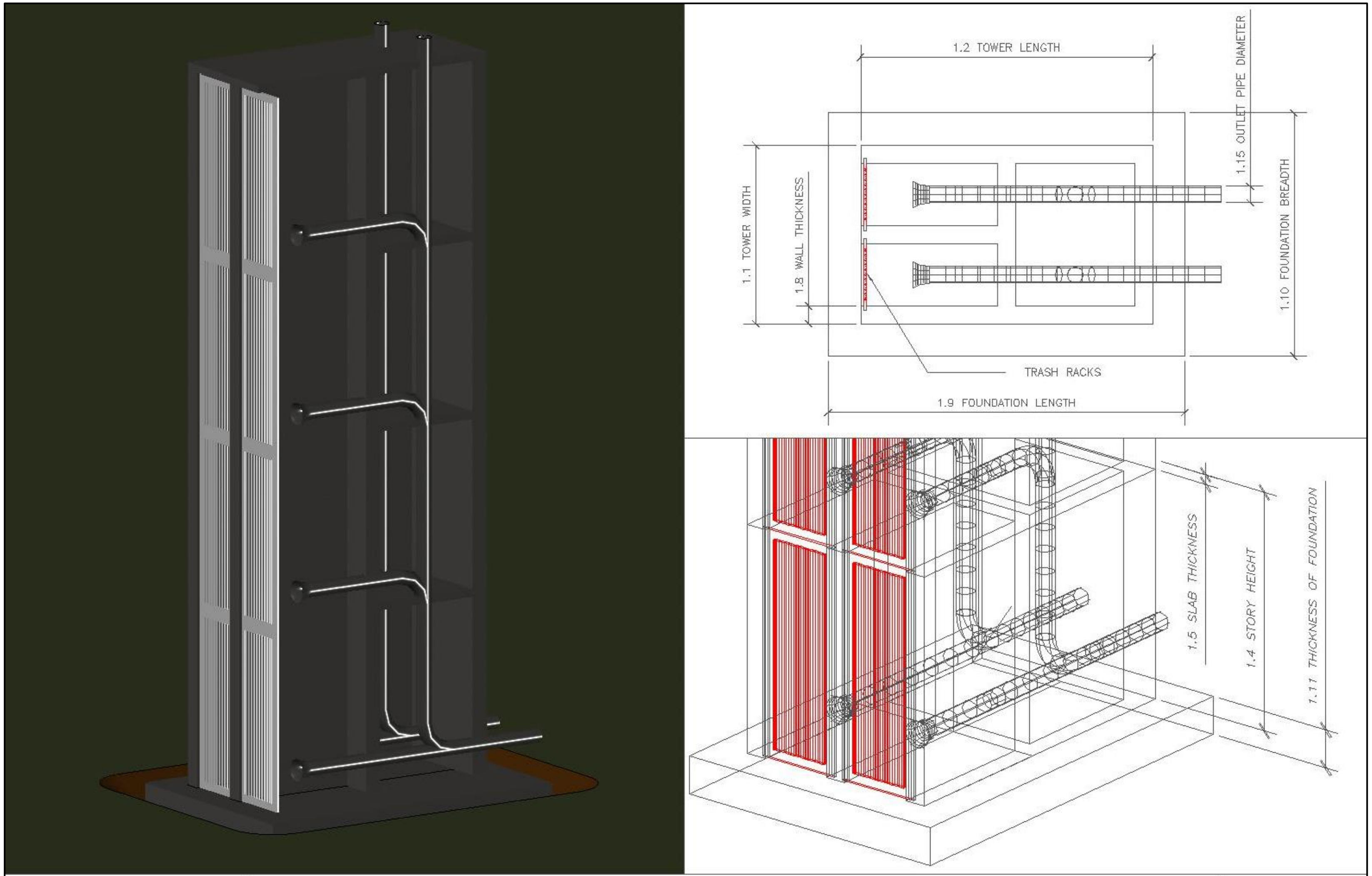


Figure 4.23: Water intake structure

AECOM INLET AND OUTLET WORKS

	Intake structure		
1	Tower Dimensions		
1.1	Tower width	10	m
1.2	Tower length	15	m
1.3	Tower height	84	m
1.4	Story height/ Lift height	12	m
1.5	Slab thickness	0.5	m
1.6	Ceiling height	11.5	
1.7	Number of stories	7	
1.8	Wall thickness	1.1	m
	Foundation dimensions		
1.9	Foundation length	17	m
1.1	Foundation breadth	12	m
1.11	Thickness of foundation	2	m
1.12	Excavation batter slopes	1	H:1
	Reinforcement		
1.13	Reinforcement in tower	100	kg/m^3
1.14	Reinforcement in foundation	50	kg/m^3
	Intake tower pipes		
1.15	Outlet pipe diameter	1.8	m
1.16	Number of outlet pipes per intake level	2	No
1.17	Number of intake levels	4	No
1.18	Pipe length from intake tower to outlet works	200	m
	Outlet works		
1.19	Foundation width	12	m
1.20	Foundation length	12	m
1.21	Foundation thickness	5	m
1.22	Reinforcing	100	kg/m^3
1.23	Excavation batter slopes	1	H:1
1.24	Floor thickness	0.5	m
1.25	Wall thickness	0.5	m
1.26	Structure length	10	m
1.27	Structure width	10	m
1.28	Structure height	10	m
	Stilling Basin		
1.29	Basin length	15	m
1.30	Wall heights	4	m
1.31	Wall thickness	1	m
1.32	Floor thickness	1	m
	Bridge		
	Bridge Deck:		
1.33	Deck width	4	m
1.34	Deck thickness	1	m
1.35	Embankment slope	2	H:1
1.36	Bridge length	168	m
1.37	Reinforcment	100	kg/m^3
	Bridge piers:		
1.38	Pier width	1	m
1.39	Pier length	1	m
1.40	Number of piers	4	No
1.41	Foundation width	3	m
1.42	Foundation length	3	m
1.43	Foundation thickness	1	m
1.44	Foundation reinforcement	100	kg/m^3
1.45	Pier reinforcment	100	kg/m^3
	Roads		
1.46	Site access roads - gravel roads	1	km
	Mechanical Items (Include)		
1.47	(a) Gates and screens	Yes	
1.48	(b) Lifting equipment	Yes	
1.49	(c) Pipework and valves	Yes	
1.50	Electrical Installation	Yes	

Figure 4.24: Intake and outlet works variable input table

Table 4.13 to **Table 4.16** provides descriptions of the variable inputs, as shown in **Figure 4.24**, for the intake structure, outlet works, stilling basin and the bridge deck respectively.

Table 4.13: Intake structure variable input components

Intake structure		
1.1	Tower width	The width of the tower in the direction of flow. The front width of the water intake tower.
1.2	Tower length	The length of the tower normal to the direction of flow.
1.3	Tower height	The height of the tower from natural ground level.
1.4	Story height	The difference in height between levels.
1.5	Slab thickness	The thickness of the floor slabs.
1.6	Ceiling height (calculated or read only)	The height calculated by subtracting the slab thickness from the story height.
1.7	Number of stories	The number of levels within the tower.
1.8	Wall thickness	The thickness of the external walls of the water intake structure.
1.9	Foundation length	The length of the foundation, which is parallel to the tower length.
1.10	Foundation breadth	The width of the foundation, which is parallel to the tower width.
1.11	Thickness of foundation	The depth of the foundation from founding level to the natural ground level.
1.12	Excavation batter slopes	The horizontal component of the slope is input.
1.13	Reinforcement in tower	The amount of reinforcement in the tower that is calculated as a mass of steel per unit of concrete.
1.14	Reinforcement in foundation	The amount of reinforcement in the tower that is calculated as a mass of steel per unit of concrete.
1.15	Outlet pipe diameter	The diameter of the outlet pipe, which extends from the inlet to the outlet works.
1.16	Number of outlet pipes per intake level	The number of intakes pipes per level. A maximum of two intakes may be placed per intake level.
1.17	Number of intake levels	The number of levels from which water can be drawn.
1.18	Pipe length from intake tower to outlet works	The distance between the intake tower and the outlet works.

Table 4.14: Outlet works variable input components

Outlet works		
2.4	Foundation width	The width of the outlet works foundation.
2.5	Foundation length	The length of the outlet works foundation.
2.6	Foundation thickness	The depth of the foundation between the founding level and the natural ground level.
2.7	Reinforcing	The amount of reinforcement that is calculated as a mass per unit of concrete for both the foundation and the outlet works superstructure.
2.8	Excavation batter slopes	The horizontal component of the batter slope is input.
2.9	Floor thickness	The thickness of the outlet work's floors.
2.10	Wall thickness	The thickness of the external walls of the outlet works.
2.11	Structure length	The length of the outlet work's superstructure.
2.12	Structure width	The width of the outlet work's superstructure.
2.13	Structure height	The height of the superstructure from the natural ground level to the top of the structure.

Table 4.15: Stilling basin variable input components

Stilling basin		
2.14	Basin length	The length of the basin from the outlet works to the point of discharge into the river.
2.15	Wall heights	The height of the walls on either side of the stilling basin.
2.16	Wall thickness	The thickness of the walls on either side of the stilling basin.
2.17	Floor thickness	The thickness of the stilling basin floor.

Table 4.16: Bridge deck variable input components

Bridge deck		
2.18	Deck width	The width of the bridge deck that runs from the embankment to the intake structure.
2.19	Deck thickness	The thickness of the bridge deck.
2.20	Embankment slope	The horizontal component of the embankment slope is an input. The embankment slope is equal to the upstream slope of the embankment.
2.21	Bridge length	(Calculated or read only) The length of the bridge is calculated from the embankment slope and the height of the intake structure.
2.22	Reinforcement	The quantity of reinforcement to be used within the bridge deck. The amount of reinforcement is determined as a mass per unit volume of concrete.
2.23	Pier width	The width of the piers used to support the bridge deck.
2.24	Pier length	The length of the piers used to support the bridge deck.
2.25	Number of piers	The number of piers required to support the bridge deck.
2.26	Foundation width	The width of the foundations used to support the bridge piers.
2.27	Foundation length	The length of the foundations used to support the bridge piers.
2.28	Foundation thickness	The thickness of the foundation. The depth of the foundation between the founding level and the natural ground level;
2.29	Foundation reinforcement	The quantity of reinforcement to be used within the foundation. The amount of reinforcement is determined as a mass per unit volume of concrete.
2.30	Pier reinforcement	The quantity of reinforcement to be used within the bridge piers. The amount of reinforcement is determined as a mass per unit volume of concrete.
2.31	Site access roads-gravel roads	The length of the gravel roads that need to be constructed in order to provide access to the water intake tower and outlet works.
2.32	Gates and screens	Select Yes/No by pushing the radio button. Indicate whether gates and screens need to be included within the cost;
2.33	Lifting equipment	Select Yes/No by pushing the radio button. Indicate whether lifting equipment needs to be included within the cost.
2.34	Pipework and valves	Select Yes/No by pushing the radio button. Indicate whether pipework and valves need to be included within the cost.
2.35	Electrical installation	Select Yes/No by pushing the radio button. Indicate whether electrical installation needs to be included within the cost.

4.3.5 Transfer tunnel input parameters

The transfer tunnel variable inputs require the input of a long section for the tunnel. The long section requires the chainage value and the corresponding natural ground level above the tunnel. Input values need to be specified for the tunnel, ventilation shafts, the adits and the inlet and outlet portals. **Figure 4.25** shows the layout of the transfer tunnel variable inputs table.

Insert the tunnel chainage and the corresponding natural ground level

Transfer tunnel, ventilation shaft and adits input tables

TRANSFER TUNNEL VARIABLE INPUTS

Tunnel alignment			Tunnel			
Position	Chainage	NGL			Variable	Unit
1	0	887.2035	1.1	Number of tunnels	1	Number
2	50	897.8023	1.2	Diameter (Outer diameter including cover)	3.5	m
3	100	907.1048	1.3	Type of tunnel	TBM	
4	150	918.6077	1.4	Rocktype	C	
5	200	930.6948	1.5	Lining thickness	250	mm
6	250	948.7162	1.6	Upstream invert level	881	masl
7	300	963.2383	1.7	Downstream invert level	885	masl
8	350	985.774	1.8	Mesh mass per m^2 of lining	1.56	kg/m^2
9	400	1008.5924	1.9	Class 4 Shotcrete thickness	50	mm
10	450	1036.3034	1.10	Class 5 Shotcrete thickness	100	mm
11	500	1056	1.11	Class 6 Shotcrete thickness	100	mm
12	550	1056.0136	1.12	Spacing of arch ribs	1	m
13	600	1078.3051	1.13	Inlet portal excavation volume	450000	m^3
14	650	1089.0644	1.14	Outlet portal excavation volume	640000	m^3
15	700	1112.3203	1.15	Adit portal excavation volume	80000	m^3
16	750	1138	1.16	Adits length	3060	m
17	800	1136.7013	1.17	Adit lining thickness	0.5	m
18	850	1144.6671	1.18	Adit diameter (Outer diameter)	4	m
19	900	1156.5361	Ventilation Shaft			
20	950	1169.9971	2.1	Internal diameter of shaft	3.5	m
21	1000	1184.3159	2.2	Concrete lining thickness	300	mm
22	1050	1198.6734	2.3	Steel encasing thickness	10	mm
23	1100	1209.6349	2.4	Shaft 1 (Chainage)	6950	m
24	1150	1218.6882	2.5	Shaft 2 (Chainage)	15300	
25	1200	1231.7872	2.6	Shaft 3 (Chainage)	27700	
26	1250	1240.8158	2.7	Density of reinforcement	7850	kg/m^3
27	1300	1256.048	2.8	Access road-Gravel	5	km
28	1350	1262.9731	2.9	Electricity to site	1	Sum
29	1400	1277.3073	2.10	Water to site - contractor (not potable)		Sum
30	1450	1296.0867	2.11	Railhead and materials handling		Sum

Figure 4.25: Transfer tunnel variable input

a) Tunnel alignment

The tunnel alignment with its corresponding chainages needs to be input in order to determine the support class and rock class along the length of the tunnel. The type of rock class is determined by the distance between the natural ground level and the invert of the tunnel. There are seven rock classes that can be used within the tunnel, namely:

- Rock class 1: Spot bolting;
- Rock class 2: Light pattern bolting;
- Rock class 3: Pattern bolting with mesh;
- Rock class 4: Bolts and mesh with shotcrete over 120 degrees;
- Rock class 5: Bolts and mesh with shotcrete over 180 degrees;
- Rock class 6: Arch ribs with mesh and shotcrete over 330 degrees; and
- Rock class 7: Pattern bolting for spalling rock.

The input of the tunnel alignment also enables the distance between natural ground level and the tunnel invert to be determined in order to calculate the required quantities related to the ventilation shafts. By typing in the chainage that specifies the position of the ventilation shaft, the distance between the natural ground level and the tunnel invert is determined.

Figure 4.26 shows the profile of the transfer tunnel with the location of the ventilation shafts. **Table 4.17** and **Table 4.18** provide descriptions of the variable inputs, as shown in **Figure 4.25**, for the tunnel alignment.

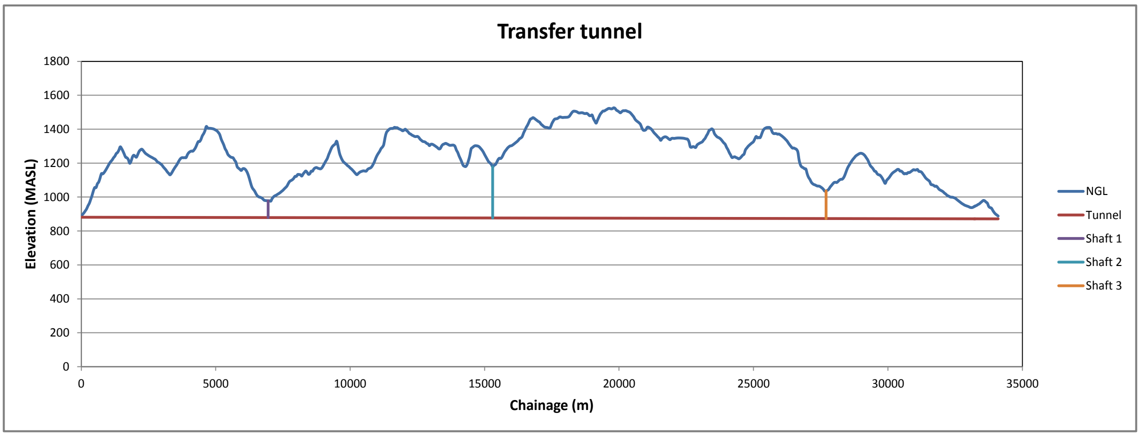


Figure 4.26: Transfer tunnel profile

Table 4.17: Tunnel alignment variable input components

Tunnel alignment		
1.1	Number of tunnels	The number of tunnels that need to be constructed.
1.2	Diameter (total diameter including lining)	The outer diameter of the tunnel.
1.3	Type of tunnel	Refers to the method that will be used to construct the tunnel. The tunnel can either be constructed using a tunnel boring machine (TBM) or by Drill and Blast (DBT). Depending on the type of method used, different support classes are relevant.
1.4	Rock type	The type or rock the tunnel will be bored. Select between rock type A, B, C, D, E, F, G, H (see **Table 4.18**).
1.5	Lining thickness	The thickness of the tunnel lining.
1.6	Upstream invert level	The invert level at the inlet portal of the tunnel.
1.7	Downstream invert level	The invert level at the outlet portal of the tunnel.
1.8	Mesh mass per m^2 of lining	The mass of the mesh per square meter of mesh.
1.9	Class 4 Shotcrete thicknesses	The thickness of the shotcrete for class 4.
1.10	Class 5 Shotcrete thickness	The thickness of the shotcrete for class 5.
1.11	Class 6 Shotcrete thickness	The thickness of the shotcrete for class 6.
1.12	Spacing of arch ribs	The distance between subsequent arch ribs.
1.13	Inlet portal excavation volume	The amount of material that needs to be excavated to form the inlet portal.
1.14	Outlet portal excavation volume	The amount of material that needs to be excavated to form the outlet portal.
1.15	Adit lengths	The length of the adits from the inlet portal at natural ground level to where they connect to the transfer tunnel.
1.16	Adit lining thickness	The thickness of the linings used within the adits.
1.17	Adit diameter (outer diameter)	The outer diameter of the adits.

The occurrence of following rock types on the tunnel alignment should be estimated (as shown in **Table 4.18**):

Table 4.18: Rock types within tunnel

Rock type		UCS
A	Sandstone	20-80 MPa
B	Interbedded sandstone and siltstone	10-80 MPa
C	Siltstone	10-50 MPa
D	Interbedded sandstone/siltstone/mudstone	5-50 MPa
E	Mudstone (Claystone)	5-20 MPa
F	Dolerite dykes	100-200 MPa
G	Dolerite sills	100-200 MPa
H	Basalt	50-150 MPa

The support class for the bolts is defined as follows with **Table 4.19** showing the number of bolts per linear metre of tunnel:

Class

I Spot bolting;

II Light pattern bolting;

III Pattern bolting with mesh over 120 degrees of crown;

IV Bolts and mesh with shotcrete min 50 mm thick over 120 degrees;

V Bolts and mesh with shotcrete min 100 mm thick over 180 degrees;

VI Arch ribs (TH16/48 1m spacing) with mesh and shotcrete 100 mm over 330 degrees; and

VII Pattern bolting for spalling rock (1.5 m length 25 mm diameter).

Table 4.19: Number of 25 mm diameter bolts per linear metre of tunnel

Support class	Tunnel diameter			
	3 m	4 m	5 m	6 m
I (bolts/m)	0.1	0.2	0.3	0.5
II	2	3	3	4
III+IV+V	4	5	6	6
VII	4	6	8	10

b) Ventilation shafts

Table 4.20 provides descriptions of the variable inputs, as shown in **Figure 4.25**, for the ventilation shafts.

Table 4.20: Ventilation shaft input components

Ventilation shaft		
2.1	Internal diameter of shaft	The internal diameter of the shaft excluding any linings
2.2	Concrete lining thickness	The thickness of the concrete lining used within the ventilation shaft
2.3	Steel encasing thickness	The thickness of the steel encasing used within the ventilation shaft
2.4	Shaft 1 (Chainage)	The position of the ventilation shaft 1 along the length of the tunnel. The chainage that is input here needs to correspond to a chainage that was input in the tunnel alignment input table
2.5	Shaft 2 (Chainage)	The position of the ventilation shaft 2 along the length of the tunnel. The chainage that is input here needs to correspond to a chainage that was input in the tunnel alignment input table
2.6	Shaft 3 (Chainage)	The position of the ventilation shaft 3 along the length of the tunnel. The chainage that is input here needs to correspond to a chainage that was input in the tunnel alignment input table
2.7	Density of reinforcement	The density of the reinforcement used within the tunnel
2.8	Access road – Gravel	The length of the gravel access roads to the inlet portal, ventilation shafts and outlet portals
2.9	Electricity to site	Whether the cost of providing electricity to site needs to be included
2.10	Water to site – contractor (not potable)	Whether the cost of providing water to site needs to be included
2.11	Railhead and materials handling	

4.3.6 Pipeline input parameters

Figure 4.27 shows the layout of the transfer tunnel variable inputs table and **Table 4.21** provides descriptions of the variable inputs.

AECOM	PIPELINE	
Tunnel		
Pipe diameter 1	2.4	m
Pipe diameter 2	2.2	m
Pipe diameter 3		m
Pipe diameter 4		m
Pipe diameter 5		m
Length of pipeline (Diameter 1)	3460	m
Length of pipeline (Diameter 2)	21000	m
Length of pipeline (Diameter 3)		m
Length of pipeline (Diamater 4)		m
Length of pipeline (Diamater 5)		m
Trench depth (Diamater 1)	3.4	m
Trench depth (Diamater 2)		m
Trench depth (Diamater 3)		m
Trench depth (Diamater 4)		m
Trench depth (Diamater 5)		m
Cathodic protection	1	km
Volume concrete valve chambers and manholes	12000	m^3
Thrust block encasings (Volume concrete)	12000	m^3
Reinforcing	100	kg/m^3
Access road - Gravel	24.46	km
River and road crossing	1	No
Structural Steelwork		t
Valves	1	No

Figure 4.27: Pipeline variable input table

Table 4.21: Pipeline input parameters

Pipeline input parameters		
1	Pipe diameter 1 - 5	The spreadsheet allows input for five different pipe diameters, which relates with the length of pipeline (diameter 1 – 5) and trench depth (diameter 1 – 5).
2	Length of pipeline (diameter 1 – 5)	The distance of pipeline required for a particular pipe diameter.
3	Trench depth (diameter 1 – 5)	The required trench depth for a particular pipe diameter. A constant depth is used for the entire length of pipeline.
4	Cathodic protection	Indicate, by selecting the Yes/No radio button, whether cathodic protection is required for the pipelines.
5	Volume concrete valve chambers and manholes	The total volume of concrete required for the valve chambers and manholes.
6	Thrust block encasings (volume concrete)	The total volume of concrete required for the thrust block encasings.
7	Reinforcing	The quantity of reinforcement in the valve chambers, manholes and thrust block encasings that is calculated as a mass of steel per unit volume of concrete.
8	Access road – Gravel	The required distance of access roads in kilometres required in order to gain access to the pipelines.
9	River and road crossing	The number of river and road crossings required in order to gain access to the pipelines.
10	Structural steelwork	The quantity of structural steelwork required for the valve chambers and manholes in tons.
11	Valves	The number of valves required for all the pipelines.

4.4 RATES INPUT

The rate input table (see **Figure 4.28**) enables the selection between rates that have been determined according to VAPS, previous projects or project specific rates. The rates can be set for a specific base year and can be inflated until the current year. For own rates or project specific rates only one base year can be inserted.

Step 1:

- Select the required rates to be used (select Rate 1, Rate 2 or Rate 3);
- Input the rate escalation percentage;
- Input the base year for each rate and the current year in which the rate is relevant;

Step 2:

- Select whether the default rate should be used or whether the own rate should be used for each item within the bill of quantities;

- Insert the rates for each of the options;

Step 3:

- Select whether the default rate escalation rate should be used or whether an individual escalation rate should be used for the item;

Note: All cells that are highlighted in yellow require an action or an input.

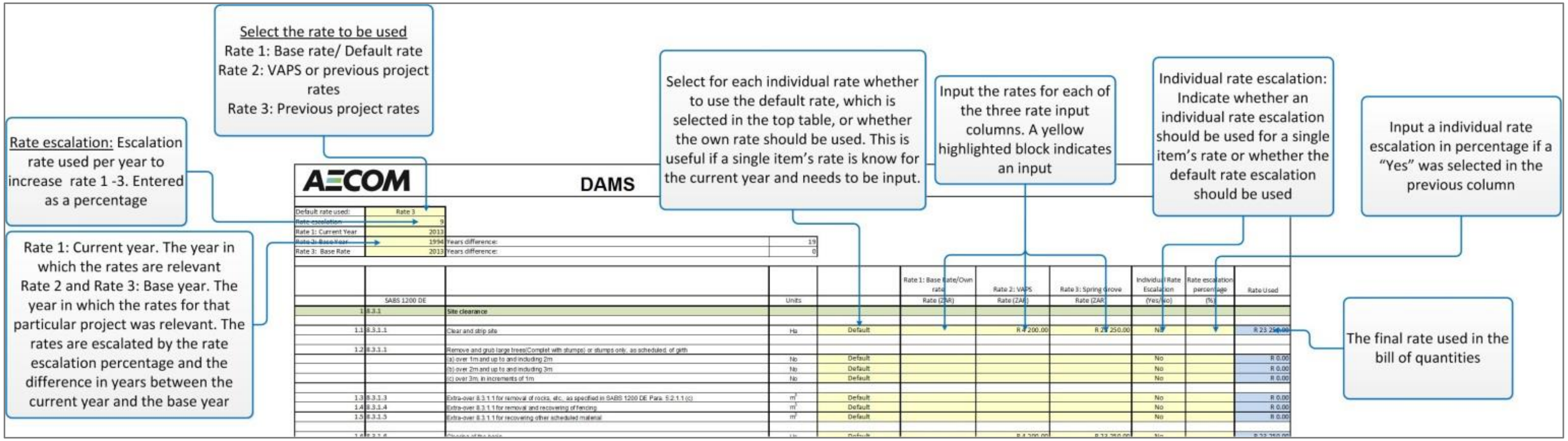


Figure 4.28: Rates input table

4.5 CALCULATIONS

The spreadsheets provides some explanation and graphics on how the final volumes are calculated. For an indepth explanation on each of the dam types and how the quantities are determined refer to the technical section of this report. No input is required on any of the calculation sheets as the input is conveyed from the variable input tables.

Each dam calculation speadsheet contains all the dam type options, this enables the selection of numerous dam designs for the river section, left flank and right flank. Only the RCC river section may be used in combination with the other dam options. Other combinations may be used but may lead to a lack of coherence in the transition from one damtype to the other. Always ensure that the spillway chainage for the left flank and right flank lie within the minimum and maximum chainage of the dam, even if the river section, right flank and left flank are of the same dam type option.

By selecting the dam type for the river section, left and right flank, the spreadsheet conveys to each dam type option which chainages the quantities for that dam type need to be determined.

Figure 4.29 shows an example of calculation spreadsheets.

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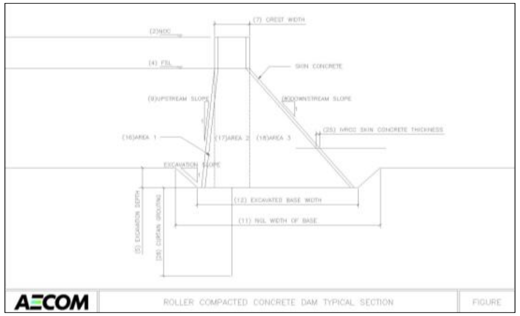
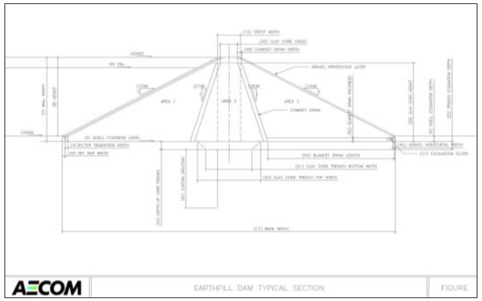
ROLLER COMPACTED CONCRETE DAM



Ogee length	160	m	80	3600	3520	3680

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
												Excavatiuon					Volume concrete				
		Section	NGL	NOC	FSL	Excavation	Section interval	Crest width	Downstream slope	Upstream slope	Excavation Slope	NGL Width of base	Excavated Base width	Footprint area at NGL (Horizontal)	Topsoil Excavation Area (Vertical)	Excavated volume	Area 1	Area 2	Area 3	Total	Volume
		1	masl	masl		(m)	(m)	(m)	(M:1)	(M:1)	(M:1)	m	m	m^2	m^2	m^3	m^2	m^2	m^2	m^2	m3
1	0.000	0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	
2	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0
3	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0
4	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0
5	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0
6	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0

EARTHFILL EMBANKMENT DAM



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
												slopes		Footprint		Excavation									
Stations	Sections	NGL	NOC	Excavation depth	Shell founding level	Wall height (NOC-Excavation line)	Height (NOC-NGL)	FSL	Water Height (FSL-excavation line)	Section interval	Crest width	Upstream slope	Downstream slope	NGL Width of Base	Footprint area	Excavation slope	Shell excavation depth	Footprint Excavation (Vertical)	Clay core trench Top width (H/2)	Clay core trench Bottom width	Trench Excavation Depth	Trench excavation area (Vertical)	Footprint volume	Trench volume	Total excavation
		m	m	m	m	m	m			m	m	H:1	H:1	m	m^2	H:1	m	m^2	m	m	m	m^2	m^3	m^3	m^3
1	0	0	0.0					0	0.0					0	0										
2	0	0	0.0					0	0.0					0	0										
3	0	0	0.0					0	0.0					0	0										
4	0	0	0.0					0	0.0					0	0										
5	0	0	0.0					0	0.0					0	0										

Figure 4.29: Example of calculation spread sheets

4.6 BILL OF QUANTITIES (BOQ)

The bill of quantities provides a breakdown of all the costs and volumes for each of the embankment dam types. No input is required as the rates and quantities are conveyed from the calculation spread sheets and rates input spread sheets.

The same bill of quantities is used for each of the dam types. Depending on what dam type is selected for the river section, left flank and right flank, the corresponding quantities will be input into the bill of quantities.

4.6.1 Dam embankment bill of quantities

AECOM — MAIN DAM BILL OF QUANTITIES — OPTION 1:

Left flank:		RCC
River section:		RCC
Right flank:		RCC

ITEM NO	PAYMENT	DESCRIPTION	UNIT	Quantity	Rate	AMOUNT (R)
	SABS 1200 DE					
1	8.3.1	**Site clearance**				
1.1	8.3.1.1	Clear and strip site	Ha	8	R 23 250.00	R 197 296.21
1.2	8.3.1.1	Remove and grub large trees(Complet with stumps) or stumps only, as scheduled, of girth				
		(a) over 1m and up to and including 2m	No	0	R 0.00	R 0.00
		(b) over 2m and up to and including 3m	No	0	R 0.00	R 0.00
		(c) over 3m, in increments of 1m	No	0	R 0.00	R 0.00
1.3	8.3.1.3	Extra-over 8.3.1.1 for removal of rocks, etc., as specified in SABS 1200 DE Para. 5.2.1.1 (c)	m^3	0	R 0.00	R 0.00
1.4	8.3.1.4	Extra-over 8.3.1.1 for removal and recovering of fencing	m^3	0	R 0.00	R 0.00
1.5	8.3.1.5	Extra-over 8.3.1.1 for recovering other scheduled material	m^3	0	R 0.00	R 0.00
1.6	8.3.1.6	Clearing of the basin	Ha	0	R 23 250.00	R 0.00
2	8.3.2	Remove topsoil to nominal depth 150mm, stockpile and maintain	m^2	84859	R 20.00	R 1 697 171.72
3	8.3.3	**Excavation**				
3.1		a) Material unsuitable for embankment	m^3	1068500	R 31.60	R 33 764 611.52
3.2		b) Material suitable for embankment from essential excavations for:				
		1) Core trench	m^3	0	R 0.00	R 0.00
		2) Spillway	m^3	0	R 0.00	R 0.00
		3) Pipe trenches	m^3	0	R 0.00	R 0.00
		4) Outlet works	m^3	0	R 0.00	R 0.00
		Extra over (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	0	R 0.00	R 0.00
		2) Hard rock material	m^3	0	R 36.50	R 0.00
3.4	8.3.4	Preparation of exposed surfaces				
		a) Core trench				
		b) Area to be covered by dam wall	m^2	52901	R 92.55	R 4 896 019.69
3.5	8.3.5	**Forming Embankment**				
		a) Selected impervious material (Clay material)	m^3	0	R 48.37	R 0.00
		b) Transition	m^3	0	R 97.94	R 0.00
		c) Unselected pervious material				
		i) Earthfill	m^3	0	R 48.37	R 0.00
		ii) Rockfill - Type 1 (Outer zone)	m^3	0	R 91.00	R 0.00
		iii) Rockfill - Type 2 (Inner zone)	m^3	0	R 91.00	R 0.00
		d) Rip-rap	m^3	0	R 438.52	R 0.00
		e) Topsoil from stockpile to downstream slope	m^3	0	R 0.00	R 0.00
		f) Coarse filter material	m^3	0	R 789.45	R 0.00
		g) Fine filter material	m^3	0	R 789.45	R 0.00
		h) Gravel capping	m^3	0	R 91.00	R 0.00
3.6		**Concrete Works**				
3.6.1		(a) Formwork				
		(i) Gang formed	m	125421	R 475.00	R 59 574 823.22
		(ii) Intricate	m	0	R 480.00	R 0.00
3.6.2		(b) Concrete				
		(i) Rollcrete	m^3	1498979	R 1 156.76	R 1 733 958 472.77
		(ii) IVRCC	m^2	125421	R 45.40	R 5 694 098.89
		(iii) CVC	m^3	2400	R 1 981.85	R 4 756 440.00
		(iv) Mass	m^3	0	R 1 981.85	R 0.00
3.6.3		(c) Reinforcing	t	240	R 12 854.15	R 3 084 996.00
3.6.4		(d) Waterstop	m	0	R 944.69	R 0.00
3.7		**Drilling & Grouting**				
3.7.1		(a) Curtain grouting	m	20753	R 1 054.15	R 21 877 243.74
3.7.2		(b) Consolidation grouting	m	0	R 1 054.15	R 0.00
TOTAL CARRIED FORWARD TO SUMMARY						R 1 869 501 174

4.6.2 Diversion works bill of quantities

AECOM DIVERSION WORKS

ITEM NO	PAYMENT		UNIT	Quantity	Rate (R)	AMOUNT (R)
		STAGE 1: PORTALS AND TUNNELS				
1	**1.0**	**SITE CLEARANCE**				
	1.1	**Clear and grub**				
		(a) Portal footprints	ha	0.12	R 23 250.00	R 2 794.38
	1.2	**Remove and grub large trees and tree stumps of girth**				
		(a) Over 1 m and up to and including 2m	No	0.00	R 0.00	R 0.00
	1.3	**Remove topsoil to nominal depth of 150 mm and stockpile**	m³	1 201.89	R 10.28	R 12 355.39
2	**2.0**	**EXCAVATION AND BACKFILL FOR DAMS AND WATERWAYS**				
		Bulk Excavation				
	2.1	**Inlet portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	3 025.00	R 91.00	R 275 275.00
		(b) Extra over for:				
		(i) Intermediate	m³	302.50	R 0.00	
		(ii) Hard Rock	m³	302.50	R 31.60	R 9 559.00
		(iii) Boulder, Class A	m³	0.00	R 0.00	R 0.00
		(iv) Boulder, Class B	m³	0.00	R 0.00	R 0.00
	2.2	**Outlet Portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	3 025.00	R 91.00	R 275 275.00
		(b) Extra over for:				
		(i) Intermediate	m³	302.50	R 0.00	
		(ii) Hard Rock	m³	302.50	R 31.60	R 9 559.00
		(iii) Boulder, Class A	m³	0.00	R 0.00	R 0.00
		(iv) Boulder, Class B	m³	0.00	R 0.00	R 0.00
	2.3	**Dewatering**	Sum	0.00	R 0.00	R 0.00
		SUB TOTAL: STAGE 1				R 584 817.77
		STAGE 2 Cofferdam				
3		**SITE CLEARANCE**				
	3.1	**Clear and grub**				
		(a) Embankment footprint	ha	0.52	R 26 546.00	R 13 910
	3.2	Remove and grub large trees and tree stumps of girth				
		(a) over 1 m and up to and including 2 m	No	0.00	R 0.00	R 0
	3.3	Remove topsoil to nominal depth of 150 mm and stockpile	m³	5 240.00	R 10.28	R 53 867
4	**4.1**	**EXCAVATIONS AND BACKFILL FOR DAMS AND WATERWAYS**				
		(a) Excavate all materials				
		(i) Topsoil at Upstream & Downstream cofferdam	m³	5 240.00	R 51.42	R 269 441
5	**5.1**	**EMBANKMENT CONSTRUCTION**				
		Earthfill Upstream & Downstream Cofferdam Construction.				
		(a) Forming Embankment				
		Using material from designated borrow areas or commercial sources				
		(i) Soil cement at 3% cement	m³	2 860.00	R 300.00	R 858 000
		(ii) Rockfill	m³	22 140.00	R 91.00	R 2 014 740
		SUB TOTAL: COFFERDAM				R 3 209 958
6		**TUNNEL CONSTRUCTION**				
	6.1	TUNNEL EXCAVATION				
		(a) Tunnel	m³	14 872.30	R 2 700.00	R 40 155 209
	6.2	ROCK SUPPORT				
		(a) Rockbolts	m	4 208.00	R 50.00	R 210 400
		(b) Shotcrete	m³	3 304.96	R 3 350.00	R 11 071 601
		(c) Reinforcing mesh	m²	3 304.96	R 35.00	R 115 673
	6.3	DEWATERING	Sum	1.00	R 100 000.00	R 100 000
		SUB TOTAL: TUNNEL				R 51 652 883
		SUB TOTAL: STAGE 1 + STAGE 2				R 55 447 659

		STAGE 3				
7		**MEDIUM PRESSURE PIPELINES**				
		Supply, lay, and bed pipes complete with couplings				
		(a) 500 mm diameter concrete pipe (class 75D) in concrete	m	0.00	R 0.00	R 0
		(b) Water control in tunnel	Prov Sum	0.00	R 0.00	R 0
8		**PLUG OF TUNNEL**				
	8.1	Scheduled Formwork items- Class 1				
		(a) Vertical formwork	m^2	0.00	R 591.29	R 0
	8.2	Scheduled Concrete items				
		Strength and Mass concrete				
		(a) Sealing of bulkheads shaft with mass concrete 25 Mpa/19 mm	m^3	0.00	R 0.00	R 0
		(b) Plug 25 MPa/19 mm	m^3	0.00		R 0
	8.3	Joints				
		(a) Swellable water stops	m	0.00	R 951.32	R 0
	8.4	Miscellaneous and Sundry items				
		(a) Bulkheads incl reinforcement at 120 kg/m^3	No	0.00	R 0.00	R 0
		Sub total: STAGE 3				R 0
TOTAL CARRIED FORWARD TO SUMMARY						**R 55 447 659**

4.6.3 Spillway and chute bill of quantities

AECOM SPILLWAY AND CHUTE

ITEM NO	PAYMENT	DESCRIPTION	UNIT	Quantity	Rate	AMOUNT (R)
		SABS 1200 DE				
	8.3.3	Excavation				
		a) Material unsuitable for embankment	m^3	325499	R 51	R 16 736 044
		b) Material suitable for embankment from essential excavations for:				
		2) Spillway	m^3	0	R 0	R 0
		3) Pipe trenches	m^3	0	R 0	R 0
		4) Outlet works	m^3	0	R 0	R 0
		SABS 1200 - GA				
		CONVENTIONAL CONCRETE FOR DAMS				
8	8.1.1	Scheduled Formwork items				
	8.1.1.1	Class F4				
		(a) Verical				
		(i) Chute	m²	15936	R 334	R 5 326 065
		(b) Sloped				
		(i) Ogee of spillway	m²	1178	R 411	R 484 522
		(ii) Round	m²	0	R 411	R 0
		(c) Sloping				
		(i) Stilling basin blocks	m²	0	R 0	R 0
		(ii) Horizontal	m²	0	R 0	R 0
	8.1.2	Scheduled Reinforcement items	t	2754	R 12 854	R 35 399 645
	8.1.2.1	Anchors				
		(a) Anchor bars	m	3158	R 0	R 0
	8.1.3	Scheduled Concrete items				
	8.1.3.1	Strength & Mass Concrete				
		(a) Grade 25 MPa/19 mm	m³	37885	R 1 414	R 53 567 207
		(i) Spillway, bridges and retaining wall	m³	0	R 1 414	R 0
	8.1.3.2	Secondary Concrete				
		(a) Grade 25 MPa/19 mm	m³	0	R 1 414	R 0
	8.1.3.3	Keyways on contraction joints				
		(a) Bridges dimensions to be given in detail design	m		R 0	R 0
	8.1.3.4	Unformed Surface Finishes				
		Class U2 (Wood-floated) finish				
		(a) Chute and Stilling basin floor	m^2	60500	R 14	R 855 440
		(b) Top of bridges	m^2	0	R 14	R 0
16		**WATERSTOPS, JOINTING AND BEARINGS**				
	16.1	Scheduled items				
		Waterstops				
						R 0
		(a) 250 mm Centre bulb PVC waterstop	m	2166	R 685	R 1 483 752
	16.2	Joint sealants				
		(a) Chute wall - 12mm expanding cork	m	0	R 0	R 0
		(b) Chute wall - 12m Impregnated Bitumen Fibre board	m	0	R 0	R 0
		(c) Chute wall - 12 x 12 mm Polysulphide sealant	m	0	R 0	R 0
17		**SUB-SOIL DRAINAGE**				
	17.1	Scheduled items				
		Excavating soft material situated within the following depth ranges below the surface level:				
		(a) 0 m to 1,5 m	m³	914	R 0	R 0
		(b) Extra over sub-item (a), irrespective of depth, for:				
		(i) Excavation in hard material	m³	0	R 0	R 0
	17.2	Natural permeable material in sub-soil drainage systems				
		(a) Sand as specified on detail drawings	m³	863	R 0	R 0
	17.3	Pipes in sub-soil drainage system				
		(a) 110 NB, Class 6, HDPE pressure pipe, non perforated, complying with SANS 533, Part II	m	0	R 0	R 0
		(b) 75 NB, flexible slotted drainage pipes with smooth bore, "Drainex" or equivalent by Kaytech	m	2538	R 0	R 0
	17.4	Caps to higher ends of sub-surface drain pipes				
		(a) High end of pipes of Drainex pipes	No	0	R 0	R 0
	17.5	Concrete outlet structures for sub-soil drainage systems complete as per drawings				
		(a) Concrete 1500 mm dia	No	0	R 0	R 0
	17.6	Overhaul for material hauled in excess of 1.0 km freehaul				
		(a) Sand for filter material (10 km)	m³.km	0	R 0	R 0
						R 0
TOTAL CARRIED FORWARD TO SUMMARY						**R 113 852 676**

4.6.4 Inlet and outlet works bill of quantities

AECOM INLET AND OUTLET WORKS

ITEM NO	PAYMENT		UNIT	Quantity	Rate (R)	AMOUNT (R)
1	1.1	Earthworks				
		(a) Clearing and grubbing	ha	0.08	R 23 250.00	R 1 907
		(b) Excavation - soft	m^3	1 070.00	R 180.00	R 192 600
		(c) Excavation - rock	m^3	1 070.00	R 300.00	R 321 000
		(d) Rockfill to abutments	m^3	0.00	R 50.39	R 0
2	2.1	Rock supports				
		(a) Rockbolts - 3m long	no	0.00	R 437.04	R 0
		(c) Rock anchors - 20m long, 25mm	no	0.00	R 218.52	R 0
		(d) Shotcrete and mesh - 75 mm long	m^2	0.00	R 299.50	R 0
					R 0.00	
3		ACCESS BRIDGE				
	3.1	Formwork				
		(a) Smooth vertical	m^2	1 016.00	R 488.46	R 496 273
		(b) Smooth horizontal	m^2	672.00	R 488.46	R 328 244
		(c) Smooth balustrade	m^2	0.00	R 730.12	R 0
	3.2	Unformed surface finish	m^2	672.00	R 14.14	R 9 502
	3.3	Reinforcing				R 0
		(a) Mild steel	t	0.00	R 12 854.15	R 0
		(b) High yield steel	t	88.20	R 13 419.74	R 1 183 621
		(c) Mesh	t	0.00	R 59.13	R 0
	3.4	Concrete				
		(a) Mass	m^3	0.00	R 1 156.87	R 0
		(b) Structural	m^3	880.00	R 1 413.96	R 1 244 282
	3.5	Miscellaneous				
		(a) Bridge bearings	No	4.00	R 16 196.23	R 64 785
		(b) Joints	m	4.00	R 170.96	R 684
		(c) Other e.g.. Rainwater goods, ducting, etc	Sum	0.00	R 102 833.23	R 0
4		INTAKE TOWER AND OUTLET WORKS				
	4.1	Drilling and grouting				
		(a) Consolidation grouting	m drill	0.00	R 287.93	R 0
	4.2	Formwork				
		(a) Smooth vertical - curved and plain	m^2	10 078.00	R 591.29	R 5 959 031
		(b) Smooth horizontal	m^2	624.00	R 591.29	R 368 966
		(c) Intricate	m^2	0.00	R 1 619.62	R 0
		(d) Form openings	m^2	0.00	R 796.96	R 0
	4.3	Uniform surface finish	m^2	774.00	R 14.65	R 11 342
	4.4	Reinforcing				
		(a) Mild steel	t	0.00	R 14 139.57	R 0
		(b) High yield steel	t	659.00	R 13 419.74	R 8 843 606
		(c) Mesh	t	0.00	R 64.27	R 0
		(d) Mechanical rebar couples	No	0.00	R 442.18	R 0
	4.5	Concrete				
		(a) Mass	m^3	0.00	R 1 156.87	R 0
		(b) Structural	m^3	6 788.00	R 1 700.00	R 11 539 600
	4.6	Structural Steelwork				
		(a) Steel sections	Sum	1.00	R 2 000 000.00	R 2 000 000
		(b) Sheeting	m^2	0.00	R 0.00	R 0
					R 0.00	
	4.7	Miscellaneous			R 0.00	
		(a) Waterstops	m	0.00	R 951.32	R 0
		(b) Other e.g.. Conduits, outlets, water proofing, etc.	Sum	0.00	R 0.00	R 0
5	5.1	Site works				
		(a) Site access roads	km	1.00	R 0.00	R 0
		(b) Site services	Sum	0.00	R 0.00	R 0
6	6.1	Contractors accommodation				R 0
7	7.1	Mechanical Items				
		(a) Gates and screens	Sum	1.00	R 20 000 000.00	R 20 000 000
		(b) Lifting equipment	Sum	1.00	R 10 000 000.00	R 10 000 000
		(c) Pipework and valves	Sum	1.00	R 15 000 000.00	R 15 000 000
8	8.1	Electrical Installation	Sum	0.00	R 0.00	R 0
TOTAL CARRIED FORWARD TO SUMMARY						R 77 565 441

4.6.5 Transfer tunnel bill of quantities

AECOM

TRANSFER TUNNEL

ITEM NO	PAY	DESCRIPTION	UNIT	Quantity	Rate	Total
1	1.0	Adits				
	1.1	Adit portal excavation	m^3	80 000	R 92.55	R 7 403 992
	1.2	Adit excavation	m^3	61 200	R 1 516.79	R 92 827 552
	1.3	Adit tunnel lining	m^3	16 830	R 2 545.12	R 42 834 409
2	2.0	Tunnel Excavation				
	2.1	(a) Rock Class I	m^3	0.0	R 1 182.58	R 0
	2.2	(b) Rock Class II	m^3	152 054.0	R 1 182.58	R 179 816 337
	2.3	(c) Rock Class III	m^3	191 638.0	R 1 285.42	R 246 334 420
	2.4	(d) Rock Class IV	m^3	0.0	R 1 439.67	R 0
	2.5	(e) Rock Class V	m^3	0.0	R 1 542.50	R 0
	2.6	(f) Rock Class VI	m^3	84 824.0	R 2 313.75	R 196 261 323
	2.7	(g) Rock Class VII	m^3	0.0	R 822.67	R 0
3	3.0	Portal excavations				
	3.1	Inlet portal	m^3	450 000	R 92.55	R 41 647 456
	3.2	Outlet portal	m^3	640 000	R 92.55	R 59 231 938
	3.2	Adit portal	m^3	80 000	R 92.55	R 7 403 992
4	4.0	Rock Support				
	4.1	(a) Rockbolts	m	306 100	R 257.08	R 78 693 126
	4.2	(b) Shotcrete	m^3	7 582	R 5 398.74	R 40 933 279
	4.3	(c) Reinforcing mesh	m^2	220 949	R 77.12	R 17 040 674
	4.4	(d) Steel arches and lagging	No	6 750	R 0.00	R 0
5	5.0	Concrete				
	5.1	(a) Linings	m^3	100 434	R 2 545.12	R 255 616 815
	5.2	(b) Overbreak concrete: TBM	m^2	2 009	R 514.17	R 1 032 795
	5.3	(c) Overbreak concrete: DBT	m^2	0	R 2 056.66	R 0
	5.4	(d) Concrete in structures	m^3		R 1 285.42	R 0
6	6.0	Formwork				
	6.1	(a) Smooth curved in tunnel	m^2		R 668.42	R 0
	6.2	(b) Structures - intricate	m^2		R 524.45	R 0
7	7.0	Reinforcement	ton	4 521	R 12 854.15	R 58 113 626
8	8.0	Pre-cast concrete inverts	m		R 1 285.42	R 0
9	9.0	Grouting	m^2	428 516	R 442.18	R 189 482 434
10	10.0	Waterproof lining	m^2	428 516	R 771.25	R 330 492 617
TOTAL CARRIED FORWARD TO SUMMARY						R 1 845 166 786

4.6.6 Ventilation shaft bill of quantities

AECOM — VENTILATION SHAFT

ITEM NO	PAY	DESCRIPTION	UNIT	Quantity	Rate	Total
		SABS 1200 D				
	8.3.1	**Site preparation**				
	8.3.1.1	Clear and strip site	m^2	31.0	R 165.49	R 5 130
	8.3.1.2	Remove of topsoil to nominal depth of 150 mm, stockpile and maintain	m^3	14.0	R 102.83	R 1 435
	8.3.2	**Bulk excavation**				
		a) Excavate in all materials and use for embankment or backfill or dispose, as ordered	m^3	7 523	R 8 226.66	R 61 888 753
		b) Extra over for				
		1) Intermediate excavation	m^3	752.3	R 9 254.99	R 6 962 485
		2) Hard rock excavation	m^3	1 505	R 10 283.32	R 15 472 188
		3) Boulder excavation, Class A	m^3	1 505	R 10 283.32	R 15 472 188
		4) Boulder excavation, Class B	m^3	1 505	R 10 283.32	R 15 472 188
	8.3.6	**Overhaul**				
		a) Limited overhaul (Provisional)	m^3		R 15.42	R 0
		b) Long overhaul (Provisional)	m^3.km		R 0.00	R 0
		SABS 1200 G				
	8.2	**Scheduled formwork items**				
		(a) Smooth curved in shaft	m^2		R 0.00	R 0
		(b) Structures - intricate	m^2		R 0.00	R 0
	8.3	**Scheduled reinforcement items**				
	8.3.1	Steel bars	t		R 0.00	R 0
	8.3.2	High tensile welded mesh	m^2		R 0.00	R 0
	8.3.3	Steel encasing	t	573	R 51 416.61	R 29 464 290
	8.4	**Scheduled concrete items**				
		(a) Linings	m^3	2 300	R 15 424.98	R 35 477 463
		(b) Overbreak concrete: TBM	m^3	115	R 0.00	R 0
		(c) Overbreak concrete: DBT	m^3		R 0.00	R 0
		(d) Concrete in structures	m^3		R 0.00	R 0
	8.4.4	**Uniformed surface finishes**				
		a) Wood-floated finish	m^2		R 0.00	R 0
		b) Steel floated finish	m^2		R 0.00	R 0
		c) Power floated finish	m^2		R 0.00	R 0
		d) Other special finish	m^2		R 0.00	R 0
	8.5	Joints	m		R 0.00	R 0
	8.7	Grouting	m^2	7 165	R 7 712.49	R 55 257 816
	9.0	Waterproof lining	m^2		R 77 124.92	R 0
TOTAL CARRIED FORWARD TO SUMMARY						R 235 473 936

4.6.7 Pipeline bill of quantities

AECOM PIPELINE

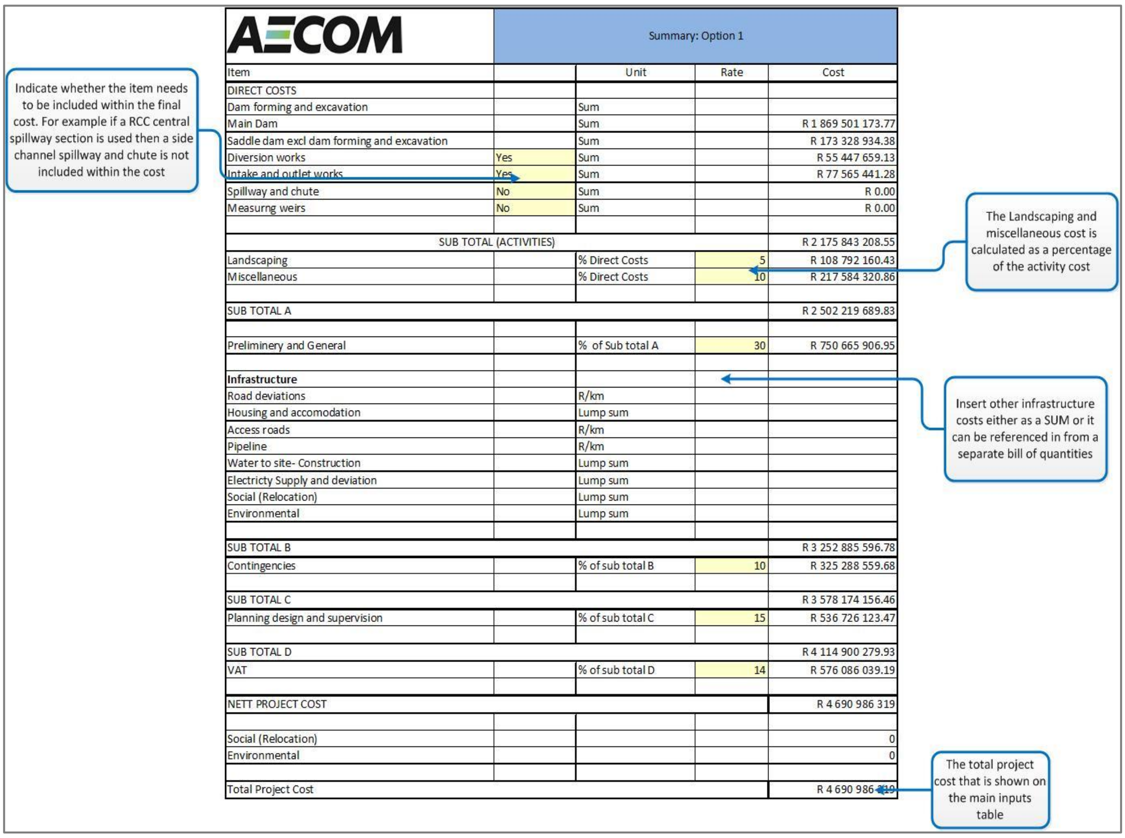
ITEM NO	PAYMENT		UNIT	Quantity	Rate (R)	AMOUNT (R)
1	1.0	Route clearing and grubbing				
	1.1	(a) Sparse	ha	2.895	R 7 198.33	R 20 842
	1.2	(b) Bush	ha	2.895	R 21 594.98	R 62 525
	1.3	(c) Trees	ha	2.895	R 35 991.63	R 104 208
2	9.3.1	River and road crossings	Sum	1	R 0.00	R 0
3	3.0	Benching (forming and terrace)				
	3.1	(a) All materials	m^3		R 46.27	R 0
	3.2	(b) extra over for rock	m^3		R 107.97	R 0
4	3.9	Trench excavation and backfilling				
	3.9.1	(a) All materials	m^3	39 997.6	R 102.83	R 4 113 082
	3.9.2	(b) Extra over for rock	m^3	9 999	R 154.25	R 1 542 406
	9.3.2	(c) Bed preparation	m	24 460	R 51.42	R 1 257 650
5		Pipelines				
	9.3.3	(a) Supply of pipes to site				
		(i) Diamater 1	m	3 460	R 22 000.00	R 76 120 000
		(ii) Diameter 2	m	21 000	R 24 000.00	R 504 000 000
		(iii) Diameter 3	m	0	R 0.00	R 0
		(iv) Diameter 4	m	0	R 0.00	R 0
		(v) Diameter 5	m	0	R 0.00	R 0
	9.3.4	(b) Laying and jointing (% of (a))	%		R 0.20	R 116 024 000
	9.3.5	(c) Cathodic protection	km	1	R 0.00	R 0
6	7.0	Concrete including formwork				
	7.7	(a) Valve chambers and manholes	m^3	12 000	R 3 085.00	R 37 019 961
	7.8	(b) Thrust blocks and encasings	m^3	12 000	R 2 056.66	R 24 679 974
7	8.0	Reinforcing	t	2 400	R 12 854.15	R 30 849 968
8		Mechanical items				
	10.1	(a) Valves	sum	1	R 0.00	R 0
	10.2	(b) Structural steelwork	t	0	R 25 708.31	R 0
9	11.0	Landscaping (% of 1-8)	%		5%	R 39 789 730.79
10	12.0	Miscellaneous (% of 1-8)	%		10%	R 83 558 434.66
		SUB TOTAL A				R 919 142 781
12	12.0	Preliminary and General (% of sub-total A)	%		30%	R 275 742 834.37
13	13.0	**Preliminary works**				
	13.1	(a) Access road	km	24	R 0.00	R 0
	13.2	(b) Electricity to site	SUM	1	R 0.00	R 0
	13.3	(c) Water to site - contractor (not) potable	SUM	1	R 0.00	R 0
	13.4	(d) Railhead and materials handling	SUM	1	R 0.00	R 0
14	14.0	Accomodation	SUM	1	R 0.00	R 0
		SUB-TOTAL B				R 1 194 885 616
15	15.0	Contingencies (% of sub-total B)	%		30%	R 358 465 685
		SUB TOTAL C				R 1 553 351 300
16	16.0	Planning design and supervision (% of sub-total C)	%		10%	R 155 335 130
		SUB TOTAL D				R 1 708 686 430
17	17.0	VAT (% of sub total C)	%		0%	R 0
		NETT PROJECT COST				R 1 708 686 430
17	17.1	Cost of relocations	SUM		0.000	R 0
	17.2	Cost of land acquisition	SUM		0.000	R 0
		TOTAL PROJECT COST				R 1 708 686 430.34

4.7 SUMMARY SHEET

The cost breakdown sheet enables the addition of social, environmental and administrative costs including the preliminary and general costs related to the dam construction site. All cells highlighted in yellow require an input value.

4.7.1 Dam summary sheet

Figure 4.30 shows the summary sheet for all the components related to the dam.



AECOM	Summary: Option 1			
Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		
Main Dam		Sum		R 1 869 501 173.77
Saddle dam excl dam forming and excavation		Sum		R 173 328 934.38
Diversion works	Yes	Sum		R 55 447 659.13
Intake and outlet works	Yes	Sum		R 77 565 441.28
Spillway and chute	No	Sum		R 0.00
Measurng weirs	No	Sum		R 0.00
SUB TOTAL (ACTIVITIES)				R 2 175 843 208.55
Landscaping		% Direct Costs	5	R 108 792 160.43
Miscellaneous		% Direct Costs	10	R 217 584 320.86
SUB TOTAL A				R 2 502 219 689.83
Preliminery and General		% of Sub total A	30	R 750 665 906.95
Infrastructure				
Road deviations		R/km		
Housing and accomodation		Lump sum		
Access roads		R/km		
Pipeline		R/km		
Water to site- Construction		Lump sum		
Electricty Supply and deviation		Lump sum		
Social (Relocation)		Lump sum		
Environmental		Lump sum		
SUB TOTAL B				R 3 252 885 596.78
Contingencies		% of sub total B	10	R 325 288 559.68
SUB TOTAL C				R 3 578 174 156.46
Planning design and supervision		% of sub total C	15	R 536 726 123.47
SUB TOTAL D				R 4 114 900 279.93
VAT		% of sub total D	14	R 576 086 039.19
NETT PROJECT COST				R 4 690 986 319
Social (Relocation)				0
Environmental				0
Total Project Cost				R 4 690 986 319

Figure 4.30: Dam cost summary sheet

4.7.2 Transfer tunnel summary sheet

Figure 4.31 shows the summary sheet for the transfer tunnel.

AECOM	TRANSFER TUNNEL SUMMARY		
Item	Unit	Rate	Cost
DIRECT COSTS			
Tunnel			R 1 845 166 785.74
Intake tower			R 235 473 936.04
Ventilation shaft			R 70 860 202.05
SUB TOTAL (ACTIVITIES)			R 2 151 500 923.83
Landscaping	% Direct Costs	5	R 107 575 046.19
Miscellaneous	% Direct Costs	5	R 107 575 046.19
SUB TOTAL A			R 2 366 651 016.21
Preliminery and General	% of Sub total A	30	R 709 995 304.86
Infrastructure			
Road deviations	R/km		
Housing and accomodation	Lump sum		
Access roads	R/km		
Pipeline	R/km		
Water to site- Construction	Lump sum		
Electricty Supply and deviation	Lump sum		
Social (Relocation)	Lump sum		
Environmental	Lump sum		
SUB TOTAL B			R 3 076 646 321.08
Contingencies	% of sub total B	15	R 461 496 948.16
SUB TOTAL C			R 3 538 143 269.24
Planning design and supervision	% of sub total C	12	R 424 577 192.31
SUB TOTAL D			R 3 962 720 461.55
VAT	% of sub total D	0	R 0.00
NETT PROJECT COST			R 3 962 720 462
Social (Relocation)			
Environmental			
Total Project Cost			R 3 962 720 462

Figure 4.31: Transfer tunnel summary sheet

4.7.3 Preliminary and general

The preliminary and general costs are added as a percentage of the direct costs. It includes the following items:

- Road deviations;
- Housing and accommodation;
- Access roads;
- Additional pipelines;
- Water to site – Construction;
- Electricity supply and deviation;
- Social (Relocation); and
- Environmental.

If the costs of these items are unknown, the percentage for P&Gs may be increased else if the costs of these items are known, they can be inserted in this column.

The unit for preliminary and general is percentage (%).

4.7.4 Preliminary works

If these items are not included in the preliminary and general costs, then these items need to be separately cost and inserted in the required cell. These items can vary depending on the configuration of the infrastructure related to the dam project and therefore could have an effect on the final cost of the project.

4.7.5 Road deviations and access roads

These items include all roads that need to be constructed or upgraded in order to provide access to the site. Roads that will be inundated by water during impoundment will need to be diverted. The access roads are usually gravel surfaced all-weather roads which are 5 to 6 m wide. The cost should include all earthworks, layer works, drainage and fences that need to be constructed.

The unit for access roads is kilometres (km).

4.7.6 Electricity supply to site

For each dam project the electricity supply to site differs and therefore a generic formula cannot be used. The unit for electricity supply to site is a lump sum.

4.7.7 Construction water to site

The quantity of water required differs for each project regarding the requirements for the dam site, canals or tunnels. Water may be extracted from the river, however the additional cost of pipelines and pumps need to be considered.

4.7.8 Accommodation

Provision needs to be made for the accommodation of on-site personnel, which includes all supervisory and contracted staff. Dam sites are usually located in remote areas with limited access to established settlements and therefore the extent to which permanent and temporary accommodation would need to be constructed will depend on the surrounding environment and resources.

The unit for accommodation is a lump sum.

4.7.9 Contingencies

The allowance for all project costs due to unforeseen circumstances, claims and extra work is allowed for as a percentage of the total cost of direct and indirect work excluding the professional and consulting fees.

4.7.10 Planning design and supervision

The cost of consulting engineer's fees is allowed as a percentage of the total of the direct and indirect work.

The unit for planning, design and supervision is percentage (%).

4.7.11 Value added tax (VAT)

Value added tax is added as a percentage of the total cost of direct and indirect work and consulting fees. In most instances, VAT is excluded because it does not significantly represent the cost of the project, particularly if it is a public project.

The unit for VAT is percentage (%).

4.7.12 Cost of relocations

Additional social costs related to the relocation of residents within the dam basin can be inserted within this cell.

The unit for relocation of services and accommodation shall be a lump sum.

4.7.13 Cost of land acquisition

Land owners within the dam basin will need to be compensated for their land that is going to be inundated with water. Such compensation will need to be assessed at both the reconnaissance and prefeasibility stage in order for financial allowances to be made.

5 TECHNICAL INFORMATION

This section of the report provides a more in-depth explanation on how the quantities are determined within the calculation spreadsheets. The technical information should be used with the Cost Model Excel Spreadsheet.

5.1 ROLLER COMPACTED CONCRETE DAM

A roller compacted concrete gravity dam is entirely dependent upon its own mass for stability. The gravity profile is essentially triangular, with an outline geometry indicated on **Figure 5.1**, to ensure stability and to avoid overstressing of the dam or its foundation. Roller compacted concrete is defined by the American Concrete Institute (RCC) as "concrete compacted by roller compaction; concrete that, in its unhardened state, will support a roller while being compacted." RCC use within dam construction is ideal as it involves large placement areas, with little or no reinforcement and a lower cost on the concrete.

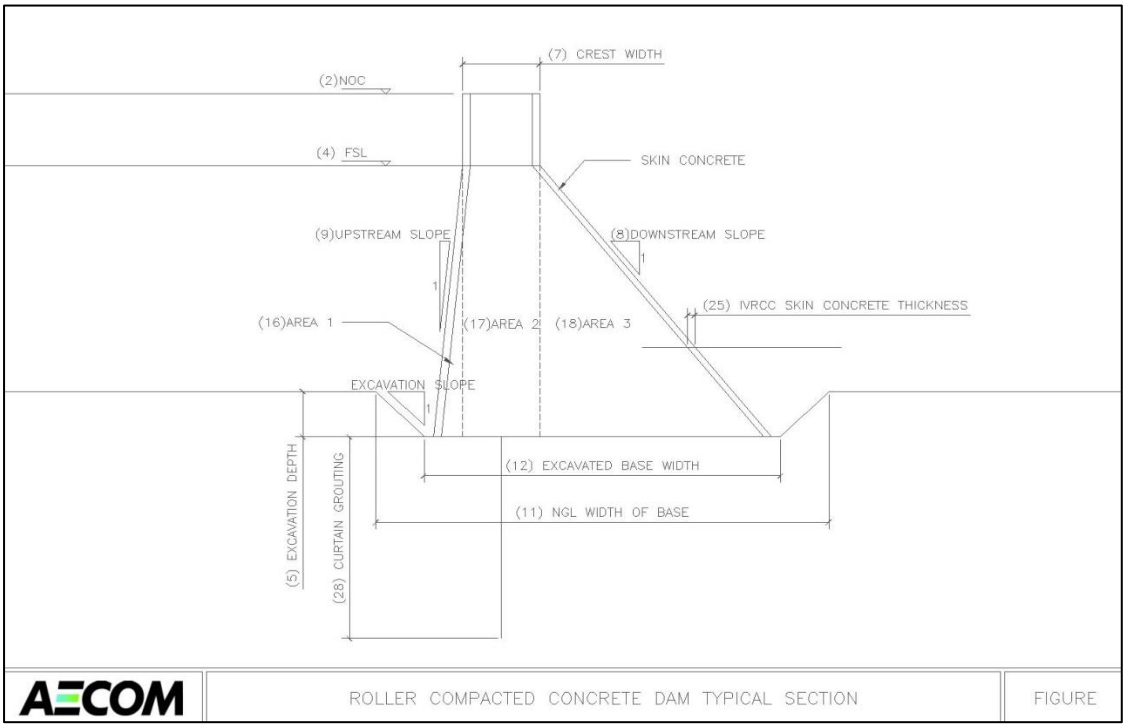
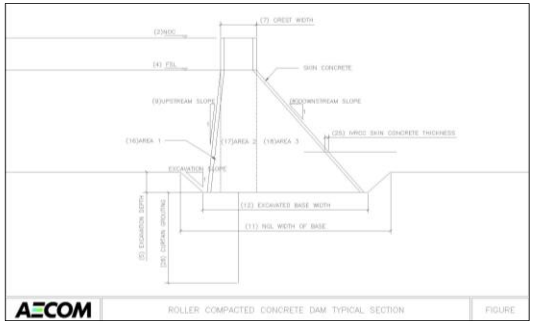


Figure 5.1: Roller compacted concrete gravity dam

Figure 5.2 shows a section of the calculation spreadsheet for the determination of the quantities of a roller compacted concrete dam.

ROLLER COMPACTED CONCRETE DAM



Ogee length	160	m	80	3600	3520	3680

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
												Excavatiuon					Volume concrete					Foundation
		Section	NGL	NOC	FSL	Excavation	Section interval	Crest width	Downstream slope	Upstream slope	Excavation Slope	NGL Width of base	Excavated Base width	Footprint area at NGL (Horizontal)	Topsoil Excavation Area (Vertical)	Excavated volume	Area 1	Area 2	Area 3	Total	Volume	Preparation
		1	masl	masl		(m)	(m)	(m)	(M:1)	(M:1)	(M:1)	m	m	m^2	m^2	m^3	m^2	m^2	m^2	m^2	m3	m^2
1	0.000	0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0		
2	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0

Figure 5.2: Calculation spreadsheet section for roller compacted concrete dam

A description of each column in the calculation spreadsheet (**Figure 5.2**) is provided in **Table 5.1** with the paragraph number relating to the column number:

Table 5.1: Roller compacted concrete gravity dam calculation sheet components

Roller compacted concrete gravity dam		
1	Sections	The dam is divided into a number of sections at a specified section interval. The smaller the section interval, the finer the solution and conversely the larger the section interval, the coarser the solution. A maximum of 200 sections may be entered.
2	NGL	Natural ground level.
3	NOC	The non-overspill crest. The NOC is calculated by adding the entered freeboard height to the FSL (Full supply level).
4	FSL	Full supply level.
5	Excavation depth	A concrete dam is normally founded on good quality rock. The depth of excavation is from the NGL to the founding level that consists of competent rock. Depending on the available information at the time of input, the depth of excavation is either specified according to VAPs or if a geotechnical survey was undertaken, this information can be entered in the long section input table. VAPs assume a constant excavation depth along the entire length of the long section.
6	Section interval	The distance between sections.
7	Crest width	Input as a variable in the variable input table.
8	Downstream slope	The horizontal component of the slope is an input (see **Figure 5.3**).

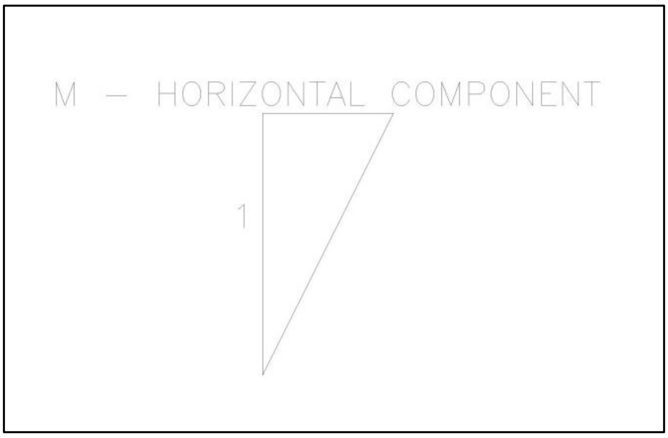


Figure 5.3: Horizontal slope input parameter

9	Upstream slope	The horizontal component of the slope is an input.

10	Excavation slope.	The batter slope of the foundation excavation.
11	NGL width at base:	Surface width parallel to a section, including the horizontal component of the upstream and downstream batter slopes.
12	Excavated base width:	The horizontal length of the base parallel to a section at the excavation depth and excludes the horizontal component of the upstream and downstream batter slopes.
13	Footprint area at NGL:	The area at NGL level calculated between two sections using the trapezoidal rule (see **Figure 5.4**); $\boldsymbol{Area} = \sum_{N=1}^{n} [\frac{[\boldsymbol{section(N)} + \boldsymbol{section(N+1)}]}{\mathbf{2}}][\boldsymbol{Section\ interval(N)}]$

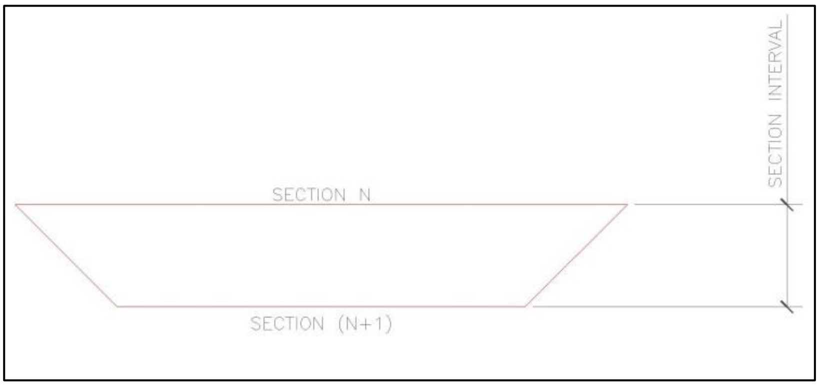


Figure 5.4: Section interval

14	Topsoil Excavation Area (Vertical)	The area calculated per section using column [5], [11] and [12]. Calculated using the trapezoidal rule; $\boldsymbol{Area} = [[\mathbf{11}] + [\mathbf{12}]][\frac{[\mathbf{5}]}{\mathbf{2}}]$
15	Excavated volume	The volume of material that needs to be excavated in order to reach the founding depth.
16	Area 1	The upstream triangular section of the section view.
17	Area 2	The central rectangular section comprising of the crest width and height between the NOC and the excavation line.
18	Area 3	The downstream triangular section of the sectional view.
19	Total	The total cross sectional area at each section; $\boldsymbol{Total} = \boldsymbol{Area}\ \mathbf{1} + \boldsymbol{Area}\ \mathbf{2} + \boldsymbol{Area}\ \mathbf{3}$
20	Volume	The volume of concrete calculated using the trapezoidal rule (see **Figure 5.5**).

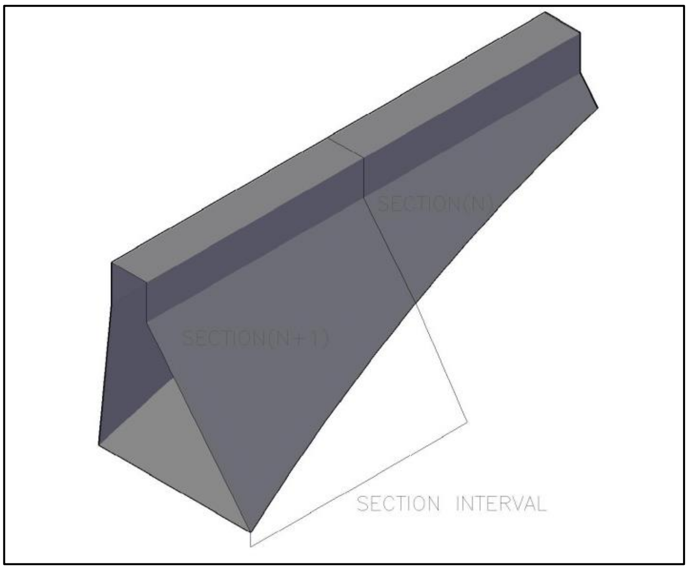


Figure 5.5: 3D model of a RCC dam section

21	Foundation preparation	Total surface area at the excavation line level excluding the batter slopes. The area is calculated using the trapezoidal rule between adjacent sections.
22	Formwork section outline	The total outline of each section that includes the upstream and downstream slopes and twice the freeboard (see **Figure 5.6**).

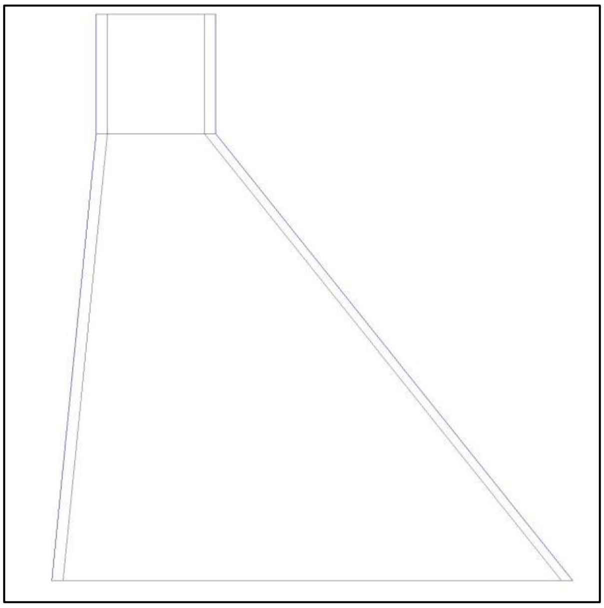


Figure 5.6: Formwork section outline and skin concrete outline

23	Formwork area	The total surface area of the dam calculated using the trapezoidal rule;
24	Immersion Vibrated Roller Compacted Concrete (IVRCC)	The IVRCC is priced according to the total surface area of the dam and therefore the same area used for the formwork is used her;

25	IVRCC skin concrete thickness	The thickness of the skin concrete specified in the variable input table.
26	IVRCC area	The area representing the skin concrete for each section in the plane of the section.
27	IVRCC volume of skin concrete:	The total volume of skin concrete is calculated between subsequent sections using the trapezoidal rule; $$\boldsymbol{Area} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}} [\boldsymbol{IVRCC\ area(N)} + \boldsymbol{IVRCC\ area\ (N-1)}][\frac{\boldsymbol{Section\ interval(N)}}{\boldsymbol{2}}] \quad \textbf{(3.1.4)}$$
28	Curtain grouting section length:	The depth of curtain grouting is specified as a percentage of the height of the dam wall (NOC – NGL + excavation depth).
29	Total grout length	Curtain grouting spacing can be less than the section interval. The total length of grout holes is calculated by averaging the height between two alongside sections and multiplying it by the number grout holes that need to be bored.
30	Consolidation grouting (blanket grouting)	The length of consolidation grouting at each section is constant and the user needs to input a value in the variable inputs table.
31	Grout length	The grout spacing length can be less than the section interval length and is multiplied by the average length between two alongside sections and is then multiplied by the number of holes that need to be bored.
32	Waterstop	The length of the waterstop is calculated by averaging the height of two alongside sections and multiplying by the waterstop interval distance/ section interval.

5.2 EARTHFILL EMBANKMENT DAM

The embankment dam can be defined as a dam constructed from natural materials excavated or obtained from a local quarry. The materials available are utilised to the best advantage in relation to their characteristics as an engineered bulk fill in defined zones within the dam section.

An embankment may be categorized as an earthfill dam if compacted soils account for over 50% of the placed volume of material. An earthfill dam is constructed primarily of selected engineering soils compacted uniformly and intensively in relatively thin layers and at a controlled moisture content.

Figure 5.7 shows a typical section of an earthfill embankment dam. **Figure 5.8** shows a section of the calculation spreadsheet for the determination of the quantities of the Earthfill Embankment Dam.

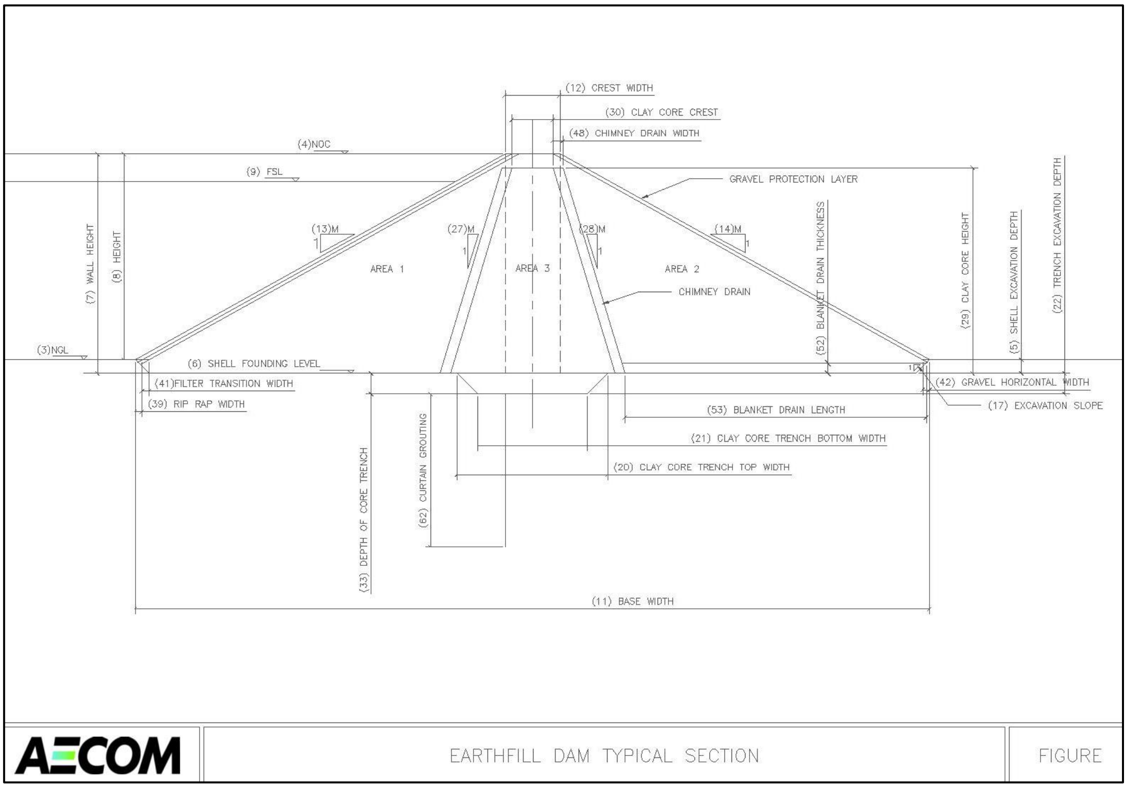
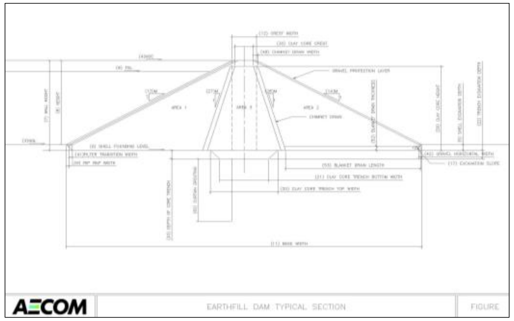


Figure 5.7: Earthfill embankment dam

EARTHFILL EMBANKMENT DAM



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
												slopes		Footprint		Excavation									
Stations	Sections	NGL	NOC	Excavation depth	Shell founding level	Wall height (NOC-Excavation line)	Height (NOC-NGL)	FSL	Water Height (FSL-excavation line)	Section interval	Crest width	Upstream slope	Downstream slope	NGL Width of Base	Footprint area	Excavation slope	Shell excavation depth	Footprint Excavation (Vertical)	Clay core trench Top width (H/2)	Clay core trench Bottom width	Trench Excavation Depth	Trench excavation area (Vertical)	Footprint volume	Trench volume	Total excavation
		m	m	m	m	m	m			m	m	H:1	H:1	m	m^2	H:1	m	m^2	m	m	m	m^2	m^3	m^3	m^3
1	0	0	0.0					0	0.0					0	0										
2	0	0	0.0					0	0.0					0	0										
3	0	0	0.0					0	0.0					0	0										
4	0	0	0.0					0	0.0					0	0										
5	0	0	0.0					0	0.0					0	0										
6	0	0	0.0					0	0.0					0	0										
7	0	0	0.0					0	0.0					0	0										

Figure 5.8: Calculation spreadsheet section for an Earthfill Embankment Dam

A description of each column in the calculation spreadsheet (**Figure 5.8**) is provided in **Table 5.2** with the paragraph number relating to the column number:

Table 5.2: Earthfill embankment dam calculation sheet components

Earthfill embankment dam		
1	Stations	The number of sections that may be input into the long section; each row in the cost model dam volume calculation spreadsheet is referred to as a station.
2	Sections	The dam is divided into a number of sections at a specified section interval. The smaller the section interval the finer the solution conversely the larger the section interval, the coarser the solution. A maximum of 200 sections may be entered.
3	NGL	Natural ground level.
4	NOC	Non-overspill crest. The NOC is calculated by adding the FSL to the freeboard height.
5	Excavation depth	The depth from the NGL to the founding level. Depending on the amount of information available, either a constant depth can be inserted in the variables input table or if a geotechnical survey was conducted, this information may be inserted in the long section inputs table.
6	Shell founding level	The founding height (NGL – excavation depth).
7	Wall height (NOC – excavation line)	The difference in height between the NOC and the excavation line.
8	Height	The difference in height between the NOC and the NGL.
9	FSL (full supply level)	The FSL is specified by the user in the variable input table.
10	Water height FSL – excavation line	The difference in height between the FSL and the excavation line.
11	Section interval	The distance normal to two alongside sections.
12	Crest width	Input as a variable in the variable input table.
13	Upstream slope	The horizontal component of the slope is an input.
14	Downstream slope	The horizontal component of the slope is an input.
15	NGL width of base	Surface width parallel to a section, including the horizontal component of the upstream and downstream batter slopes.
16	Footprint area	The area at the NGL level calculated between two alongside sections using the trapezoidal rule; $$\boldsymbol{Area} = \sum_{N=1}^{n}[\boldsymbol{Excavation\ base\ width}\ (\boldsymbol{N}) + \boldsymbol{Excavation\ base\ width}\ (\boldsymbol{N}-\mathbf{1})][\frac{\boldsymbol{Section\ interval}}{\mathbf{2}}] \quad (3.2.1)$$

17	Excavation slope	The batter slope of the foundation excavation.
18	Shell excavation depth	The depth from the NGL to the founding level, a constant value for each section may be entered, else if a geotechnical survey was conducted, this information could be input in the long section input table.
19	Footprint excavation (vertical)	The vertical area for each section is calculated using the trapezoidal rule.
20	Clay core trench top width ($^{H}/_{2}$)	The width of the clay core for each section is dependent on the height of the dam. If the height of the dam divided by two is less than one plus the horizontal component of the batter slopes of the clay core trench, the width of the trench is one plus the horizontal component of the batter slopes of the clay core trench, else the width is equal to the height of the dam divided by two.
21	Clay core trench bottom width	The width is equal to the clay core trench top width subtracted the horizontal components of the batter slopes.
22	Trench excavation depth	Depending on the available information, a constant depth can be input or a separate depth can be input for each section. Depends on the available information and whether a geotechnical investigation has being conducted prior to the setup of the cost model.
23	Trench excavation area (vertical)	The vertical area for each section is calculated using the trapezoidal rule; $\textbf{Area} = [[\textbf{21}] + [\textbf{20}]][\frac{[\textbf{22}]}{\textbf{2}}]$ **(3.2.2)**
24	Footprint volume	The volume is calculated using the trapezoidal rule using two alongside footprint excavation areas and the section interval;
25	Trench volume	The volume is calculated using the trapezoidal rule using two alongside trench excavation areas and the section interval; (see **Figure 5.9**).

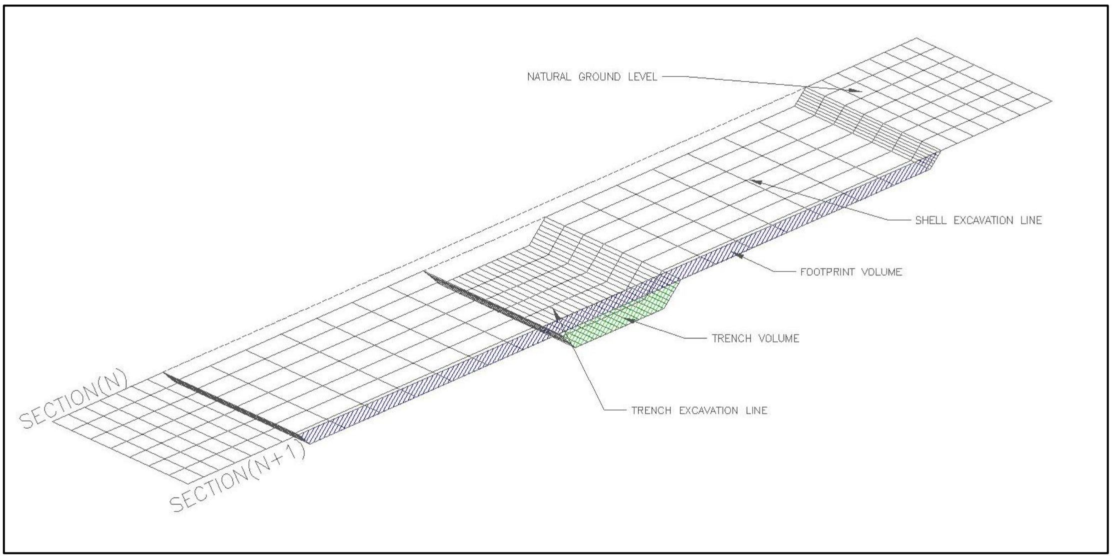


Figure 5.9: 3D drawing showing the dam foundation excavation

26	Total excavation	The sum of the footprint excavation volume and the trench volume.

27	Upstream slope	The upstream slope of the internal clay core. The horizontal component is input in the variable input table.
28	Downstream slope	The downstream slope of the internal clay core. The horizontal component is input in the variable inputs table.
29	Clay core height	The height of the clay core that is equal to the wall height [8] subtracted one metre.
30	Clay core crest	The crest width of the clay core that is input as a variable in the variable inputs table.
31	Shell founding level base width	The width of the clay core at the founding level of the shell; not necessarily equal to the clay core trench top width.
32	Core Area (vertical)	The clay core area for each section excluding the trench.
33	Core volume	The volume of clay material calculated using the trapezoidal rule and two sequential sections (see **Figure 5.10**).

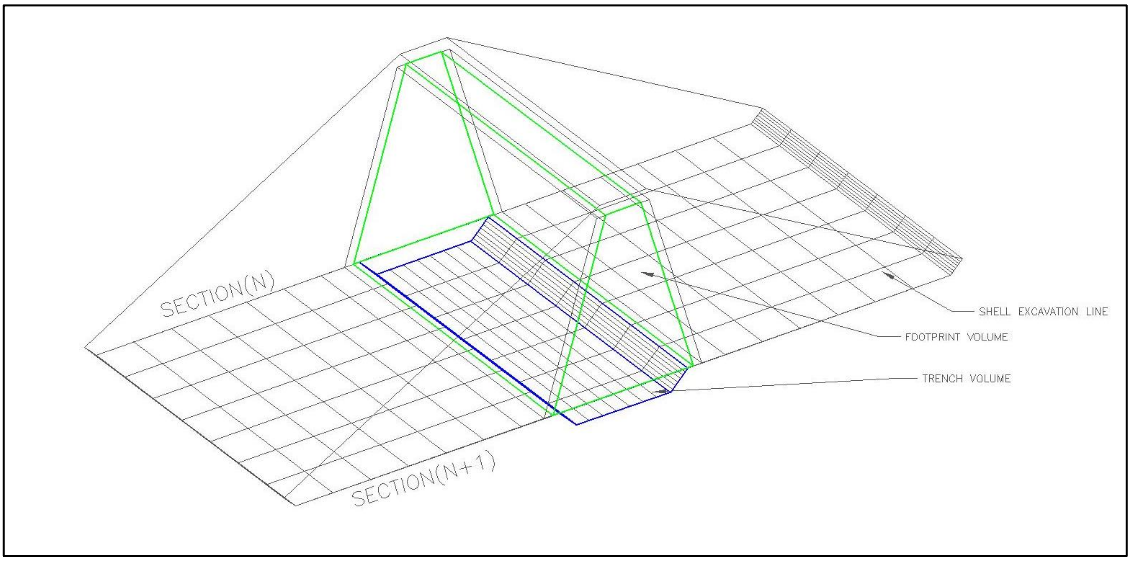


Figure 5.10: 3D drawing showing the volume of the core for a section of the dam

34	Trench volume	The volume of clay material calculated using the trapezoidal rule and alongside sections.
35	Area 1: Upstream slope	The triangular section represented by the upstream slope of the embankment.
36	Area 2: Downstream slope	The triangular section represented by the downstream slope of the embankment.
37	Area 3: Crest	The rectangular section represented by the crest section of the embankment; (see **Figure 5.11**).

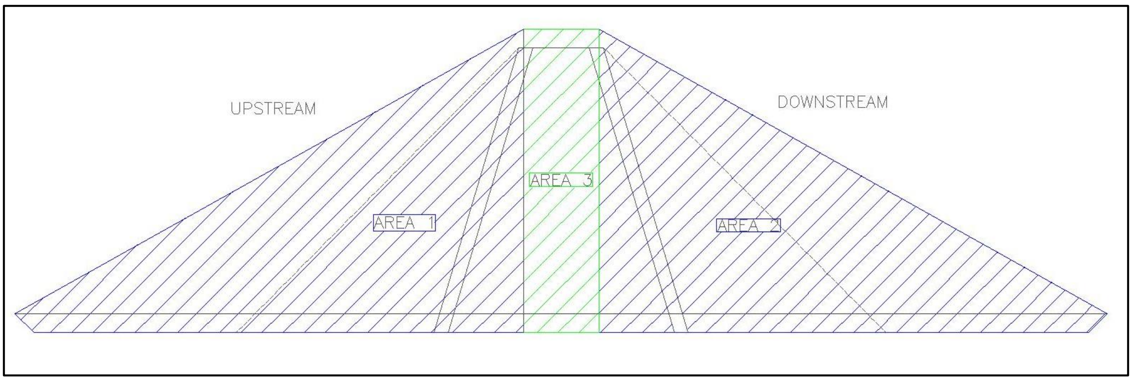


Figure 5.11: Shows the three areas used to calculate the total cross sectional area

38	Total cross sectional area	Summation of Area 1: Upstream slope, Area 2: Downstream slope and Area 3: Crest to get the total area for each cross section.
39	Rip-rap width	The horizontal width of the upstream rip-rap layer.
40	Rip-rap cross sectional area	The vertical cross sectional area of rip-rap for each section of the dam.
41	Rip-rap volume	The volume of rip-rap calculated using the trapezoidal rule using two sequential sections (see **Figure 5.12**).

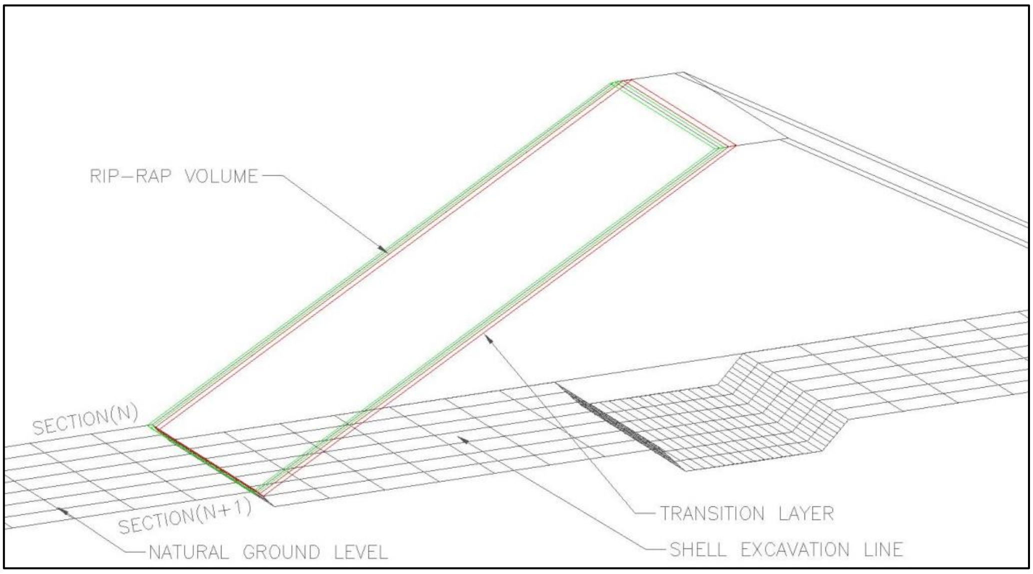


Figure 5.12: 3D illustration of a section of the upstream rip-rap layer

42	Gravel horizontal width	The horizontal width specified for each section for the gravel protection layer on the downstream slope of the dam.
43	Gravel cross sectional area	The vertical cross sectional area in the plane of the section calculated for each section of the dam.
44	Gravel protection volume	The volume of gravel calculated using two alongside sections using the trapezoidal rule.

<table>
<tr><td rowspan="2">45</td><td rowspan="2">Filters transition width</td><td>The horizontal width specified for each section for the filters on the upstream slope of the dam. If the upstream filter consists of a number of layers, the total width is input and the subsequent volume of material can be proportioned according to the thickness of each layer (see Figure 5.13);
$$V_1 + V_2 + \cdots + V_n = V_t \quad (3.2.2.1)$$
$$\frac{F_1}{F_1 + F_2 + \cdots + F_n} . V_t = V_1 \quad (3.2.2.2)$$
$$\frac{F_2}{F_1 + F_2 + \cdots + F_n} . V_t = V_2 \quad (3.2.2.3)$$
$$\frac{F_n}{F_1 + F_2 + \cdots + F_n} . V_t = V_n \quad (3.2.2.4)$$</td></tr>
<tr><td>Where:
V_t = Total volume of filter transition material
V_1 = Volume of filter transition material for layer one
V_2 = Volume of filter transition material for layer two
V_n = Volume of filter transition material for layer n
F_1 = Horizontal thickness of layer one
F_2 = Horizontal width of layer two
F_n = Horizontal width of layer n</td></tr>
</table>

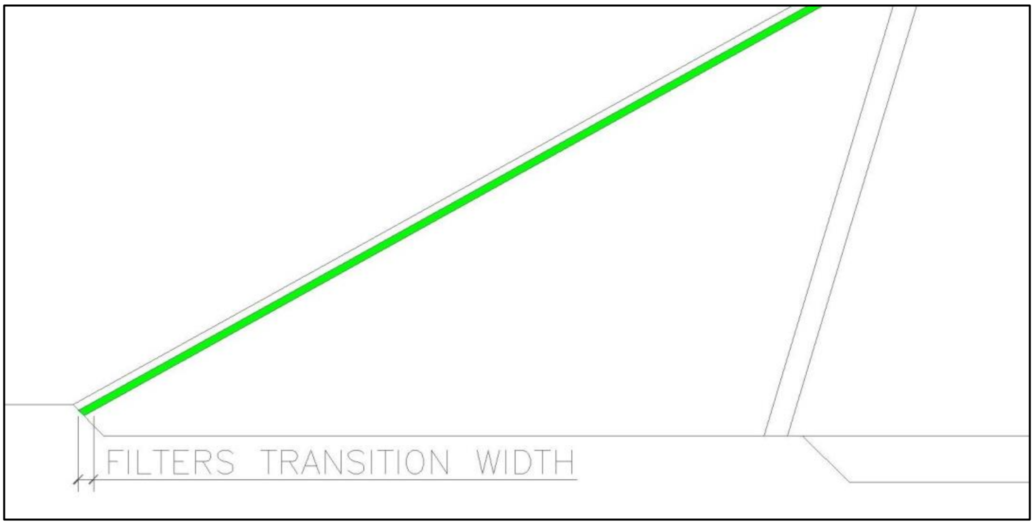


Figure 5.13: Upstream filter transition layer

46	Transition cross sectional area	The cross sectional area calculated for each section of the dam filter material.
47	Transition volume	The volume of filter material calculated using two alongside sections using the trapezoidal rule.
48	Chimney drain horizontal width	The horizontal width specified for each section of chimney drain downstream of the clay core.
49	Clay core height	The height of the clay core that is equal to the wall height subtracted [8] one (as per [29]).
50	Chimney drain cross sectional area	The cross sectional area of the chimney drain calculated for each section of the dam.
51	Chimney drain material volume	The volume of filter material for the chimney drain calculated using two alongside sections using the trapezoidal rule.
52	Blanket drain thickness	The vertical thickness of the blanket specified as a variable input in the variable input table.
53	Blanket drain length	The length of the blanket drain calculated as the distance between the downstream toe of the clay core and the downstream toe of the dam.
54	Blanket drain area	The cross sectional area calculated for each section of the dam. Calculated by multiplying the blanket drain thickness and the blanket drain length.
55	Blanket drain material volume	The volume of filter material for the blanket drain calculated using two alongside sections using the trapezoidal rule.
56	Crest width	As per number column [12]. Input as a variable in the variable inputs table.
57	Footprint width	Equal to the sum of the horizontal components of the upstream and downstream slopes including the crest of the dam for each section;
58	Shell cross sectional area	Total cross sectional area of the shell material. It can be seen that the area is calculated by subtracting the clay core area, upstream filter area and the downstream chimney and blanket drain area.
59	Total shell volume	The volume of material is calculated by using the trapezoidal rule and two alongside sections and the section interval.
60	Foundation preparation section width	The sum of the horizontal components of the upstream and downstream slopes and the crest excluding the batter slopes.
61	Foundation preparation horizontal area	The foundation surface area is calculated at the excavation line. The area is determined using the trapezoidal rule by using two alongside foundation preparation section widths and the sectional interval;
62	Curtain grouting	The length of the curtain grouting is calculated as a percentage (input in the variable inputs table) of the height of the dam. The grout spacing is entered as a variable in the variable input table. The total length of curtain grouting is calculated by averaging two alongside grout depths and multiplying it by the number of intervals, which is determined by dividing the section interval by the grout spacing (see **Figure 5.14**);

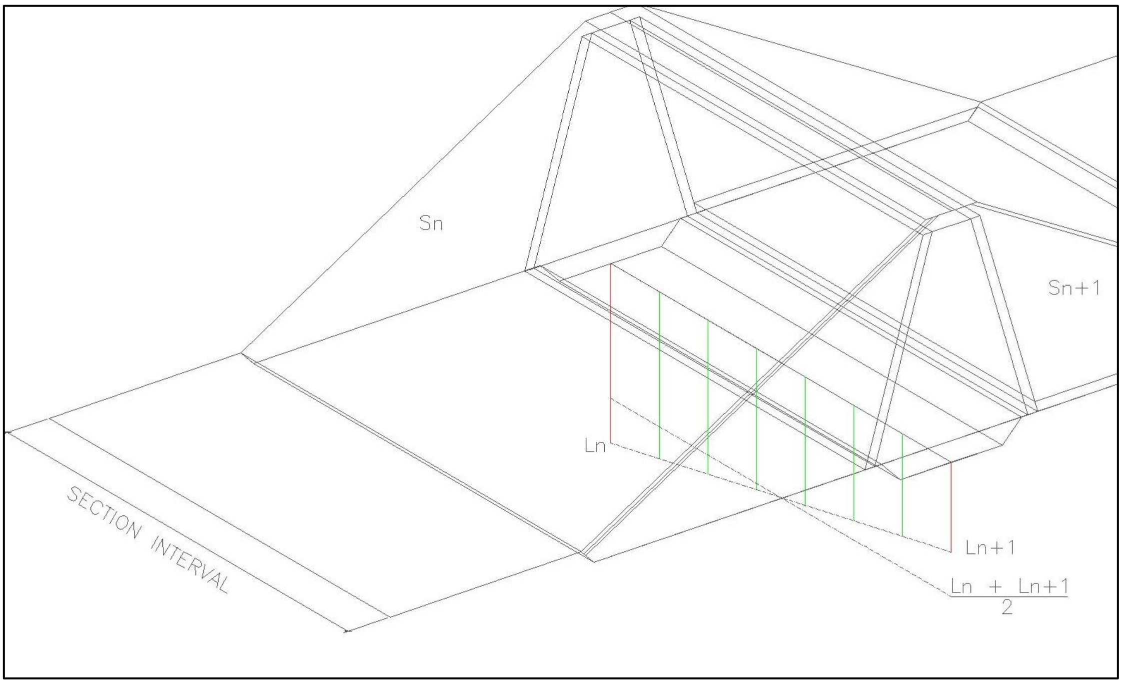


Figure 5.14: Curtain grouting calculations

63	Blanket grout	A constant depth of blanket grout is input as a variable in the variable input table. The length of the blanket or consolidation grouting is determined by multiplying the grout length by the number of holes, which is determined by dividing the section interval by the grout spacing.

5.3 EARTH CORE ROCKFILL EMBANKMENT DAM

The embankment dam can be defined as a dam constructed from natural materials excavated or obtained from a local quarry. The materials available are utilised to the best advantage in relation to their characteristics as an engineered bulk fill in defined zones within the dam section.

In the rockfill embankment the section includes a discrete element of compacted earthfill often with a number of transition layers between the clay core material and the rockfill material. The designation rockfill embankment is appropriate where over 50% of the fill material may be classified as rockfill, i.e. coarse-grained frictional material. Rockfill embankment dams often result in having slopes that are steeper in comparison with the earthfill embankment dam as a result of a higher angle of internal friction. The steeper slopes often results in lower material volumes that could result in lower costs.

Figure 5.15 shows a typical section of an earth core rockfill embankment dam. **Figure 5.16** shows a section of the calculation spreadsheet for the determination of the quantities of the earth core rockfill embankment dam.

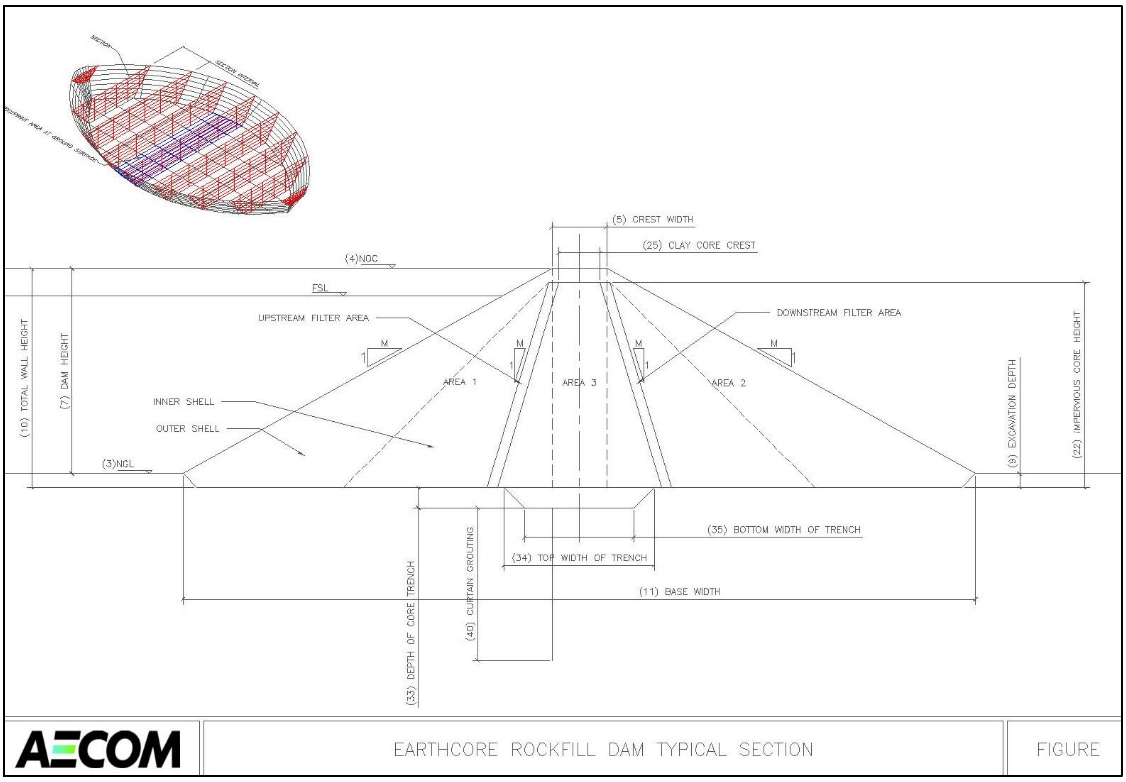
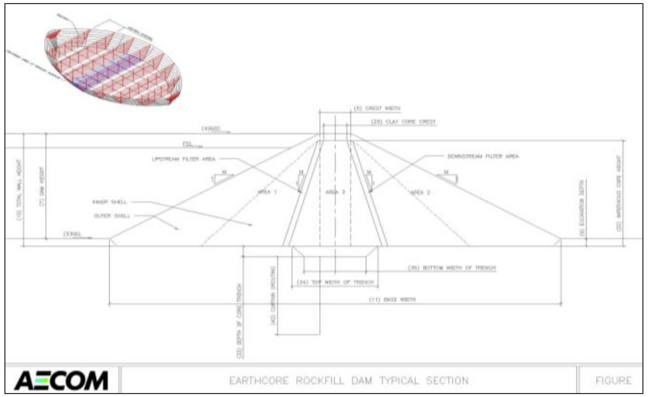


Figure 5.15: Earth core rockfill dam embankment

EARTHCORE ROCKFILL DAM



1	2	3	4	5	6	7	8	9	10	11	12	13	14
								Excavation volumes					
Station	Sections	NGL	NOC	Crest width	Section intervals	Dam height (NOC-NGL)	H_{avg} $\frac{([7]_n+[7]_{n+1})}{2}$	Excavation depth/ Founding depth	Total wall height NOC-NGL+Excavtion depth ([4]-[3]+[9])	Base width	Footprint area	Excavation vertical cross sectional area	Foundation excavation volume
	m	masl	masl	m	m	m	m	m	m	m	m^2	m^2	m^3
1	0	0											
2	0	0											
3	0	0											
4	0	0											
5	0	0											

Figure 5.16: Calculation spreadsheet section for an earth core rockfill embankment dam

A description of each column in the calculation spreadsheet (**Figure 5.16**) is provided in **Table 5.3** with the paragraph number relating to the column number:

Table 5.3: Earth core rockfill embankment dam calculation sheet components

	Earth core rockfill embankment dam	
1	Station	The number of sections that may be input into the long section; each row in the cost model dam volume calculation spreadsheet is referred to as a station.
2	Section	The dam is divided into a number of sections at a specified section interval. The finer the section interval the finer the solution, conversely the larger the section interval, the coarser the solution. A maximum of 200 sections may be entered.
3	NGL	The natural ground level.
4	NOC	The non-overspill crest that is determined by adding the FSL and freeboard of the dam.
5	Crest width	The width of the crest of the dam. Input as a variable in the variable input table.
6	Section intervals	The distance normal to two alongside sections.
7	Dam height	The difference in height between the NOC and the NGL.
8	H_{avg}	The average height between two alongside sections; $$H_{avg} = \frac{S_n + S_{n+1}}{2} \quad (3.3.1)$$
9	Excavation depth/ Founding depth	The depth from the NGL to the founding level, a constant value for all the sections may be entered; else if a geotechnical investigation was undertaken, a separate depth may be entered for each section in the long section input table.
10	Total wall height	Includes the height determined by subtracting the NGL from the NOC and the addition of the excavation depth
11	Base width	The horizontal NGL length for each section determined by adding the horizontal component of the upstream and downstream slope including the crest width of the dam.
12	Footprint area	The horizontal natural ground level surface area calculated by using the base width of two alongside sections and the section interval. The area is calculated using the trapezoidal rule.
13	Excavation vertical cross sectional area	The area of a section of the dam that represents the excavation (see **Figure 5.17**).

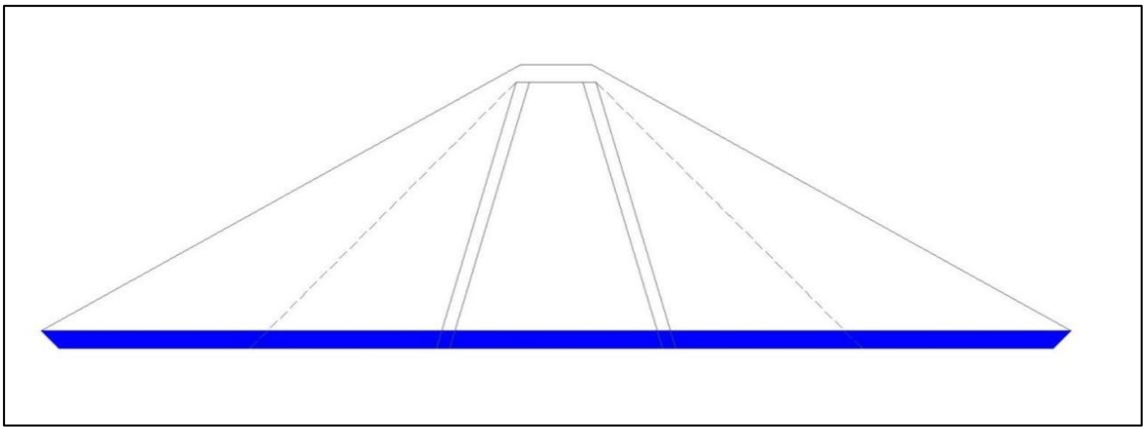


Figure 5.17: Excavation vertical cross sectional area

14	Foundation excavation volume	The volume of material that needs to be excavated in order to reach the founding level. The volume is calculated by summing all the volumes determined by using two alongside sections and the section interval. $$\boldsymbol{Volume} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}} \big(\boldsymbol{Sectional\ area}(\boldsymbol{N-1}) + \boldsymbol{Sectional\ area}(\boldsymbol{N})\big)\left(\frac{\boldsymbol{Sectional\ interval}(\boldsymbol{N})}{\boldsymbol{2}}\right) \quad \textbf{(3.3.2)}$$
15	Total wall height	Includes the height determined by subtracting the NGL from the NOC and adding the excavation depth.
16	Crest width	The width of the crest of the dam. Input as a variable in the variable inputs table.
17	Area 1 Crest area	The rectangular area calculated by multiplying the total wall height by the crest width; $$\boldsymbol{Area} = [\boldsymbol{Total\ wall\ height}] \times [\boldsymbol{Crest\ width}] \quad \textbf{(3.3.3)}$$
18	Area 2 Upstream	The triangular area calculated by using the total wall height and the upstream slope of the dam; $$\boldsymbol{Area} = [\boldsymbol{Total\ wall\ height}]^{\boldsymbol{2}} \times \frac{[\boldsymbol{Upstream\ slope}]}{\boldsymbol{2}} \quad \textbf{(3.3.4)}$$
19	Area 3 Downstream	The triangular area calculated by using the total wall height and the downstream slope of the dam; $$\boldsymbol{Area} = [\boldsymbol{Total\ wall\ height}]^{\boldsymbol{2}} \times \frac{[\boldsymbol{Downstream\ slope}]}{\boldsymbol{2}} \quad \textbf{(3.3.5)}$$
20	Total cross sectional area	The sum of Area 1: Crest, Area 2: Upstream slope, Area 3: Downstream slope.

21	Volume of the embankment	The sum of all the sectional volumes calculated by using two alongside sections and the sectional interval. The trapezoidal rule is used to calculate the volume; $$\boldsymbol{Volume} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}}\left(\boldsymbol{Sectional\ area}(\boldsymbol{N-1}) + \boldsymbol{Sectional\ area}(\boldsymbol{N})\right)\left(\frac{\boldsymbol{Sectional\ interval}(\boldsymbol{N})}{\boldsymbol{2}}\right) \quad \textbf{(3.3.6)}$$
22	Impervious core height	The height of the clay core.
23	Area 1: Upstream	The triangular area calculated using the clay core height and the upstream slope of the clay core; $$\boldsymbol{Area} = [\boldsymbol{Impervious\ core\ height}]^{\boldsymbol{2}} \times \frac{[\boldsymbol{Clay\ core\ upstream\ slope}]}{\boldsymbol{2}} \quad \textbf{(3.3.7)}$$
24	Area 2 Downstream	The triangular area calculated using the clay core height and the downstream slope of the clay core; $$\boldsymbol{Area} = [\boldsymbol{Impervious\ core\ height}]^{\boldsymbol{2}} \times \frac{[\boldsymbol{Clay\ core\ downstream\ slope}]}{\boldsymbol{2}} \quad \textbf{(3.3.8)}$$
25	Clay core crest width	The width of the clay core crest. Input as a variable in the variable inputs table.
26	Area 3 Crest core area	The rectangular area calculated by using the clay core crest width and the impervious core height.
27	Total area impervious core (vertical)	The sum of the Area 1: Upstream, Area 2: Downstream and Area 3: Crest core area.
28	Impervious core volume	The sum of the individual section volumes calculated by using two alongside sections and the section interval; $$\boldsymbol{Volume} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{N}}\left([\boldsymbol{27}]\boldsymbol{Total\ area\ impervious\ core}(\boldsymbol{N-1}) + [\boldsymbol{27}]\boldsymbol{Total\ area\ impervious\ core}(\boldsymbol{N})\right)\left(\frac{\boldsymbol{Sectional\ interval}(\boldsymbol{N})}{\boldsymbol{2}}\right) \quad \textbf{(3.3.9)}$$
29	Upstream filter area	The area of the upstream filter is calculated by multiplying the impervious core height by the horizontal filter width; $$\boldsymbol{Area} = [\boldsymbol{Filter\ width}] \times [\boldsymbol{22\ Impervious\ core\ height}] \quad \textbf{(3.3.10)}$$

30	Upstream filter volume	The volume is determined by the sum of all the sectional volumes, which is determined by using two alongside sections and the sectional interval. The trapezoidal formula is used to calculate the volume; $$\boldsymbol{Volume} = \sum_{N=1}^{n}([29]\boldsymbol{Upstream\ filter\ area(N-1)} + [29]\boldsymbol{Upstream\ filter\ area(N)})(\frac{\boldsymbol{Sectional\ interval(N)}}{2}) \quad \textbf{(3.3.11)}$$
31	Downstream filter area	The downstream filter area is located adjacent to the clay core and is calculated by multiplying the clay core height by the downstream filter width; $$\boldsymbol{Area} = [\boldsymbol{Filter\ width}][22] \quad \textbf{(3.3.12)}$$
32	Downstream filter volume	The volume is determined by the sum of all the sectional volumes, which is determined by using two alongside sections and the section interval. The trapezoidal formula is used to calculate the volume; $$\boldsymbol{Volume} = \sum_{N=1}^{n}([31]\boldsymbol{Downstream\ filter\ area(N-1)} + [31]\boldsymbol{Downstream\ filter\ area(N)})(\frac{\boldsymbol{Sectional\ interval(N)}}{2}) \quad \textbf{(3.3.13)}$$
33	Depth of the core trench	Depending on the available information, a single depth can be input for all the sections or if a more detailed geotechnical investigation has been conducted, individual depths for each section can be input in the long section input table.
34	Top width of trench	The top width is calculated at the shell excavation depth and is determined using the total wall height; $$\boldsymbol{Top\ width} = \frac{\boldsymbol{Total\ wall\ height}}{2} \quad \textbf{(3.3.14)}$$
35	Bottom width of the trench	The bottom width of the trench is calculated by subtracting the horizontal component of the batter slopes from the top width of the trench. If this results in a value less than zero, the bottom width is set to zero.
36	Trench section area (vertical)	The vertical area is calculated for each section that represents the trench area. The area is calculated using the trapezoidal rule; $$\boldsymbol{Area} = ([34]\boldsymbol{Top\ width\ of\ trench} + [35]\boldsymbol{Bottom\ width\ of\ trench}) \times ([33]\boldsymbol{Depth\ of\ core\ trench}) \quad \textbf{(3.3.15)}$$

37	Volume of trench	The volume of the trench is calculated by determining the sum of the volumes of all the section intervals. The section interval volumes is calculated using two alongside sections and the section interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n}\left([36]\boldsymbol{Trench\ section\ area}(N-1) + [36]\boldsymbol{Trench\ section\ area}(N)\right)\left(\frac{\boldsymbol{Sectional\ interval}(N)}{2}\right) \quad (3.3.16)$$
38	Footprint width	The width determined at the shell excavation line by calculating the sum of the crest width and the horizontal components of the upstream and downstream slopes.
39	Footprint area	The area of the footprint calculated at the shell excavation line. The area is calculated using the trapezoidal rule using two alongside footprint widths and the section interval. The sum is determined by adding all the individual section interval areas; $$\boldsymbol{Volume} = \sum_{N=1}^{n}\left([38]\boldsymbol{Footprint\ width}(N-1) + [38]\boldsymbol{Footprint\ width}(N)\right)\left(\frac{\boldsymbol{Sectional\ interval}(N)}{2}\right) \quad (3.3.17)$$
40	Curtain grout	The length of the curtain grout is calculated as percentage (Input in the variable inputs table) of the height of the dam. The grout spacing is entered as a variable in the variable inputs table. The total length of the grout is calculated by averaging two alongside section grout depths and multiplying it by the number of intervals calculated by dividing the section interval by the grout spacing.
41	Blanket grout	A constant depth of the grout is input as a variable in the variable inputs table. The length of the blanket grout or consolidation grouting is determined by multiplying the grout length by the number of holes, which is determined by dividing the section interval by the grout spacing.
42	Outer shell area	The sectional area that is determined by subtracting the upstream and downstream filter volumes, clay core volume from the total sectional area (see **Figure 5.18**).

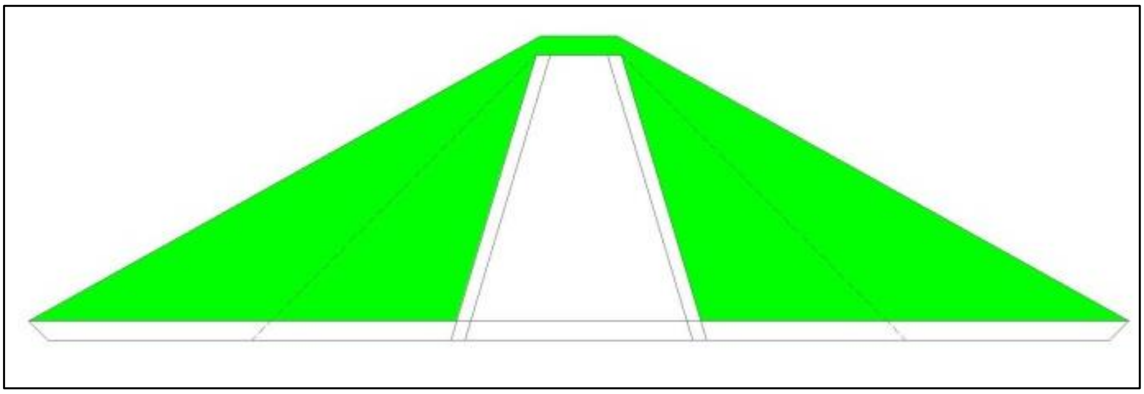


Figure 5.18: Outer shell area

43	Inner shell (vertical area) Upstream	The area calculated using the clay core height and the upstream inner shell zone slope that is specified in variable inputs table (see **Figure 5.19**)

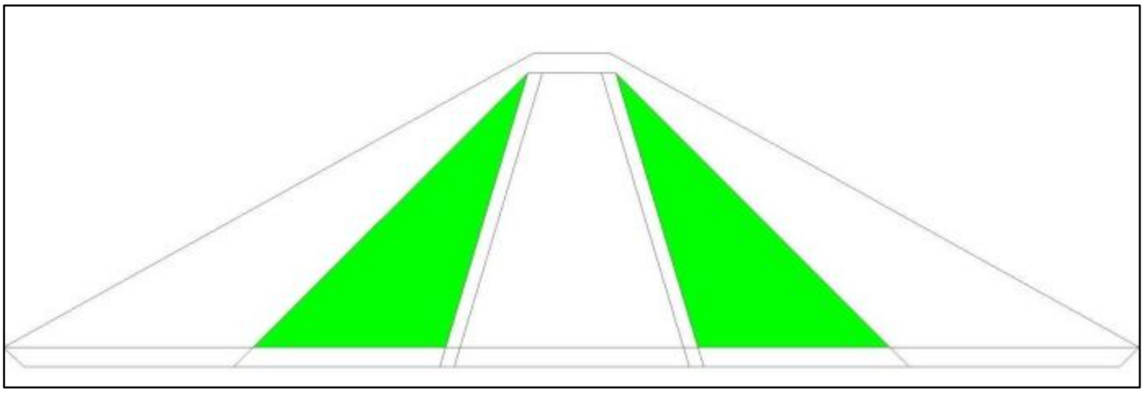


Figure 5.19: Inner shell (Vertical area) Upstream

44	Inner shell (vertical area) Downstream	The area calculated using the clay core height and the downstream inner shell zone slope that is specified in the variable input table.
45	Total inner zone area	The sum of the “Inner shell (vertical area) Upstream” and the “Inner shell (vertical area) Downstream” inner shell zones.
46	Total outer zone area	Is determined by subtracting the total inner zone area from the outer shell area (see **Figure 5.20**).

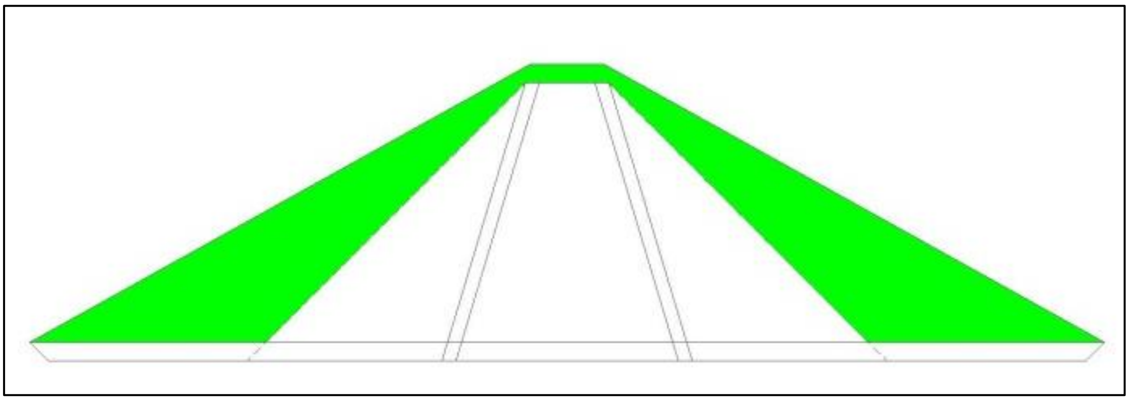


Figure 5.20: Total outer zone area

47	Inner shell volume	Is determined by calculating the sum of all the section interval volumes. Each section interval volume is calculated using the trapezoidal rule by using two alongside sections and the sectional interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n}\left([\mathbf{45}]\boldsymbol{Total\ inner\ zone\ area}(\boldsymbol{N}-\mathbf{1}) + [\mathbf{45}]\boldsymbol{Total\ inner\ zone\ area}(\boldsymbol{N})\right)\left(\frac{\boldsymbol{Sectional\ interval}(\boldsymbol{N})}{\mathbf{2}}\right)$$ **(3.3.18)**
48	Outer shell volume:	Is determined by calculating the sum of all the section interval volumes. Each section interval volume is calculated using the trapezoidal rule by using two alongside sections and the section interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n}\left([\mathbf{46}]\boldsymbol{Total\ outer\ zone\ area}(\boldsymbol{N}-\mathbf{1}) + [\mathbf{46}]\boldsymbol{Total\ outer\ zone\ area}(\boldsymbol{N})\right)\left(\frac{\boldsymbol{Sectional\ interval}(\boldsymbol{N})}{\mathbf{2}}\right)$$ **(3.3.19)**

5.4 CONCRETE FACED ROCKFILL DAM

The concrete faced rockfill dam can be defined as a dam constructed from natural materials excavated or obtained from a local quarry with a concrete slab cast on the upstream slope. The materials available are utilised to the best advantage in relation to their characteristics as an engineered bulk fill in defined zones within the dam section. Because the earthfill/rockfill material does not become saturated, a phreatic surface does establish and as a result steeper slopes may be used. CFRD is also suitable when cohesive material cannot be found on site.

Figure 5.21 shows a typical section of a concrete faced rockfill dam. **Figure 5.22** shows a section of the calculation spreadsheet for the determination of the quantities of the concrete faced rockfill dam.

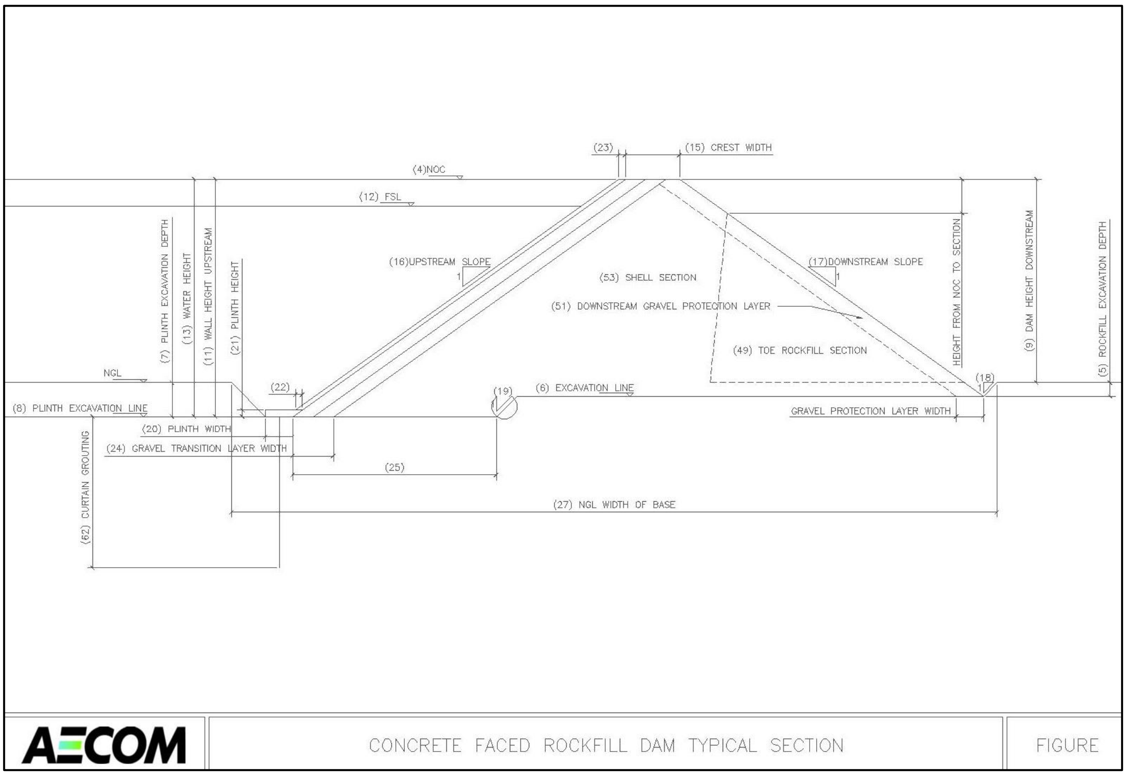
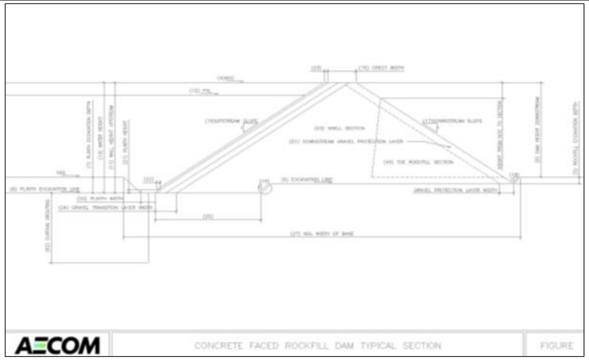


Figure 5.21: Concrete faced rockfill dam

CONCRETE FACE ROCKFILL DAM



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
				Rockfill		Plinth														
Station	Section	NGL [Variable Input]	NOC [FSL]+[Free board] [Variable Input]	Rockfill Excavation depth [Variable input]	Rockfill Excavation line [3]-[5]	Plinth Excavation depth	Plinth Excavation line [3]-[7]	Dam Height NOC-NGL [4]-[3]	Wall Height Downstream NOC-Rockfill excavation line [4]-[6]	Wall Height Upstream NOC-Plinth excavation line [4]-[8]	Full Supply Level [Variable Input]	Water height [12]-[8]	Section Interval $[1]_i - [1]_{i-1}$	Crest width [Variable Input]	Upstream slope [Variable Input]	Downstream slope [Variable Input]	Rockfill Excavation slope [Variable Input]	Plinth Excavation slope [Variable Input]	Plinth width [Variable Input]	Plinth height [Variable input]
		m	mamsl	m	m	m	m	m	m	m	masl	masl	m	m	H:1	H:1			m	m
1	0	0																		
2	0	0																		
3	0	0																		
4	0	0																		
5	0	0																		
6	0	0																		

Figure 5.22: Calculation spreadsheet section a concrete faced rockfill dam

A description of each column in the calculation spreadsheet (**Figure 5.22**) is provided in **Table 5.4** with the paragraph number relating to the column number:

Table 5.4: Concrete faced rockfill dam calculation sheet components

Concrete faced rockfill dam		
1	Station	The number of sections that may be input into the long section; each row in the cost model dam volume calculation spreadsheet is referred to as a station.
2	Section	The dam is divided into a number of sections at a specified section interval. The smaller the section interval the finer the solution conversely the larger the section interval, the coarser the solution. A maximum of 200 sections may be entered.
3	NGL	Natural ground level.
4	NOC	Non-overspill crest. The NOC is calculated by adding the FSL to the freeboard height.
5	Rockfill excavation depth	The depth from the NGL to the founding level. Depending on the amount of information available, either a constant depth can be input for all the sections in the variable inputs table, else if a geotechnical survey has being conducted, this information can be input.
6	Excavation line	The height above sea level calculated by subtracting [5] Rockfill excavation depth from the NGL.
7	Plinth excavation depth	The depth at which the plinth will be founded on. The depth is given from natural ground level.
8	Plinth excavation line	The height above sea level at which the plinth is founded and is determined by subtracting the [7] Plinth excavation depth from the natural ground level.
9	Dam height	The difference in height between the NOC and the NGL.
10	Wall height downstream	The difference in height between the NOC and the rockfill excavation line.
11	Wall height upstream	The difference in height between the NOC and the plinth excavation line.
12	Full supply level	The maximum water level in the dam, which corresponds to the spillway height.
13	Water height	The difference in height between the FSL and the plinth excavation line.
14	Section interval	The distance normal to two alongside sections.
15	Crest width	The width of the crest that is input as a variable in the variable input table.
16	Upstream slope	The horizontal component of the slope is an input in the variable input table.
17	Downstream slope	The horizontal component of the slope is an input in the variable input table.
18	Rockfill excavation slope	The batter slope at the downstream toe of the drain between the NGL and the rockfill excavation line.
19	Plinth excavation slope	The batter slope at the upstream toe of the dam between the NGL and the plinth excavation line.

20	Plinth width	The width of the plinth in the direction of a section of the dam. The plinth width is input as a variable in the variable input table.
21	Plinth height	The height of the plinth specified as an input in the variable input table.
22	Facecrete width at plinth excavation line	The horizontal width of the concrete slab at the plinth excavation line. Input as a variable in the variable input table.
23	Facecrete width at NOC of dam	The horizontal width of the concrete slab at the NOC of the dam. Input as variable in the variable input table.
24	Gravel transition layer width	The total width of all the upstream transition layers. If more than one material is going to be used, the proportion of each material can be determined from the total width (see **Figure 5.23**). $$T_{total} = T_1 + T_2 + T_3 + \cdots + T_n \quad (3.4.1.1)$$ $$Volume(T_1) = \frac{T_1}{T_{total}} \quad (3.4.1.2)$$ $$Volume(T_n) = \frac{T_n}{T_{total}} \quad (3.4.1.3)$$

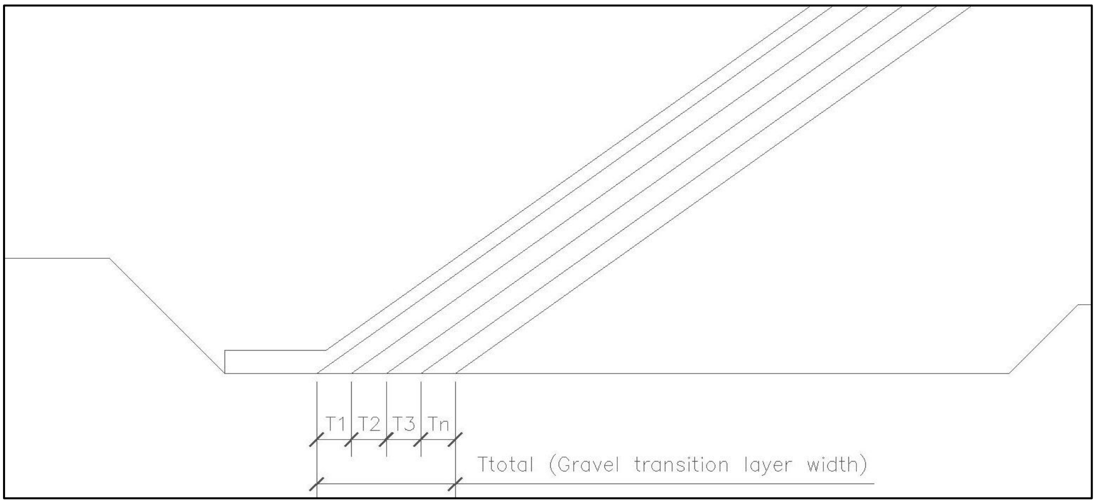


Figure 5.23: CFRD transition layers

25	Plinth rockfill under excavation width	The length of the plinth excavation trench extension into the dam wall. The length starts at the upstream toe and continues downstream of the upstream toe.
26	Curtain grout spacing	Specified as an input in the variable input table.
27	NGL width at base	The base width for each section is calculated from the horizontal components of the upstream and downstream slopes, crest width, plinth width and batter slopes.
28	Footprint area at NGL	The horizontal footprint area calculated using two alongside NGL widths of base and the section interval;

		$$Area = \sum_{N=1}^{n}([NGL\ width\ of\ base(N) + NGL\ width\ of\ base\ (N-1))(\frac{[Section\ interval]}{2}) \quad (3.4.2)$$
29	Footprint excavation area	The vertical area between the NGL and the rockfill excavation line. The trapezoidal rule is used to calculate the area.
30	Footprint excavation volume	The sum of all the section interval volumes that needs to be excavated in order to reach the rockfill excavation line. The trapezoidal rule is used to calculate the volume; $$Volume = \sum_{N=1}^{n}([(29)Footprint\ excavation\ area(N) + (29)Footprint\ excavation\ area(N-1))(\frac{[Section\ interval]}{2}) \quad (3.4.3)$$
31	Plinth excavation area	The vertical area between the rockfill excavation line and the plinth excavation line that needs to be excavated (see **Figure 5.24**).

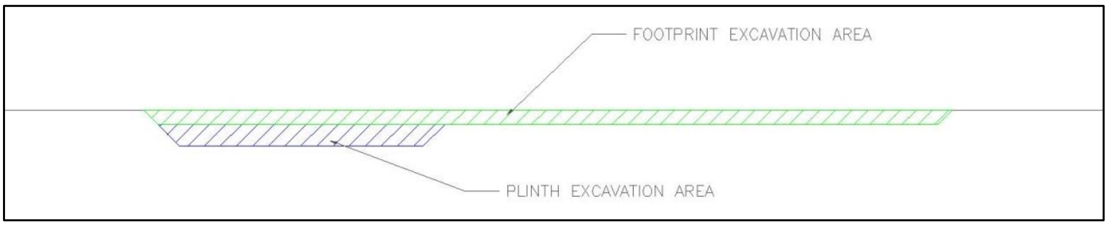


Figure 5.24: Plinth excavation area

32	Plinth excavation volume	The volume of material that needs to be excavated between the rockfill excavation line and the plinth excavation line. The sum of the total volume is determined by calculating each individual section volume using the trapezoidal rule; $$Volume = \sum_{N=1}^{n}(Plinth\ excavation\ area(N) + Plinth\ excavation\ area(N-1))(\frac{[Section\ interval]}{2}) \quad (3.4.4)$$
33	Plinth excavation area from NGL	The vertical sectional area corresponding to the area between the NGL and the plinth excavation line (see **Figure 5.25**).

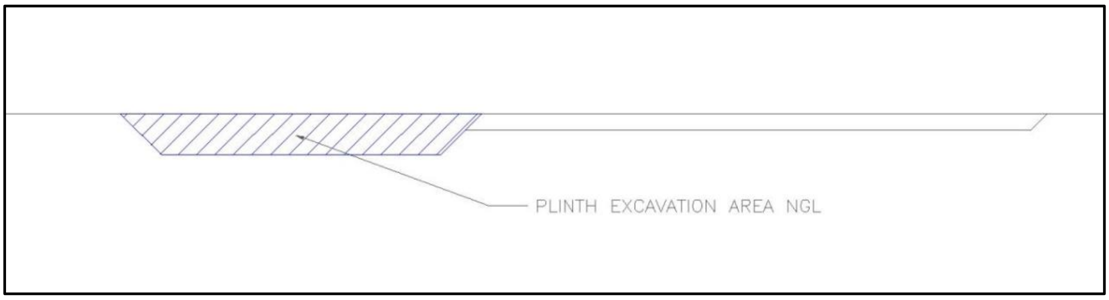


Figure 5.25: Plinth excavation area from NGL

34	Plinth excavation volume from NGL	The sum of the volume of all the sectional interval volumes calculated using the trapezoidal rule. Each sectional interval volume is calculated using two alongside sections and the section interval; $\boldsymbol{Volume} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}} (\boldsymbol{Plinth\ excavation\ area\ from\ NGL}(\boldsymbol{N}) + \boldsymbol{Plinth\ excavation\ area\ from\ NGL}(\boldsymbol{N} - \boldsymbol{1}))(\frac{[\boldsymbol{Section\ interval}]}{\boldsymbol{2}})$ **(3.4.5)**
35	Gravel transition layer section area	The vertical section area of the gravel transition layer that is equal to the horizontal gravel transition width multiplied by the upstream wall height.
36	Gravel transition layer section volume	The sum of all the section interval volumes. The section interval volumes are calculated using the trapezoidal rule; $\boldsymbol{Volume} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}} (\boldsymbol{Gravel\ transition\ layer\ section\ area}(\boldsymbol{N}) + \boldsymbol{Gravel\ transition\ layer\ section\ area}\ (\boldsymbol{N} - \boldsymbol{1}))(\frac{[\boldsymbol{Section\ interval}]}{\boldsymbol{2}})$ **(3.4.6)**
37	Curtain grouting section length	The depth of the curtain grouting is specified as a percentage of the height of the dam wall; $\boldsymbol{Length} = [\boldsymbol{11}] \times [\boldsymbol{Ratio}]$ **(3.4.7)**
38	Total grout length	Curtain grouting spacing can be less than the section interval. The total length of the grout holes is calculated by averaging the height between the two alongside sections and multiplying it by the number of grout holes that need to be bored.

$$\boldsymbol{Length} = \sum_{\boldsymbol{N=1}}^{\boldsymbol{n}} (\frac{[\boldsymbol{Section\ interval}]}{[\boldsymbol{Curtain\ grout\ spacing}]}) \times \frac{(\boldsymbol{Curtain\ grouting\ section\ length}(\boldsymbol{N}) + (\boldsymbol{Curtain\ grouting\ section\ length}(\boldsymbol{N} - \boldsymbol{1}))}{\boldsymbol{2}} \quad \textbf{(3.4.8)}$$

39	Foundation preparation section width	The sum of the upstream and downstream horizontal slope components, the crest width, the plinth width and the length of the batter slopes between the rockfill excavation line and the plinth excavation line.
40	Foundation preparation horizontal area	The foundation surface area calculated as the combined surface between the rockfill excavation line and the plinth excavation line. Does not consider the upstream and downstream batter slopes. The area is calculated using the trapezoidal rule by using two alongside foundation preparation section widths and the section interval; $$\textbf{Volume} = \sum_{N=1}^{n} (\textbf{Foundation preparation section width}(N) + \textbf{Foundation preparation section width}(N-1))(\frac{[\textbf{Section interval}]}{2}) \quad \textbf{(3.4.9)}$$
41	Plinth foundation preparation horizontal area	The foundation surface area calculated using the plinth width and the section interval; $$\textbf{Volume} = \sum_{N=1}^{n} (\textbf{Plinth width}(N) + \textbf{Plinth width}(N-1))(\frac{[\textbf{Section interval}]}{2}) \quad \textbf{(3.4.10)}$$
42	Facecrete section area	The section area representing the facecrete. It is calculated by averaging the width at the NOC level and plinth level and multiplying it by the height of the dam; $$\textbf{Volume} = \sum_{N=1}^{n} (\textbf{Facecrete section area}(N) + \textbf{Facecrete section area}(N-1))(\frac{[\textbf{Section interval}]}{2}) \quad \textbf{(3.4.11)}$$
43	Total dam section area	The total sectional area that includes all the material (see **Figure 5.26**).

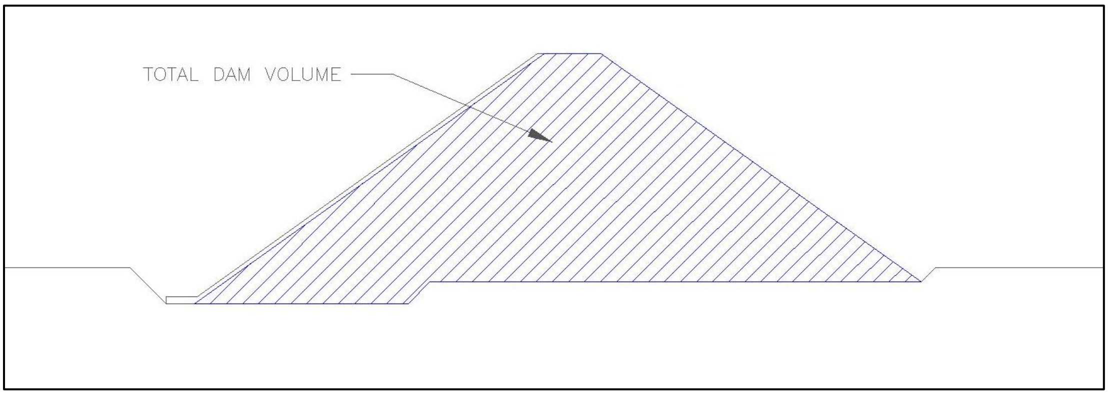


Figure 5.26: Total dam section area

44	Total dam volume	The sum of all the sectional interval volumes that are calculated using two alongside total dam section areas and the section interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n} (\textbf{Total dam section area}(\boldsymbol{N}) + \textbf{Total damsection area}(\boldsymbol{N} - \mathbf{1}))(\frac{[\boldsymbol{Section\ interval}]}{\mathbf{2}}) \quad \textbf{(3.4.12)}$$
45	Rockfill section area	The sectional area representing the area of rockfill. It is calculated by subtracting the line upstream gravel transition layer area [35] from the total dam section area [44]; $$\boldsymbol{Area} = [\boldsymbol{Total\ dam\ section\ area}]_{\boldsymbol{N}} - [\boldsymbol{Gravel\ transition\ layer\ section\ area}]_{\boldsymbol{N}} \quad \textbf{(3.4.13)}$$
46	Total rockfill volume	The sum of the rockfill sectional interval volume that is calculated using two alongside rockfill section areas and the section interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n} (\textbf{Rockfill section area}(\boldsymbol{N}) + \textbf{Rockfill section area}(\boldsymbol{N} - \mathbf{1}))(\frac{[\boldsymbol{Section\ interval}]}{\mathbf{2}}) \quad \textbf{(3.4.14)}$$
47	The toe section height	If a different material is specified for the toe section of the dam then the height of the toe section is equal to the difference in height between the downstream wall height [10] subtracted the variable input specified for the height from the NOC level to the top of the toe section.
48	Toe rockfill section area	The sectional area of the rockfill material (see **Figure 5.27**).

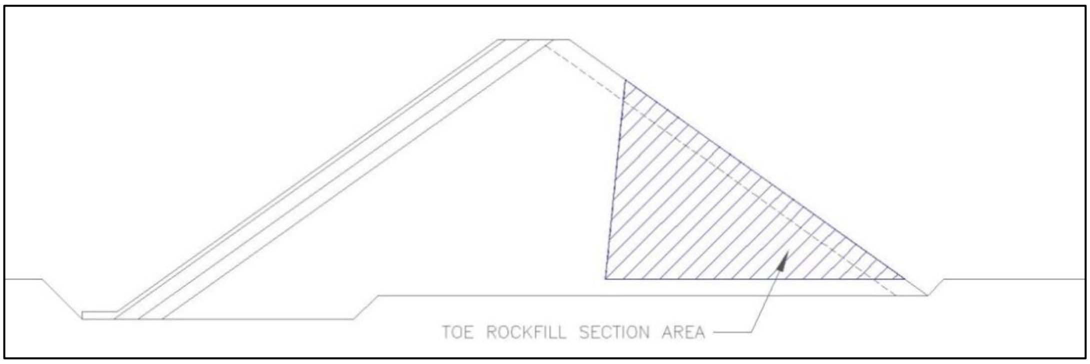


Figure 5.27: Toe rockfill section area

49	Toe rockfill volume:	The sum of the sectional interval volumes, which is calculated by using two alongside toe rockfill section areas and the section interval; $$\boldsymbol{Volume} = \sum_{N=1}^{n} (\textbf{Toe rockfill section area}(\boldsymbol{N}) + \textbf{Toe rockfill section area}(\boldsymbol{N} - \mathbf{1}))(\frac{[\boldsymbol{Section\ interval}]}{\mathbf{2}}) \quad \textbf{(3.4.15)}$$

50	Downstream gravel protection layer section area:	If a downstream gravel protection layer is used in the dam, the area is equal to the specified input width multiplied by the height of the dam.
51	Downstream gravel protection layer volume	The sum of the sectional interval volume, which is calculated using two alongside downstream gravel protection layer section areas and the section interval (see **Figure 5.28**); $$\boldsymbol{Volume} = \sum_{N=1}^{n} (\textbf{Downstream gravel protection later section area} + \textbf{Downstream gravel protection later section area}(\boldsymbol{N} - \mathbf{1}))(\frac{[\boldsymbol{Section\ interval}]}{\mathbf{2}}) \quad \textbf{(3.4.16)}$$

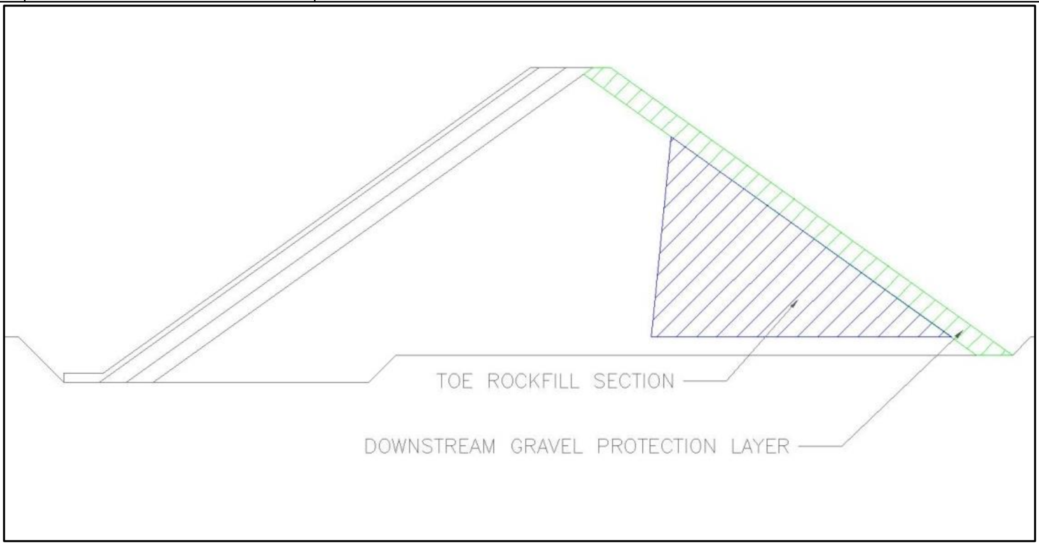


Figure 5.28: Downstream gravel protection layer volume

If both a gravel protection layer and a toe section material are used then the toe height will start at the transition from the rockfill material to the gravel protection layer.

52	Total shell rockfill volume	The volume of rockfill material required excluding the downstream protection layer volume and the toe section volume (see **Figure 5.29**).

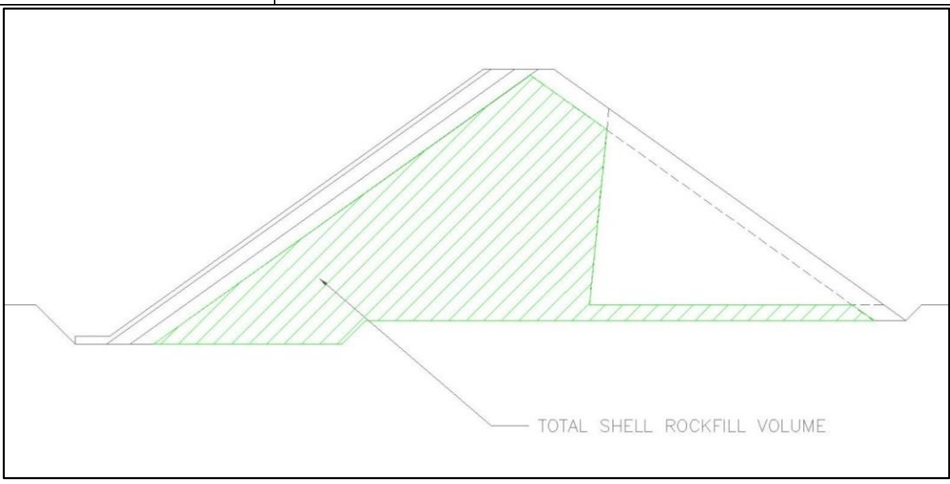


Figure 5.29: Total shell rockfill volume

5.5 SPILLWAY AND CHUTE

Side channel spillways are predominantly used in earthfill and rockfill dams when it is not possible or advisable to use a direct over fall spillway. They are placed on either the left or right side of the dam and include a spillway proper, a flume (channel) downstream of the spillway, followed by a chute. The spillway proper is usually designed as a normal over fall spillway. The depth, width, and bed slope of the flume must be designed in such a way that even the maximum flood discharge passes with a free over fall over the entire horizontal spillway crest, so that the reservoir level is not influenced by the flow in the channel. The flow in a side-channel spillway is an example of a spatially varied non-uniform flow that is best solved by the application of the momentum principle, assuming that the lateral inflow into the channel has no momentum in the direction of flow, but that there is energy dissipation in the channel. The design calculations are taken from *Design of Small Dams (United States Department of the Interior, 1987)*. Taking the slope of the channel, S_o, and the resistance (friction slope S_f) into account results, for a cross section of the channel, A, wetted perimeter, P, depth y^+ of the centre of gravity of section A, and length (in the direction of flow) Δx, in:

$$\frac{dM}{dx} = \frac{d}{dx}\left(\frac{Q^2}{gA} + Ay^+\right) = A(S_0 - S_f) \quad (3.5.1)$$

Using the momentum equation the following equation is derived:

$$\Delta y = -\frac{\alpha Q_1(V_1 + V_2)}{g(Q_1 + Q_2)}\left(\Delta V + \frac{V_2 \Delta Q}{Q_1}\right) + (S_0 - S_f)\Delta x \quad (3.5.2)$$

Through an iterative process, Equation (3.5.2) can be solved for Δy, with Q_1, V_1, S_0, Δ_x, Q_2 and the channel shape is known, and an assumed value of y_2 (and therefore V_2) which must agree with $\Delta y = y_2 - y_1$. The solution starts from the control section and proceeds upstream. The control section is either the outflow from the channel or the critical depth section inside the channel.

Table 5.5: Ogee design calculations

Ogee design calculations		
1.1	$P/H_o = 1$	
1.2	C_o = 2.14 (variable input) Coefficient form $Q=CLH^{1.5}$	
1.3	Q_{design} = safety evaluation flood = Q_{sef}	
1.4	Spillway length (input)	
1.5	Short side A	Spillway section parallel to the chute (see **Figure 5.30**).
1.6	Long side B	Spillway section perpendicular to the chute inlet (see **Figure 5.30**).

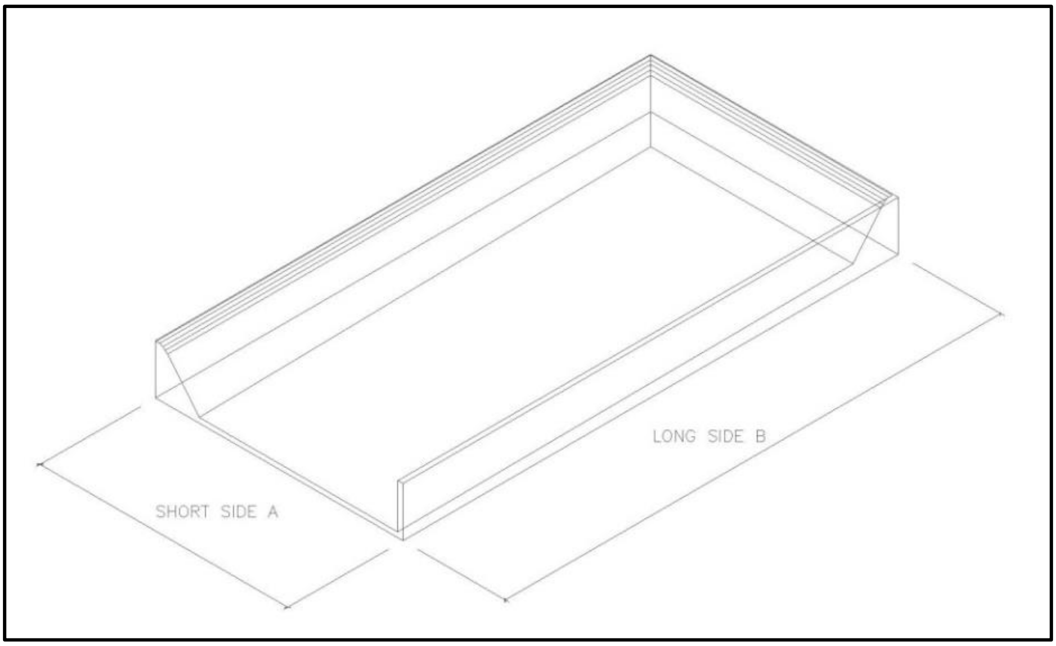


Figure 5.30: Spillway

1.7	Q_A	The flow of water over the short side A
1.8	Q_B	The flow of water over the long side B.
1.9	Q_b/m	The flow of water of the long side per unit length of B.
1.10	The water height above the ogee section (see **Figure 5.31**)	

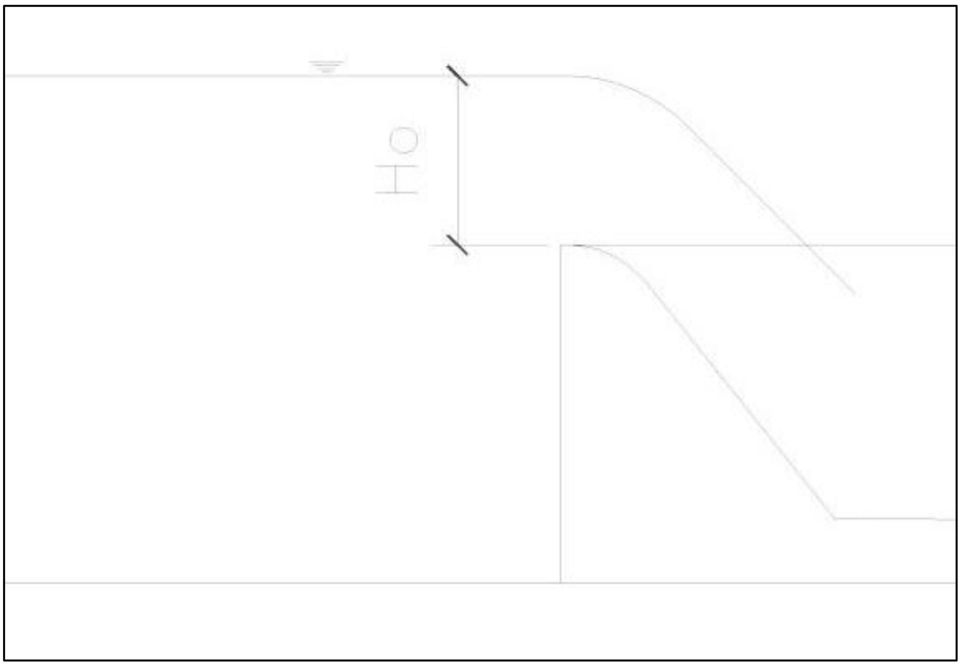


Figure 5.31: The water height above the ogee section

1.11	Width of control section C	The width of the transition section.
1.12	Q	The unit flow rate through the transition zone (see **Figure 5.32**) $q_1=Q_{sef}/C$ **(3.5.3)**

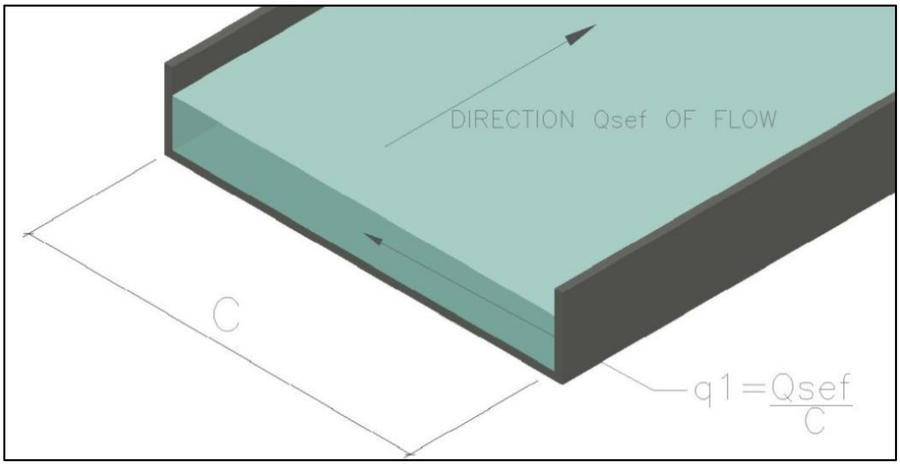


Figure 5.32: The unit flow rate through the transition zone

1.13	Gravity (g)	$g = 9.81 m/s^2$
1.14	d_c	The flow height at C when critical where Froude = 1 (F_r = 1) $d_c = \left(\frac{q_1{}^2}{g}\right)^{\frac{1}{3}} = \left(\frac{q_1{}^2}{g}\right)^{\frac{1}{3}}$ **(3.5.4)**
1.15	V_c	The flow velocity at critical flow when F_r = 1;

1.16	h_{vc}	The velocity component of the energy head; $h_{vc} = \frac{V_c^2}{2 * g}$ **(3.5.5)**
1.17	Section width at A	= short section A: (=1.11)
1.18	Transition loss	$0.2(h_{vc} - h_{v0})$
1.19	Side slope or ogee slope (N), (see **Figure 5.33**)	

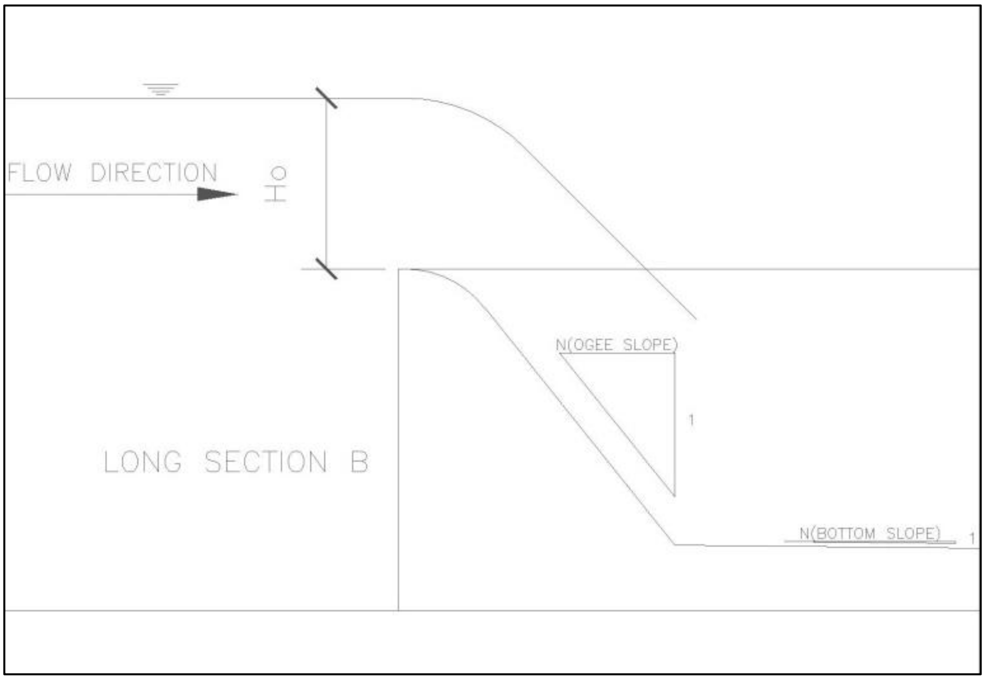


Figure 5.33: Side slope or ogee slope

1.20	Bottom slope	Spillway section slope
1.21	d_2	The depth the water will flow through at the start of the transition zone; $d_2 > d_c$ (subcritical flow)
1.22	A_2	The area the water flows through at the start of the transition zone.
1.23	V_2	The velocity the water flows through at the transition zone.
1.24	h_{v2}	The velocity component of the energy head; $\boldsymbol{h_{v2} = \frac{V_2{}^2}{2 * g}}$ **(3.5.6)**
1.25	Transition length (D)	The transition zone between the spillway section and the chute.
1.26	Left = Right	$\boldsymbol{d_2 + h_{hv20} = d_c + h_{vc} + 0.2(h_{vc} - h_{v0})}$ **(3.5.7)**
1.27.1	Station	Section along the long side B at which calculations are done. Zero is at the short side A and at the chute, the station is equal to the long side B.

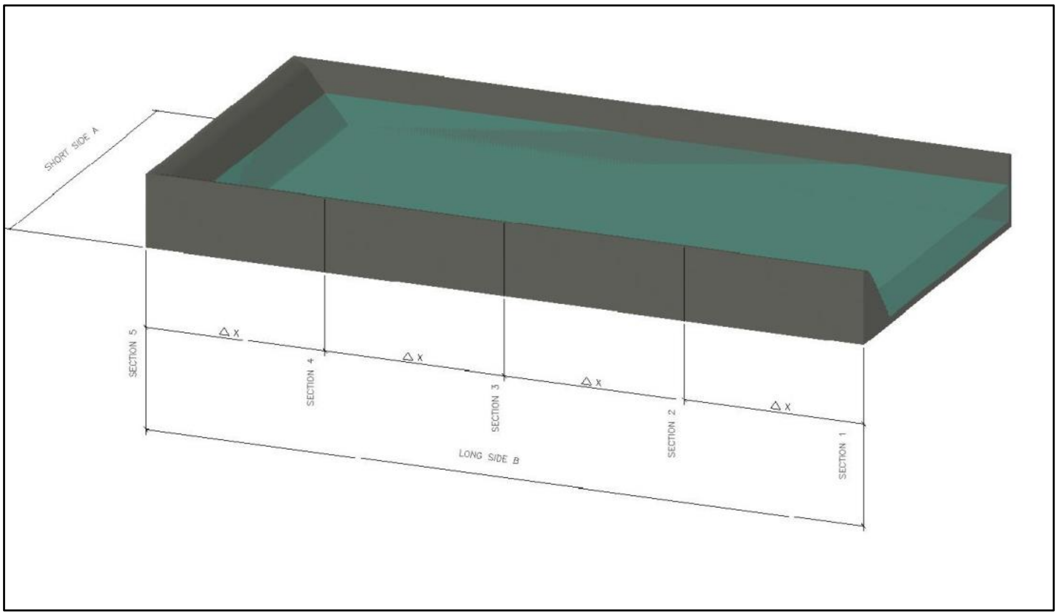


Figure 5.34: Spillway design

1.27.2	Δx	Change in x = the distance between the sections.
1.27.3	The elevation bottom	The height above sea level at each section.
1.27.4	Trial Δy	The column is an input in the variable input table. Each input is iterated until (1.27.4) = (1.27.19).
1.27.5	Water surface elevation	Iterative
1.27.6	d_n	The static height of the water above the water surface elevation for each section.
1.27.7	Width	The base width that is equal to the short side A.
1.27.8	Section area	The cross sectional area of water at each section.
1.27.9	Q	The flow at each section.
1.27.10	Velocity	The velocity of water at each section.
1.27.11	$Q_n + Q_{n-1}$	The sum of the flow of section n + section n-1.
1.27.12	$\frac{\boldsymbol{Q_n}}{\boldsymbol{g} * (\boldsymbol{Q_n} + \boldsymbol{Q_{n+1}})}$	
1.27.13	$\boldsymbol{V_n} + \boldsymbol{V_{n-1}}$	
1.27.14	$\boldsymbol{V_n} + \boldsymbol{V_{n-1}}$	
1.27.15	$\boldsymbol{Q_n} - \boldsymbol{Q_{n-1}}$	
1.27.16	$\frac{(\boldsymbol{Q_n} - \boldsymbol{Q_{n-1}})}{\boldsymbol{Q_n}}$	
1.27.17	$\boldsymbol{V_{n-1}} \times \frac{(\boldsymbol{Q_n} - \boldsymbol{Q_{n-1}})}{\boldsymbol{Q_n}}$	
1.27.18	$\boldsymbol{V_n} + \boldsymbol{V_{n-1}} + \boldsymbol{V_{n-1}} \times \frac{(\boldsymbol{Q_n} - \boldsymbol{Q_{n-1}})}{\boldsymbol{Q_n}}$	
1.27.19	$\frac{\boldsymbol{Q_n}}{\boldsymbol{g} * (\boldsymbol{Q_n} + \boldsymbol{Q_{n-1}})} \times (\boldsymbol{V_n} + \boldsymbol{V_{n-1}}) \times (\boldsymbol{V_n} - \boldsymbol{V_{n-1}}) \times \boldsymbol{V_{n-1}} \times \frac{(\boldsymbol{Q_n} - \boldsymbol{Q_{n-1}})}{\boldsymbol{Q_n}}$	
1.28	Crest level	It can be seen that the crest level is equal to the full supply level of the dam.
1.29	Reservoir water level	The full supply level plus the flood surcharge (H_o).
1.30	Submergence < 2/3 H_o:	The spillway can only be allowed to submerge 2/3 of the H_o.
1.31	Equals to the FSL plus the 2/3 H_o.	
1.32	The highest water level above the crest in the spillway section.	

Table 5.6: Chute design calculations

Chute design calculations		
2.1	Width	The width of the chute.
2.2	Q_{des}	The design flood in the chute (= Q_{sef}).
2.3	q_1	The flow per unit width of the chute.
2.4	g	Gravity acceleration.
2.5	The depth of the water at the start of the chute.	
2.6	V_c	Critical flow velocity.
2.7	$h_{vc} = \frac{V_c^2}{2 * g}$	The velocity component of the energy head.
2.8.1	Q_d	The design flood through the chute.
2.8.2	N	Manning's n-value (roughness value) Concrete = 0.015.
2.8.3	Width	Width of the chute.
2.8.4	Elevation	The elevation of the chute above mean sea level.
2.8.5	Δz	The change in elevation between two points.
2.8.6	Stretch	Distance between two sections.
2.8.7	D_n	The height of the water above the chute elevation.
2.8.8	Area	The cross sectional of the chute.
2.8.9	Perimeter	The wetted perimeter of the chute at each section.
2.8.10	R	Hydraulic radius.
2.8.11	V	The flow velocity at each section.
2.8.12	H_{v1}	$h_{vn} = \frac{V_n^2}{2*g}$ The velocity component of the energy head.
2.8.13	Slope	The slope of the chute at each section.
2.8.14	Average slope	The average slope between two sections; $\frac{S_n + S_{n-1}}{2} = S_{average}$ **(3.5.8)**
2.8.15	Δh_l	Energy loss between two sections
2.8.16	Bernoulli equation	The Bernoulli equation is used to determine energy heads at each of the sections. If the left is equal to the right then it's in equilibrium; [Left = right] therefore equilibrium.
2.8.17	Froude number	Determine whether the flow is subcritical or supercritical Fr < 1: Subcritical Fr > 1: Supercritical
2.9	The weighted average of the water height alone the length of the chute.	

Table 5.7: Ogee and chute volumes

Ogee and chute volumes		
3.1	Crest level	Equal to the full supply level.
3.2	Top spillway floor	The level of the spillway floor at the start of the spillway section at the short side A.
3.3	Bottom spillway floor	The level of the end of the spillway section at the beginning of the transition zone.
3.4	H_{start}	The difference in height between the crest level and the start of the spillway section.
3.5	H_{end}	The difference in height between the FSL and the end of the spillway section.
3.6	$H_{average}$	The weighted average height between H_{start} and H_{end}.
3.7	x & y	The top width of the spillway section derived from: $x^2 = 2 \times H \times y$ (3.5.9) Where: H_o = the water head above the crest level at the Q_{design}/Q_{sef};
3.8	Area 1	Equal to H/4 × H_{avg}.
3.9	Area 2	$x \times (H_{avg} - y)$
3.10	Area 3	The area representing the ogee spillway; $Area = x \times y - \frac{1}{6} \times \frac{x^3}{H_o}$ (3.5.10)
3.11	Area 4	The cross sectional area representing the downstream slope.
3.12	Base	The width of the base of the ogee; $Base = \frac{H_o}{4} + x + (H_{avg} - H_o) \times S_{ogee}$ (3.5.11)
3.13	Area total	The sum of Area 1, Area 2, Area 3 and Area 4.
3.14	Volume	The volume of concrete in the ogee section. Is equal to the average area multiplied by the length of the ogee.
3.15	Reinforcing	The total amount of steel is calculated by multiplying the volume of concrete by a proportion of the steel per unit concrete.
3.16	Vertical shuttering	The vertical shuttering on the upstream face of the ogee spillway.
3.17	Slope shuttering	The shuttering on the sloped section on the downstream face of the ogee spillway.

Table 5.8: Spillway and transition wall volumes

Spillway and transition wall volumes		
4.1	Wall length	The sum of the two transition walls and the spillway wall parallel to the long side B.
4.2	Height	The weighted height between the transition walls and the ogee spillway wall.
4.3	Wall volume	The wall length multiplied by the wall height.
4.4	Reinforcing steel	Is calculated as a proportion of the wall volume by multiplying the concrete volume by a reinforcing weight per unit concrete.
4.5	Vertical shuttering	Is equal to the wall length multiplied by two, multiplied by the wall height.
4.6	Float finish	In order to obtain a smooth finish, to reduce friction, a float finish is required. The area requiring a float finish is equal to the wall length multiplied by the weighted average height.

Table 5.9: Chute wall volumes

Chute wall volumes		
5.1	Wall volumes	Calculated by multiplying the length of the chute by the height and multiplied by two.
5.2	Reinforcing steel	Calculate as a weight of reinforcing per unit of concrete.
5.3	Vertical shuttering	The total vertical surface area of the chute.
5.4	Float finish	The internal vertical chute areas.
5.5	Joints	The number of joints is calculated by dividing the length of the chute by the joint spacing.

Table 5.10: Floor of the spillway

Floor of the spillway		
6.1	Floor volume	Calculated using two adjacent end lengths, the spillway and the length of the spillway using the trapezoidal rule and multiplying the surface area by the spillway floor thickness.
6.2	Reinforcing steel	Determined as a proportion of the concrete volume in tons.
6.3	Float finish	The surface area of the spillway and transition.

Table 5.11: Floor of the chute

Floor of the chute		
7.1	Floor concrete volume	The volume of concrete for the base of the chute.
7.2	Reinforcing steel	The amount of reinforcement calculated as a proportion of the concrete volume.
7.3	Float finish	The inclined base surface area of the chute.
7.4	Core drain	The drains placed beneath the chute. It is calculated by taking the chute length and dividing it by the drainage spacing and multiplying it by the chute width.
7.5	Filter sand	The sand required for the core drain filters.
7.6	Anchors	The anchors are placed on a grid n x n beneath the chute. The spacing and length of the anchors is input as a variable in the variable input table.
7.7	Core drain excavation	Equal to the total volume that needs to be excavated for the coredrain. The total length of the core drain multiplied by (0.6 x 0.6).

Table 5.12: Excavation for spillway and chute

Excavation for spillway and chute		
8.1 – 8.10	Input parameters or previously calculated parameters.	
8.11	Spillway excavation volume	The volume of material that needs to be excavated for the spillway.
8.12	Transition excavation volume	The volume of material that needs to be excavated for the transition section.
8.13	Chute excavation volume	The volume of material that needs to be excavated for the chute.

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Appendix A

Final cost model used for the uMkhomazi Water Project (CD)

(Note: Excel spreadsheet is protected. Password: J0176)