

University of Southern Queensland
Faculty of Engineering and Surveying

Accuracy of Volumes From MX(moss) Design Software

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Abstract:

Earthwork volumes are one of the most important factors in the delivery of a major civil project. From when feasibility estimates are generated at the concept stage of a project, until when volumes become a vital component of the contractual agreements between owners and contractors it is essential they are within a reasonable range of accuracy.

MX(moss) road design software is a commonly used program for major highway projects. It is generally assumed that volume errors are contained within the road design software used to determine these volumes. This paper will undertake analysis the accuracy of earthworks volume calculations from MX(moss).

The approach taken was to take different simplified road profiles of a known volume and model them in MX(moss). The mathematical and MX(moss) volume can now be compared and error percentages calculated. For additional analysis traditional and more complex MX(moss) triangulation volume techniques were used. Ranking of these results will enable different project management techniques to be applied and the risk to be assessed.

The findings of the technical review of MX(moss) showed that different volume calculations do produce different errors. However to give the results some perspective in the delivery of a project some research of previous project management theory and qualitative analysis of senior road engineers and managers was undertaken. The survey results indicated some simple procedural items and changing trends in the industry to higher degrees of error being acceptable during construction. Overall the results were under the error limits defined for various stages of a project.

The results from the above quantitative and qualitative analysis enables senior executives and governments making 'go' or 'no go' decisions during feasibility and contract administration greater understanding of the errors and risks in their decision making. Feasibility stages of a project where high levels of accuracy are not needed, to the other end of the scale where high accuracy is needed at the detailed stages of a project so managers producing cost plans and contracts can be better managed. The data presented in this paper reduces the risk for these people.

Benefits from this study include reduced risk and achieving greater consistency within a design office. Recommendations in this paper could be used to form design checklists or part of a quality assurance system. Recommendations also include reference to developing a risk adverse culture where the risk of getting the wrong numbers is understood.

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LIST OF ACRONYMS AND THEIR MEANINGS

Acronym	Meaning
AIPM	Australian Institute of Project Management
AASHTO	American Association of State Highway and Transportation Officials
CPM	Critical Path Method
DTM	Digital Terrain Model
FSP	Final Sketch Plan
GHD	Guttridge Haskins Davey Pty Ltd
MX	MX Roads design software (Bentley)
PIM	Project Management Institute
PMBok	Project Management Body of Knowledge
PSP	Preliminary Sketch Plan
QA	Quality Assurance
QDMR	Queensland Department of Main Roads
RTA	Road Traffic Authority of New South Wales
SP	Spot Point
TQM	Total Quality Management
VICROADS	Roads Corporation, Victorian State Government.
WBS	Work Breakdown Structure

DEFINITIONS

Term	Definition	Reference
Alignment	The geometric form of the centreline of a carriageway in both the horizontal and vertical directions.	(RTA 1988)
Alignment co-ordination	A design technique in which various rules are applied to ensure that the combination of horizontal and vertical alignment is both safe and aesthetically pleasing.	(RTA 1988)
Balanced earthworks	Earthworks in which the quantity of material taken from cuttings along the road mathematically equals the fill required to construct the embankments (after taking into account bulking).	(RTA 1988)
Batter	<ol style="list-style-type: none"> 1. The side slope of walls, embankments, cuttings etc; and 2. The degree of such slope usually expressed as a ratio of x horizontal to 1 vertical. 	(RTA 1988)
Carriageway	That portion of a road or bridge used by vehicles, (inclusive of shoulders and auxiliary lanes).	(RTA 1988)
Centreline	The basic line, which defines the axis or alignment of the centre of the road or other work.	(RTA 1988)
Cross Section	The transverse elements of the longitudinal elements.	(Austroads 2003)
Cut	The material excavated from a cutting.	(RTA 1988)
Grade	The rate of longitudinal rise (or fall) of a carriageway with respect to the horizontal, expressed as a percentage.	(Austroads 2003)
Hinge Point	The point in the cross-section of a road at which the extended batter line would intersect the extended verge line.	(Austroads 2003)
Horizontal Alignment	The bringing together of the straights and curves in the plan view of a carriageway.	(Austroads 2003)
Horizontal Curve	A curve in the plan view of a carriageway.	(Austroads 2003)
Intersection	A place at which two or more roads meet.	(Austroads 2003)

Term	Definition	Reference
K Value	The length required for a 1% change of grade on a parabolic vertical curve.	(Austroads 2003)
Lane (Traffic)	A portion of the carriageway allocated for the use of a single line of vehicles.	(Austroads 2003)
Longitudinal Friction Factor	The friction between vehicle tyres and the road pavement under locked wheel braking conditions, measured in the longitudinal direction.	(Austroads 2003)
Longitudinal Section	A vertical section, usually with an exaggerated vertical scale, showing the existing.	(Austroads 2003)
Normal Cross Section	The cross section of the carriageway where it is not affected by superelevation or widening.	(Austroads 2003)
Operating speed	A nominal speed fixed to determine the geometric features of a road.	(Austroads 2003)
Pavement	That portion of a road designed for the support of, and to form the running surface for, vehicular traffic.	(Austroads 2003)
Reaction Time	The time between the driver's reception of stimulus and taking appropriate action.	(Austroads 2003)
Reverse Curve	A section of road alignment consisting of two curves turning in opposite directions and having a common tangent point or being joined by a short length of tangent.	(Austroads 2003)
Road (way)	A route trafficable by motor vehicles; in law, the public right-of-way between boundaries of adjoining property.	(Austroads 2003)
Sag Curve	A concave vertical curve in the longitudinal profile of a road.	(Austroads 2003)
Shoulder	The portion of formed carriageway that is adjacent to the traffic lane and flush with the surface of the pavement.	(Austroads 2003)

Term	Definition	Reference
Sight Distance	<p>Sight Distance Approach Sight Distance (ASD) The distance required for a driver to perceive marking or hazards on the road surface approaching an intersection and to stop.</p> <p>Car Stopping Distance (SSD) The distance required for a car driver to perceive a hazard, react and brake to a stop. For design purposes, wet weather conditions and locked wheel braking are assumed.</p> <p>Entering Sight Distance (ESD) The sight distance required for minor road drivers to enter a major road via a left or right turn, such that traffic on the road is unimpeded</p> <p>Manoeuvre Sight Distance The distance required for an alert car driver to perceive an object on the road and to take evasive action.</p> <p>Overtaking Sight Distance The sight distance required for a driver to initiate and safely complete an overtaking manoeuvre.</p> <p>Safe Intersection Sight Distance (SISD) The distance required for a driver in a major road to observe a vehicle entering from a side road, and to stop before colliding with it.</p> <p>Stopping Sight Distance The sight distance required by an average driver (car or truck depending on design requirements), travelling at a given speed, to react and stop before striking an object on the road.</p>	(Austroads 2003)
Verge	That portion of the formation not covered by the carriageway or footpath.	(Austroads 2003)
Superelevation	A slope on a curved pavement selected so as to enhance forces assisting a vehicle to maintain a circular path.	(Austroads 2003)
Table drain	The side drain of a road adjacent to the shoulder, having its invert lower than the pavement base and being part of the formation.	(Austroads 2003)

Term	Definition	Reference
Terrain	<p>Topography of the land.</p> <p>Level Terrain Is that condition where road sight distance, as governed by both horizontal and vertical restrictions, are generally long or could be made to be so without construction difficulty or major expense.</p> <p>Undulating Terrain Is that condition where road sight distance is occasionally governed by both horizontal and vertical restrictions with some construction difficulty and major expense but with only minor speed reduction.</p> <p>Rolling Terrain Is that condition where the natural slopes consistently rise above and fall below the road grade and where occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment. The steeper grades cause trucks to reduce speed below those of passenger cars.</p> <p>Mountainous Terrain Is that condition where longitudinal and transverse changes in the elevation of the ground with respect to the road are abrupt and where benching and side hill excavation are frequently required to obtain acceptable horizontal and vertical alignment. Mountainous terrain causes some trucks to operate at crawl speeds.</p>	(Austroads 2003)
Transition Curve	A curve of varying radius to model the path of a vehicle entering or leaving a horizontal circular curve.	(Austroads 2003)
Traffic Lane	A portion of the carriageway allocated for the use of a single line of vehicles.	(Austroads 2003)
Verge	That portion of the formation not covered by the carriageway or footpath.	(Austroads 2003)
Vertical Alignment	The longitudinal profile along the design line of a road.	(Austroads 2003)
Vertical Curve	A curve (generally parabolic) in the longitudinal profile of a carriageway to provide for a change of grade at a specified vertical acceleration.	(Austroads 2003)

1 INTRODUCTION

Earthwork volumes are one of the most important factors in the delivery of a major project. From a projects conception when senior executives need some context to the decisions they are making until volumes become a vital component of the contractual agreements between owners and contractors. It is essential that the volumes be accurately computed because disagreements related to earthwork volumes often cause the owner and the contractor to look to the courts for settlement (Said 2003).

MX(moss) road design software is a commonly used program for major highway projects. It is generally assumed that errors are contained within the road design software used to determine these volumes (Gardner 2006). This paper will undertake analysis the accuracy of earthworks volume calculations from MX(Moss) using the complex algorithms within the software and traditional volume calculation methods from a road profile of a known volume. The following simplified road profiles will be produced:

- Flat grade straight alignment;
- At grade straight alignment;
- Sag curve vertical alignment; and
- Crest curve vertical alignment.

These simplified road profiles will be mathematically calculated so analysis of the MX volumes calculations can be drawn and errors determined.

These simple profiles however don't allow for other elements such as superelevation and plan transitions, which add complexity to volume calculations. Road design theory will be presented so that the reader can understand the complexity of why volumes are a difficult area to manage within a design office.

The following technical and management issues will be discussed so a total project perspective is delivered in this paper:

- Basic road design;
- Introduction to MX;
- Basic Mathematics on volumes calculations;
- Specification for the models; and
- Need for different accuracies at different stages of the project;

Because of the importance of these volumes they have to be related within the context of contractual and project management requirements. These areas of expertise within a project require risk assessments and the volumes created from the design software is often one of the greatest risks for a project. A ten (10) percent error can sometimes result in millions of dollars of variations. Projects continue through a long process before errors in the accuracy of these volumes are determined, however high levels of the accuracy are not required at all stages of the project due to the decision making process.

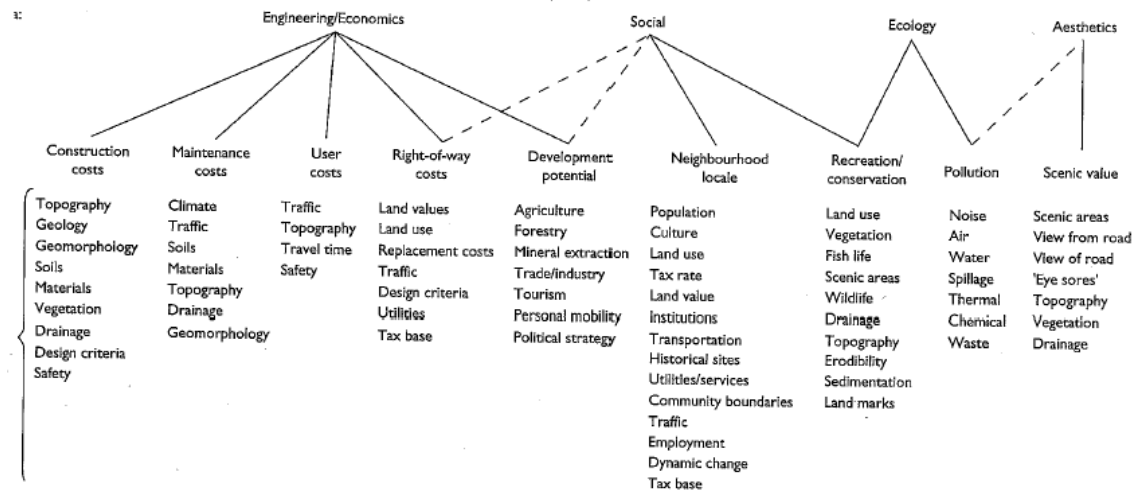
Recommendations will be related to project phases with generalised percentage errors. This reflects the process of senior executives and governments making 'go' or 'no go' decisions during early feasibility stages of a project where high levels of accuracy are not needed. The benefits of this paper will add senior executives and junior draft persons evaluate the risk and apply procedures, which assist in determining the appropriate volume calculations.

2 ROAD DESIGN BACKGROUND

2.1 Discussion

Many important geometric factors affect the earthwork volumes for a typical roadwork's project. Robinson & Thagesen (2004) show the factors which determine the selection of a road alignment and hence volumes. These factors are shown in Figure 2.1:1.

Figure 2.1:1: Factors Affecting Road Alignment Selection



(Source: Robinson & Thagesen 2004, p.238)

Ideally the coordination between the above factors shown in Figure 2.1:1 would result in the volume of material excavated within the limits of the road scheme being equal to the amount in embankments, so that there is no need to waste good on site material or import expensive off site material (O'Flaherty 2002). Balancing earthworks is a vital component in the environmental and economic design of a roadway. However safety factors outweigh any of the above constraints.

2.2 Operating Speed

The first design variable to be considered is the operating speed. 'Operating speed is a selected speed used to determine the various geometric design features of a

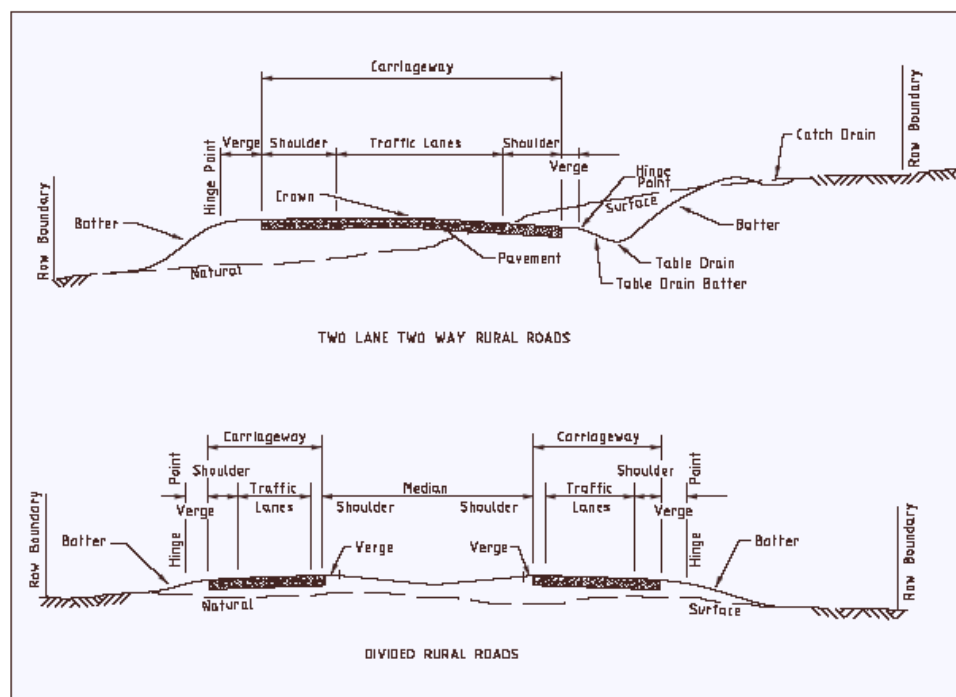
roadway, the assumed operating speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use and the functional classification of the highway' (AASHTO 2004a).

AASHTO (2004b) states that there is a strong link between the selection of the appropriate operating speed and the risk assessment for a particular project. Designers should strive to provide the least number of minimum radius curves. The adoption of a number of minimum elements may produce an overall unsafe design (Jordan & Barton 1992).

2.3 Typical Cross Section

A typical cross section for a normal two lane two-way rural road and divided rural road is shown below in Figure 2.3:1.

Figure 2.3:1: Elements of Cross Sections



(Source: Austroads 2003, p.60)

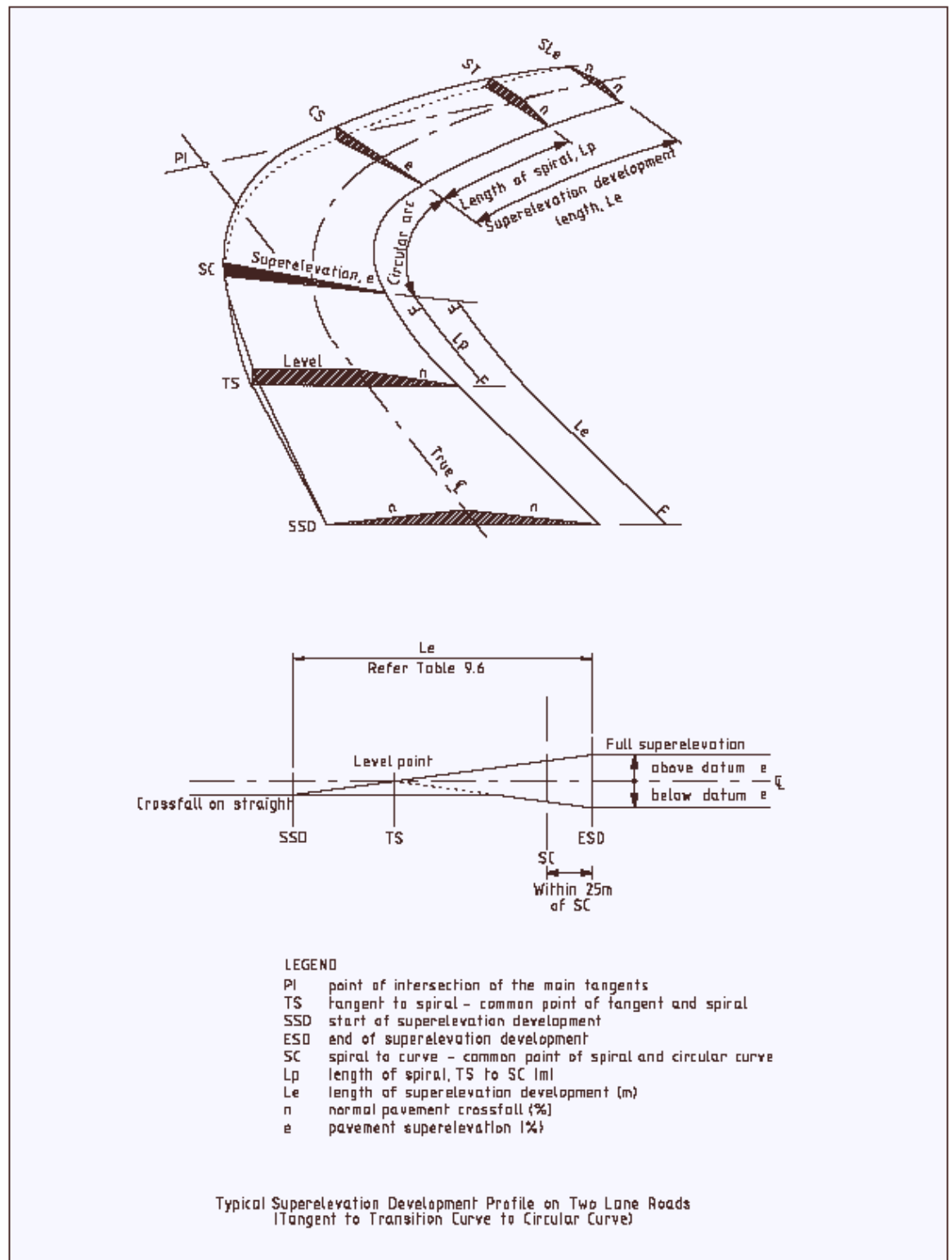
These sections show the typical transverse movement of material needed to construct a road. Again balancing these volumes is vital to effective management of the project.

2.4 Horizontal Design

The horizontal design of a road is a plan view and usually consists of a series of straights and circular curves (USQ 2005). A combination of elements such as curve radius, superelevation and plan transitions are used to assist the circular movement of a vehicle (RTA 1988). A typical curve with superelevation is shown in Figure 2.4:1.

The effects on superelevation will not be discussed in this paper due to the difficulties in producing an accurate mathematical model. However it is widely accepted by road designers that the end area method of volume analysis produces errors for superelevated sections because they are cut perpendicular to the control line (Robinson 2006). This style of cutting produces an overestimate on the inside of the curve and an underestimate on the outside. By inspection of Figure 2.4:1 it can be seen that greater volumes are on the outside of a superelevated curve. Thus an error is created when using end area for super elevated curves.

Figure 2.4:1: Typical Development of Super Elevation on Two Lane Roads



(Source: Austroads 2003, p.47)

Table 2.4:1 Horizontal Curve Design Parameters for Rural Roads

Curve Design Speed Km/h	Radius 1,2,3 m	Super - elevation	Friction coefficient	Desirable min. curve length
60	95	6	0.24	100
	113	5	0.20	100
	142	4	0.16	100
	189	3	0.12	100
70	94	10	0.31	180
	103	9	0.29	180
	116	8	0.25	140
	132	7	0.22	140
	154	6	0.19	140
	185	5	0.16	140
80	222	5	0.13	140
	232	4	0.13	140
	309	3	0.13	140
	140	10	0.26	240
	153	9	0.24	200
	172	8	0.21	200
90	196	7	0.19	200
	204	7	0.18	180
	230	6	0.16	180
	275	5	0.13	180
	300	5	0.12	180
	344	4	0.11	180
	440	4	0.07	180
	441	4	0.07	180
458	3	0.08	180	
100	213	10	0.20	230
	224	9	0.20	230
	252	8	0.17	230
	288	7	0.15	230
	336	6	0.13	230
	400	5	0.11	230
	440	5	0.09	230
	441	5	0.09	230
500	4	0.09	230	
671	3	0.07	230	
100	303	10	0.16	280
	315	9	0.16	280
	328	8	0.16	280
	375	7	0.14	280
	437	6	0.12	280
	441	6	0.12	280
	525	5	0.10	280
650	4	0.08	280	
875	3	0.06	280	

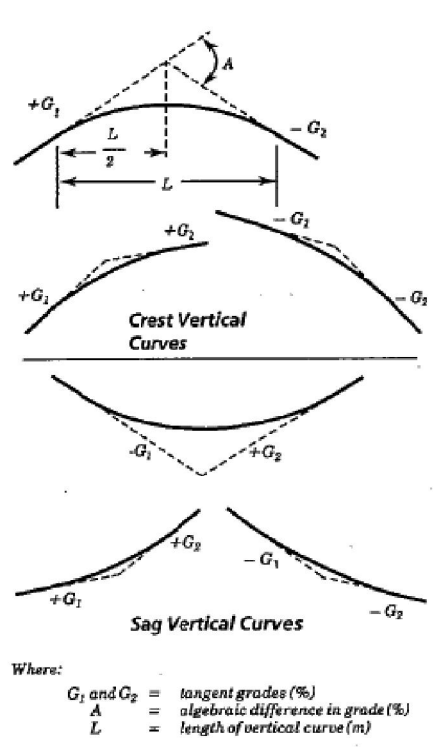
(Source: Adapted QDMR 2002, p. 10-11)

By inspection of Table 2.4:1, the road design process clearly involves the efficient coordination of a number of different variables to produce a safe result. All of which add greater complexity to the task of determining volumes.

2.5 Vertical Design

Another important feature in road design is the vertical geometry. This is the elevation of the control line of the horizontal alignment (RTA 1988). Many factors such as sight distance and bulk haulage influence the vertical design. RTA (1988) states that there are six possible variations of vertical curves. As shown in Figure 2.5:1.

Figure 2.5:1: Types of Vertical Curves



(Source: RTA 1988, p. 2-27)

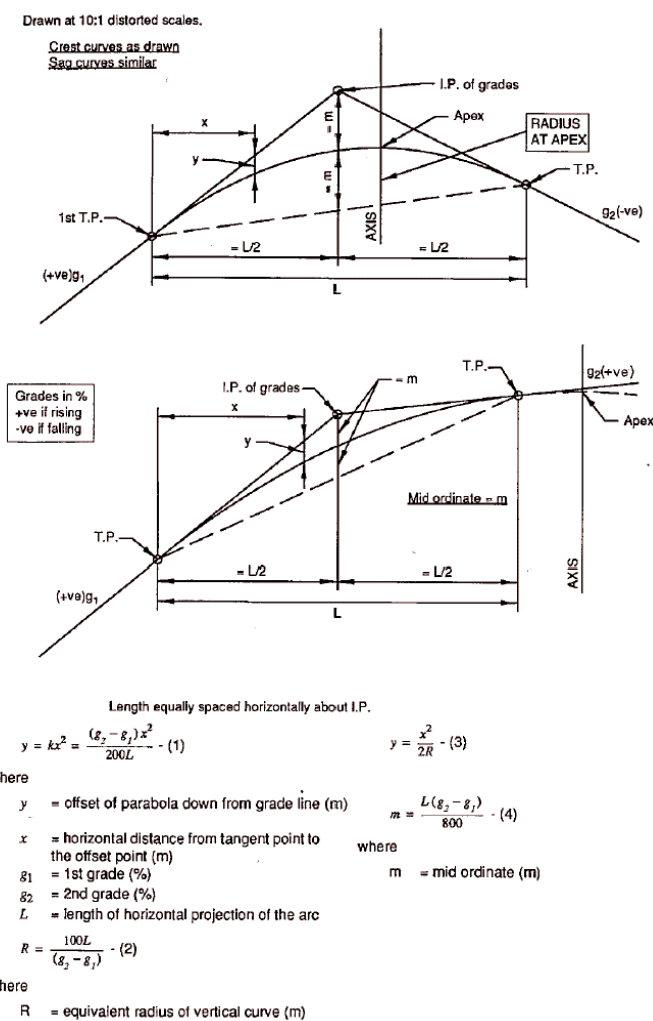
Figure 2.5:2 details the parameters, which include radius, length and grade difference and their correlation of a typical vertical curve. Traditional parabola's are used because of there simplicity, however polynomials may be used, which

have much more complex calculations (RTA 1988). Equation 1 below is used to calculate the design level; refer below (QDMR 2001):

$$Y = kx^2 \quad (1)$$

Where: Y = vertical offset;
 k = constant; and
 x = horizontal distance.

Figure 2.5:2: Typical Vertical Curve



(Source: QDMR 2002, p. 12-5)

Table 2.5:1 represents the design crest curve radii used at various speeds (QDMR 2001). For a particular design speed the required crest curve is usually governed by

the sight distance requirements (RTA 1988). Austroads (2003) recommends using a reaction time (Rt) of 2.5 seconds, which is the time between the driver’s reception of stimulus and taking appropriate action (QDMR 2001).

Table 2.5:1 Minimum Radius Crest Vertical Curves

Design Speed	Type C1 Restrictions To Visibility		
	$h_1 = 1.15m \quad h_2 = 0.2m$		
	Manoeuvre Sight Distance	Stopping Sight Distance	
	Rt = 2.0s	Rt = 2.5s	Rt = 2.0s
50	440		440
60	780		900
70	1200		1600
80	2000	2900	2400
90	3100	4200	3700
100	5200	6300	
110		9500	

(Source: QDMR 2001, p. 12.8)

Table 2.5:2 represents the design radius used for sag design curves at various speeds (QDMR 2001). On sag curves sight distance is not resisted unless overhead obstacles are present, for this reason headlight and comfort criteria become the governing constraints (RTA 1988).

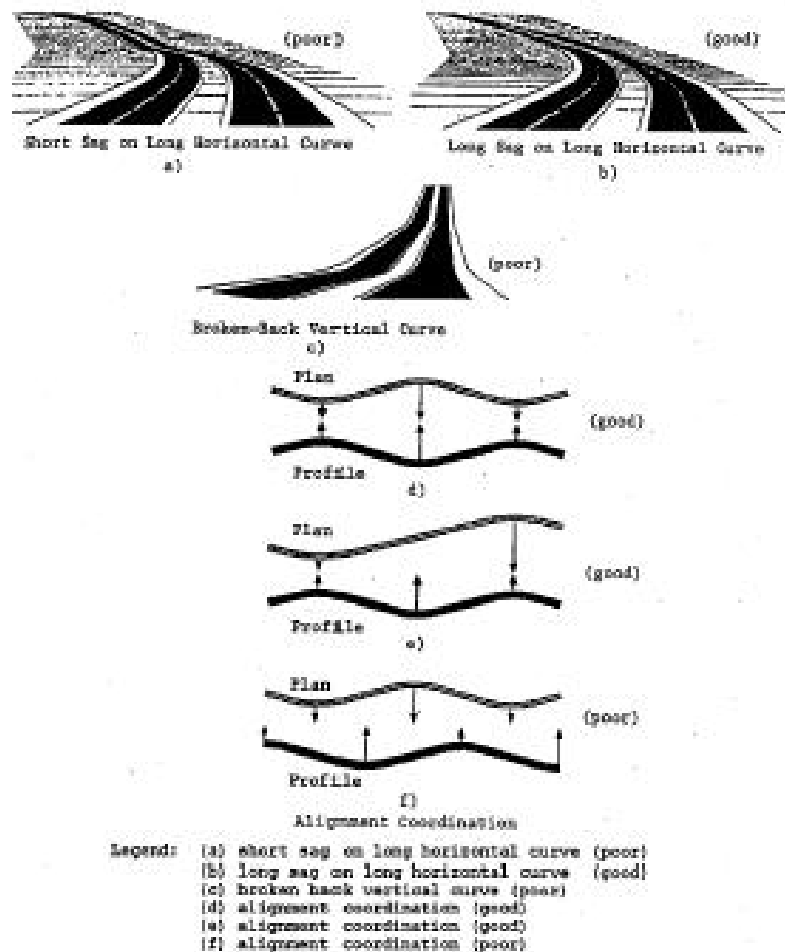
Table 2.5:2 Minimum Radius Sag Vertical Curves

Design Speed	Comfort Criteria		Type C1 Restrictions To Visibility		
	a = 0.05g	a = 0.1g	$h_1 = 1.15m \quad h_2 = 0.2m$		
			Manoeuvre Sight Distance	Stopping Sight Distance	
			Rt = 2.0s	Rt = 2.5s	Rt = 2.0s
50	390	200	660		660
60	570	280	1000		1100
70	770	390	1400		1600
80	1000	500	1900	2400	2100
90	1300	640	2500	3100	2800
100	1600	790	3500	3900	
110	1900	950		5000	
120	2300	1100		6100	
130	2700	1300		7500	

(Source: QDMR 2001, p. 12.9)

Vertical curves should be considered in conjunction with the horizontal alignment so that the design is coordinated (phased) properly (Austroads 2003).

Figure 2.5:3: Example of Poor and Good Road Geometry



(Source: Ruediger, Basil & Mailaender 1999, p. 16.17)

In coordination with minimum vertical curve, these considerations contribute to design solutions, which may produce large amounts of road works. These are factors of safety, which cannot be compromised.

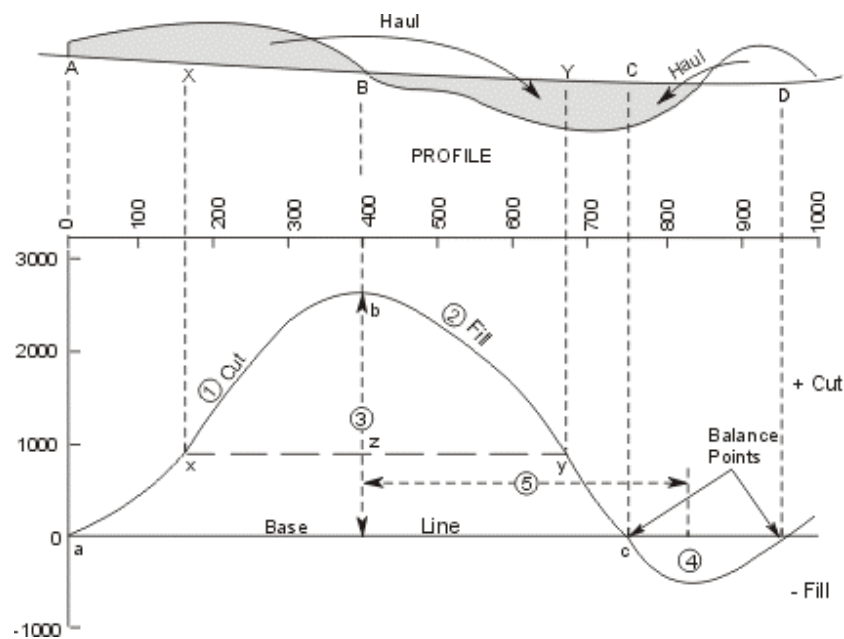
2.6 Mass Haul Diagrams

Effective longitudinal road design normally determined by balanced earthworks so that the project does not incur additional cost of carting excess material off site (Wright & Dixon 2004). For this reason longitudinal vertical alignments will consider the hauling of materials so that:

- Cartage is minimised; and
- Earthworks volumes are balanced.

The principal of mass haul is demonstrated in Figure 2.6:1.

Figure 2.6:1: Mass Haul Diagram



(Source: AASHTO 2000)

Moffitt & Bossler (1998) contend that effective mass haul design is essential for the optimisation of earthworks.

2.7 Stability of Slopes and Batters

Cut and fill batters are usually expressed in metres horizontal per metre vertical, for example four (4) to one (1) (Underwood 1995).

Typical batter slopes are shown in Table 2.7:1.

Table 2.7:1 Design Batter Slopes (without safety barriers)

CLASSIFICATION		CUT SLOPES			FILL SLOPES		
		Height	Desirable	Maximum	Height	Desirable	Maximum
ARTERIAL	RURAL DIVIDED	H < 3m	1 on 3	1 on 2	H < 3m	1 on 6	1 on 4
		H > 3m	1 on 2	1 on 1.5	H 3 - 12m	1 on 4	1 on 2 ⁽²⁾
					H > 12	1 on 2 ⁽²⁾	1 on 2 ⁽²⁾
			1 on 0.5	1 on 0.25	-	-	-
			1 on 6	1 on 2		-	-
			1 on 10	1 on 6		1 on 10	1 on 6
	RURAL UNDIVIDED	H < 3m	1 on 3	1 on 2	H < 3m	1 on 6	1 on 3
		H > 3m	1 on 2	1 on 1.5	H > 3m	1 on 4	1 on 4
			1 on 4	1 on 2		-	-
LOCAL							
		H < 3m	1 on 2	1 on 1/5 ⁽¹⁾	H < 3m	1 on 4	1 on 2
		H > 3m	1 on 2	1 on 1/5 ⁽¹⁾	H > 3m	1 on 4	-1 on 2 ⁽²⁾
			1 on 4	1 on 2		1 on 6	1 on 4

Notes:

(1) May be steeper in rock cut. Source: Ref. 99

(2) Batter with roadside safety barrier installed.

(3) A benched fill slope batter of 1 on 1.5 may be considered in specific cases.

(4) Batter slopes may vary depending on height and geotechnical reports.

(Source: Austroads 2003, p.47)

All typical values for batters should be confirmed by stability of slope calculations (AASHTO 2004). The geotechnical properties of the material being moved greatly effects the earthworks volumes because of these above design batters.

2.8 K Values

Austrroads (2003), RTA (1988) & VicRoads (1995) express vertical geometry curves using K values. RTA (1988) defines K as a measure of vertical curvature. Equation 2 shows the approximate relationship to the vertical radius (RTA 1988):

$$K = L/A \quad (2)$$

Where:

L = Length of vertical curve;

A = Algebraic difference of vertical grades percentage (%); and

K = Length of vertical curve (m) for 1 percent (%) change of grade
(m/unit %)

For design purposes the K value also has the advantage of easily determining the approximate radius of large parabolic vertical curves. Equation 3 is an approximation of K related to radius.

$$R = 100K \quad (3)$$

2.9 Summary

This section has been provided to summarise the basic constraints in a road design and set the scene on why they are a high-risk elements in a road design project. In particular the safety feature of maintaining high levels of sight distance while minimising earthworks can be an extremely difficult exercise in mountainous terrain. All the design constraints listed above can add greatly to the volume calculations of a road design. Now that this paper has identified design issues, which contribute to volume calculations, it is important to discuss the tools, which are used to produce these designs so that we understand how these take place.

3 INTRODUCTION TO MX(MOSS)

Bentley, which markets MX describes its product as below:

'MXROAD is an advanced, string-based modelling tool that enables the rapid and accurate design of all road types. With MXROAD, you can quickly create design alternatives to build the "ideal" road system. After a final design alternative is selected, you can automate much of the design detailing process, saving time and money. Intersection design, along with other functionality in MXROAD, is string-model based. This allows you to dynamically re-grade intersections as needed. Problem areas can be resolved during the design phase rather than incurring the high cost of rework onsite.'

MX differentiates itself from other popular design programs by being a string-based program instead of a template-based program.

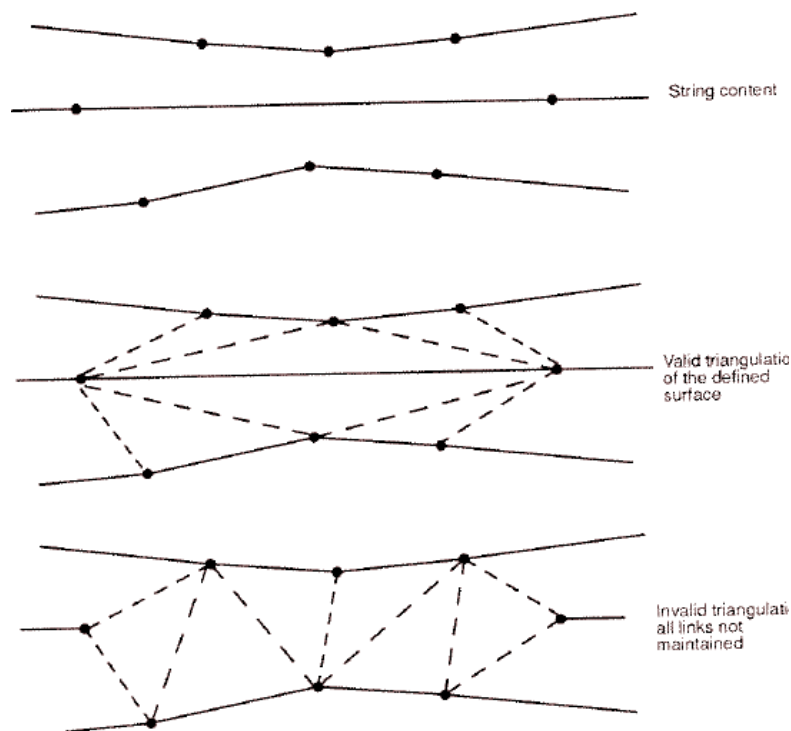
3.1 Terminology

Term	Definition	Reference
String:	A string is a sequential series of liked points defining a feature or surface.	QDMR 2001
Alignment String	A alignment string is the basic horizontal and vertical position of a design	QDMR 2001
Interface	An interface is where steps projected from one surface intersect another surface.	QDMR 2001
Model	<i>A model is a unit of data, used to separate and store string or tin (triangular irregular network) information into components within a project and is defined by a unique name usually reflecting the nature of the information it contains. Data is organised into models according to the physical features represented, for example strings defining an existing terrain surface or a design surface.</i>	QDMR 2001

3.2 Digital Terrain Model (DTM)

The first stage in the electronic design model process of is the input of a survey of the site. A total station normally undertakes this survey. The existing terrain triangulation model is normally taken from this model using the triangulation features of MX(moss) (QDMR 2002). Design volume areas clearly are related to a DTM in which they interface. Clearly this DTM may have errors. A common error with any electronic triangulation is when the survey data does not define strings in a manner in which the triangulation algorithm can make appropriate discussions. Bentley (2006) demonstrates this point in Figure 3.2:1, showing two different triangulations from the same set of points. This type of error has significant affect on roadwork's volumes. This point is important to identify, however beyond the scope of this paper. Effective design office practice should have an effective checking of the existing survey DTM, prior to any design work.

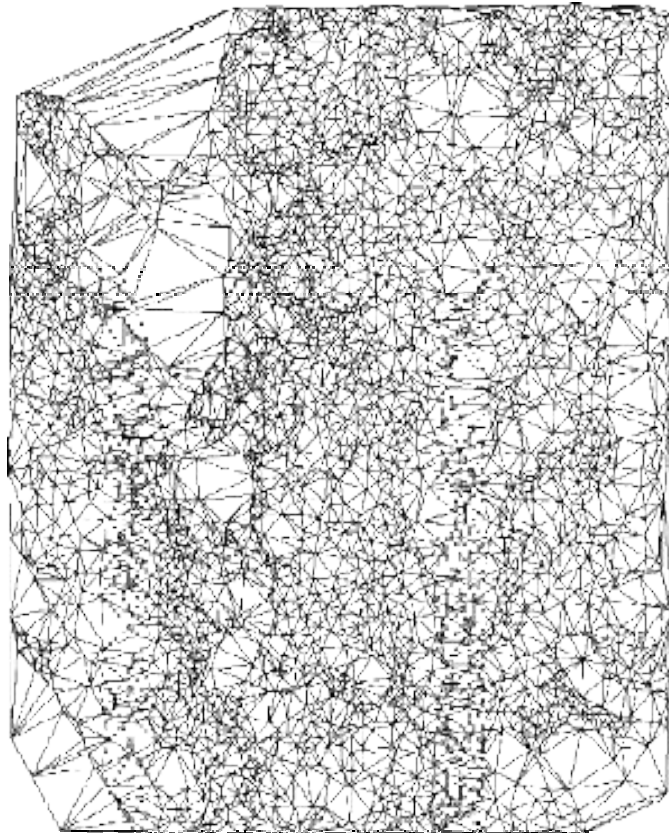
Figure 3.2:1: Triangulation and String Links



(Source: Bentley 2006)

An example of an effective triangulation using spot levels is given in Figure 3.2:2.

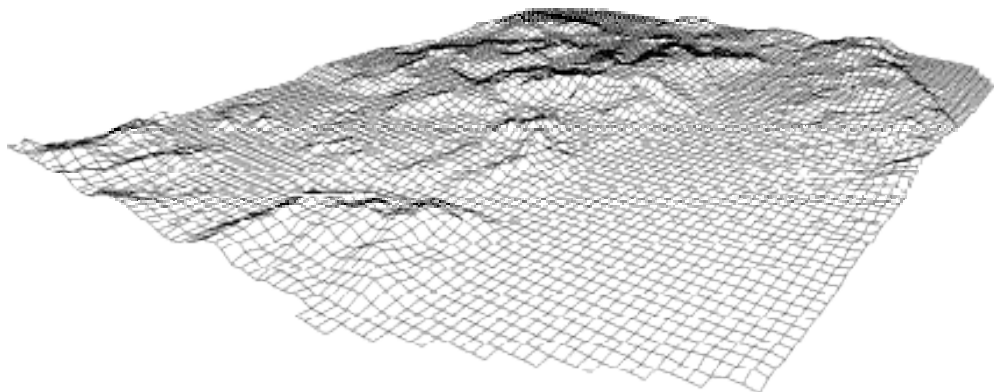
Figure 3.2:2: Sample Result of Triangulation from Spot Levels



(Source: Swinburne University 2006)

A perspective view of a triangulation is shown below in Figure 3.2:3.

Figure 3.2:3: Sample results of Triangulation From Spot Levels, Perspective



(Source: Swinburne University 2006)

Bentley (2006) contention is that errors occur in the DTM due to the following reasons:

- *Intersecting string links. Both links are maintained by adding the intersection point to the triangulation. If the Z value at the intersection on one link is different to that on the other link, the first encountered Z value is taken;*
- *Duplicate point - different Z values. The second point is replaced by the original point and all links are maintained; and*
- *Duplicate link. This is a special case of duplicate points and the first link encountered is accepted.*

If the extent of survey has not been correctly errors may occur when the design model extends beyond the survey model limits (Robinson 2006). It is norm that the triangulations at the edge of a survey are not a correct.

3.3 MX Volumetric Analysis

MX(moss) has a quick volumetric analysis, which is a build in function of MX(moss). The reference material states that it should be consider a quick method of volume analysis. It uses the difference in models from sting point levels. This function will be included in this papers analysis.

3.4 Isopachyte Analysis

Bentley (2006) states that isopachyte analysis is an important extension to the theory of representing surfaces by a triangular mosaic. Rather than triangulating one surface only and then contouring it, two surfaces (that is, two models) may be independently triangulated and the differences between them derived. The differences may themselves be analysed, with the result that the interface between two surfaces and also volumes may be accurately assessed. The technique is particularly appropriate for spoil heap analysis, open cast mining, or interchange design, where traditional sectioning techniques are less

accurate. The method used to automatically produce isopachs relies on the triangulation of each surface to ensure all the surface features are considered. Two methods exist for the creation of an isopachyte triangulation.

The generation of isopachs using full analysis employs the following steps:

1. Both models are triangulated. Each vertex on the first triangulation is compared with the second triangulation to obtain a Z value difference.
2. Each vertex on the second triangulation is compared with the first triangulation to obtain a Z value difference.
3. Points of intersection between the triangulations are also considered. Both sets of Z value difference strings are combined and triangulated. This ensures that all angular features from both models are included in the analysis.
4. Isopach contours or volume calculations may then be produced. This method is very accurate but time-consuming for larger models.
5. Volumes calculated by Prism when using both the full and quick isopachyte analysis methods yield the following approximate errors in the simple isopachyte technique:

Cut 1.7%

Fill 0.3%

The comparison uses the following test data:

	<i>Full isopachyte analysis</i>	<i>Quick analysis</i>
<i>Calculated points</i>	32317	7791
<i>Calculated triangles</i>	26300	13354
<i>Model file records required</i>	2630	1336
<i>Approximate disk space required</i>	5.3 Mbytes	2.7 Mbytes

Triangulation model 1 contained 1949 points. Triangulation model 2 contained 1556 points.

The results demonstrate that the quick isopachyte analysis provides a solution within a reasonable band of error, with less demanding model file overheads.

Isopachyte triangulation of major design projects requires the creation of boundary models so that volumes of different separate portions can be determined.

3.5 Delaunay Triangulation

The triangulating algorithm used by MX(moss) utilises the principal of Delaunay triangulation.

University of California (2006) define Delaunay triangulation as:

The Delaunay triangulation of a point set is a collection of edges satisfying an "empty circle" property: for each edge we can find a circle containing the edge's endpoints but not containing any other points. These diagrams their and their duals (Voronoi diagrams and medial axes)) have been reinvented, given different names, generalized, studied, and applied many times over in many different fields. The Delaunay triangulation is also closely related by the so-called "lifting transformation" to convex hulls in one higher dimension. Many common methods for function interpolation and mesh generation are based in some way on Delaunay triangulations, but there are also many other ways in which this structure has been applied.

Considering that for any 'given a set of points, there are usually a vast number of triangulations possible' (Florida State University 2006). A consistent triangulation algorithm is vital. Chen (2004) contends that an optimal Delaunay Triangulation is one that minimises the interpolation error among all triangulations with the same number of vertices.

Significant data has been written about Delaunay Triangulation and this paper no intention to further investigate this method, however some knowledge of how

MX(moss) algorithm produces this triangulation is important. As stated by Chen (2004) Delaunay Triangulation is an optimal triangulation for linear approximation with fixed grid points. Other roadwork's design software do not use a Delaunay Triangulation algorithm.

3.6 Input Files: Linemode

Input files are used by MX to generate the design (QDMR 2002). These have a file extension of .inp and are used by designers to back up works. Linemode is a powerful tool, which enables multiple designers to work on the same project. GENIO files are also used to back up MX design and are also the specified file format for transfer of the design model for survey setout (QDMR 2002).

'The MX(moss) command language is called Linemode. Using Linemode, you can perform all of the functions on a model that you can through the user interface. The commands can be typed in and actioned immediately, grouped together and actioned, or saved in an input file for processing later' (Bentley 2006). 'Major options perform operations on models, files and drawings. They also define the models to be operated on by subsequent minor options' (Bentley 2006). 'Minor options are numeric and perform operations on strings and points. Command macros consist of a combination of major and/or minor options, with values assigned to variables at run time (Bentley 2006)'. An example of linemode coding requirements is shown in Figure 3.6:1.

Figure 3.6:1: Sample Linemode Coding

Bentley MX 2004 Edition

Show Back Forward Home Print Options

Linemode Reference

100 Add string: constant H / constant C

Option 100 creates, extends or amends part of a string between normals erected horizontally from a **reference string**. At the same time, you can apply a constant vertical crossfall. The horizontal offset applied is constant along the length of the string.

The crossfall is calculated along the normal to the reference string.

Syntax

Minor option 100

Field 1* Reference string.

Field 2 **Subsidiary string** (optional)

Field 3* New, extended or amended string.

Field 4 Crossfall to be applied with respect to the subsidiary string (reference string by default).
If zero is coded the resultant level of the new string will be the same as the subsidiary string; if the field is left blank the levels will be set to -999.0

Field 5 & 6 **SPRD** start.

Field 7* Constant horizontal offset to be applied.

Field 8 & 9 **SPRD** end.

Example

To generate inner and outer channels from a master alignment:

```
DESIGN,NEW THORNBROUGH
GENERATE INNER AND OUTER CHANNELS FROM MASTER ALIGNMENT
100,MAST,,ICL1,5=0.0,7=-2,100.0
102,MAST,,ICL1,5=100.0,7=-2,200.0,10=-6.0
100,MAST,ICL1,0CL1,5=0.0,,,-6.0,220.0
999
```

Linemode Reference: DESIGN: 100 Add string: constant H / constant C

<Major> <Minor>

Bentley MX 2004 Edition

Show Back Forward Home Print Options

Linemode Reference

```
100,MAST,,ICL1,5=0.0,7=-2,100.0
102,MAST,,ICL1,5=100.0,7=-2,200.0,10=-6.0
100,MAST,ICL1,0CL1,5=0.0,,,-6.0,220.0
999
```

To generate an outer channel from an inner channel:

```
DESIGN,NEW THORNBROUGH
GENERATE OUTER CHANNEL FROM INNER CHANNEL
100,ICL1,,OCL1,5=250.0,300.0,-6.0,280.0,0,305.0
999
```

Note that the strings OCL1 generated in the above examples are not the same. In the first case the offset is normal to the master alignment MAST, but in the second case the offset is normal to ICL1.

It is possible in the case of linear and reverse curve offsetting for the resultant string to cross the **reference string**. If this occurs, the sign of the crossfall is changed once the crossover occurs. See the diagram below.

Linemode Reference: DESIGN: 100 Add string: constant H / constant C

<Major> <Minor>

(Source: Bentley 2006)

3.7 Design String Attributes

A design models consists of many different strings. The process of road design the electronic design model has three different types of strings, which include the elements shown in Table 3.7:1.

Table 3.7:1 Design String Point Attributes

Attribute	Description	Design String Type		
		Alignment String	Feature Design String with Curves	All other Feature Design Strings
1	X coordinate	Y	Y	Y
2	Y coordinate	Y	Y	Y
3	Z coordinate	Y	Y	Y
4	Chainage	Y	Y	
5	Bearing	Y	Y	
6	Radius	Y	Y	
7	Vertical Grade	Y		
8	Vertical M Value	Y		
9	Horizontal Tangent Point Code	Y		
10	Vertical Tangent Point Code	Y		
11	Horizontal Element Name	Y		
12	Vertical Element Name	Y		

(Source: QDMR 2002, p. 18-24)

QDMR (2002) has specified the string requirements of Table 3.7:1 as the minimum attributes needed for contractors to define the geometric requirements of the road.

The mathematics of roadwork volumes will be discussed in the next section.

4 MATHEMATICS ON VOLUMES

4.1 Basic Volumes

Hughes-Hallett et al. (1998) state that the volume of a rectangle is a function of $f(xyz)$.

Equations used for volumes of rectangles and triangles are shown below.

$$\text{Rectangle volume} = x * y * z \quad (4)$$

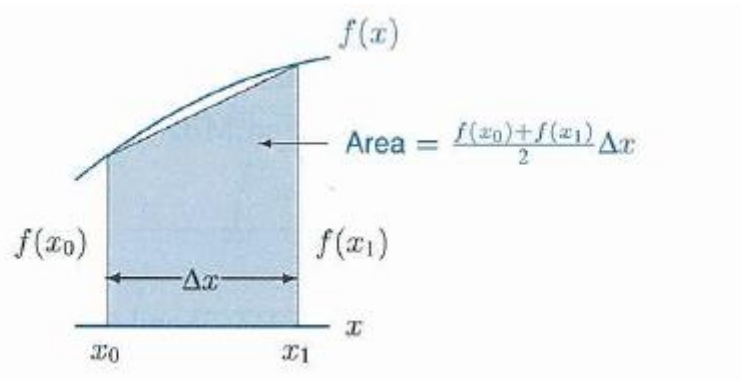
$$\text{Triangle volume} = \frac{1}{2} (x * y * z) \quad (5)$$

4.2 The Trapezoid Rule

Hughes-Hallett et al. (1998) demonstrate the process of end area volumes calculations by using the Trapezoid Rule. The Trapezoid Rule averages the values of a function f at the left and right endpoints (these will be design levels on the road profile) and taking an average, refer Figure 4.2:1 (Hughes-Hallett et al. 1998). This approximation is called the Trapezoid Rule (Hughes-Hallett et al. 1998, p.346):

$$\text{TRAP}(n) = (\text{LEFT}(n) + \text{RIGHT}(n)/2) \quad (6)$$

Figure 4.2:1: Area Used by the Trapezoid Rule



(Source: Hughes-Hallett et al. 1998, p. 346).

'The standard method of calculating earthwork volumes for road works has been the end area method, it's main appeal has been it's simplicity' (ISAUST 2006), and is expressed as follows:

$$\text{Volume} = (\text{End area 1} + \text{End area 2})/2 * \text{Length} \quad (7)$$

The end area method described by Said (2003) is clearly the trapezoid rule times by the length of road section interval (Δx).

Hughes-Hallett et al. (1998) states that the Trapezoid Rule produces an overestimate and underestimate depending on the curve function. These errors are demonstrated below in Figure 4.2:2.

Figure 4.2:2: Error in the Trapezoid Rule

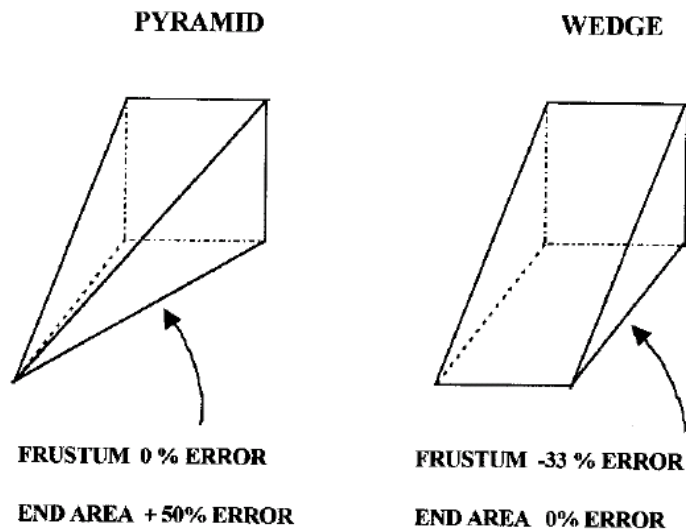


(Source: Hughes-Hallett et al. 1998, p. 347).

Hughes-Hallett et al. (1998) further states that as the step size is reduced the error is reduced. This paper will analyse this theory by producing end area calculations using smaller section intervals of cross sections.

The road design process can produce a number of different shapes. In extreme situations frustum pyramid triangles can be created, refer Figure 4.2:3. Sprott (2001) states that end area calculations can produce a fifty (50) percent error. The mathematical volume of a frustum pyramid will be discussed in the next section.

Figure 4.2:3: Error in the Volumes



$$\text{FRUSTUM VOLUME} = \frac{(A1 + \sqrt{A1 \cdot A2} + A2) \cdot \text{LENGTH}}{3}$$

(Has been around since 1890 BC. Rigorous for end areas that are similar. Contours are approximately similar. In general underestimates Volumes.)

$$\text{END AREA VOLUME} = \frac{(A1 + A2) \cdot \text{LENGTH}}{2}$$

(In general overestimates Volumes.)

(Source: Sprott 2001).

4.3 Volume of a Frustum Pyramid

A pyramidal frustum is a frustum made by cutting the top off a pyramid. It is a special case of a prismatoid. Equation 8 the expression shown in Figure 4.2:3, which is shown below.

$$\text{Volume Frustum Pyramid} = \frac{(A1 + \text{SORT}(A1 \cdot A2) + A2)}{3} \quad (8)$$

4.4 Summary

This section has defined the mathematical parameters for the analysis of the simplified road profiles, which will be defined in the next section.

5 MODELS

5.1 Discussion

The purpose of this section is to determine the requirements for the models to be volumed. As discussed in Section 2, normal road geometry includes horizontal curves and straights and vertical crest and sag curves. All these elements add complexity to the task of determining volumes. This paper will look at the following simple road geometry profiles adding complexity as we go:

- Flat grade straight alignment;
- At grade straight alignment;
- Sag curve vertical alignment; and
- Crest curve vertical alignment.

5.2 Model Specifications

The original project specification the model proposed to use a simple rectangular shape, which could easily be constructed and manually volumed. Later consideration was given to the errors, which occur because of the geometry, in particular the effect on the error from vertical and sag curves.

Initial MX modelling had vertical walls so the mathematical model can be determined easily. However as discussed previously, MX has trouble interpreting different Z values with the same location. Clearly MX cannot pick, which level is appropriate to determine the appropriate section and a fifty (50) percent error is calculated.

To alleviate these problem simple batters included into the simulation road model. By including these one (1) horizontal to one (1) vertical batter the interpretation error was eliminated. This enables MX to successfully identify strings from left to right and produce an accurate cross section, which could be volumed.

5.3 Operating Speed

First stage in preparation of a simulation model was determining the design speed. This is a process that a road designer would undertake in a project, making design decisions between eighty (80) to one hundred (100) kilometre design speeds. In this paper, an eighty kilometre operating speed was adopted.

5.4 Matlab

With the aid of Matlab, a mathematical program has been written so that the volumes of the various simulated models can be determined. The program code is shown in Appendix C: Matlab Script: Volume Analysis. The following sections will show the outputs from this program, which will later be analysed against the MX volumes calculations.

5.5 Flat Grade Straight Alignment

5.5.1 Flat Grade Model

The specification for the flat grade simulation model is shown in Appendix B: Model Profiles.

5.5.2 Mathematical Volume: Flat Grade

The volume output from Matlab is shown below in Table 5.5:1.

Table 5.5:1 Volume Output Matlab Flat Grade

This program forms part of the engineering report into the accuracy of volume calculation from MX. This program is calculates the mathematical volume of the simulated profile so further analysis can be undertaken in MX.

Two types of profiles are common, the use must make a choice of which profile is to be simulated

For Flat Alignment enter '1'

For At Grade enter '2'

For Sag Curves enter '3'

For Crest Curves enter '4'

1

Base (m) =1000

Vertical (m) =10

Width(m) =20

VOL =

300000

The mathematical volume of the flat grade alignment is 300,000.00m³.

5.6 At Grade Straight Alignment

5.6.1 At Grade Model

The specifications for the at grade simulation model is shown in Appendix B: Model Profiles.

5.6.2 Mathematical Volume: At Grade

The volume output from Matlab is shown below in Table 5.6:1.

Table 5.6:1 Volume Output Matlab At Grade

```

This program forms part of the engineering report into
the accuracy of volume calculation from MX. This program is calculates the
mathematical volume
of the simulated profile so further analysis can be undertaken in MX.

Two types of profiles are common, the use must make a choice of which profile is to be
simulated
For Flat Alignment enter '1'
For At Grade      enter '2'
For Sag Curves   enter '3'
For Crest Curves enter '4'
2
Base 1(m)      =1000
Vertical 1(m)  =0
Vertical 2(m)  =50
Width(m)       =20
VOL =
  1.3333e+006
>>

```

The mathematical volume of the at grade alignment is 1,333,333.33m³.

5.7 Crest Curve

5.7.1 Crest Curve Model

Table 2.5:1 shows the design value of an eighty (80) kilometre design crest, with a 2.5 sec reaction time is a 2,900 metre radius.

The profile for the crest curve simulation model is shown in Appendix B: Model Profiles.

5.7.2 Mathematical Volume: Crest Curve

The volume output from this program is shown below in Table 5.7:1.

Table 5.7:1 Volume Output Matlab Crest Curve

This program forms part of the engineering report into the accuracy of volume calculation from MX. This program is calculates the mathematical volume of the simulated profile so further analysis can be undertaken in MX.	
Two types of profiles are common, the use must make a choice of which profile is to be simulated	
For Sag Curves	enter '1'
For Crest Curves	enter '2'
2	
Base 1(m)Crest	=100
Base 2(m)Crest	=462.53
Base 3(m)Crest	=100
Vertical 1(m)Crest	=20
Vertical 2(m)Crest	=28
Vertical 3(m)Crest	=28
Vertical 4(m)Crest	=20
Width(m)Crest	=20
rad(m)Crest	=2900
alpha(deg)Crest	=9.14784
VOL	= 1052477.806

The mathematical volume of the crest curve is 1052477.806m³.

5.8 Sag Curve

5.8.1 Sag Curve Model

Table 2.5:2 show the design value of eighty (80) kilometre design sag, with a 2.5 sec reaction time is a 2400 metre radius.

The specification for the sag curve simulation model is shown in Appendix B: Model Profiles.

5.8.2 Mathematical Volume: Sag Curve

Table 5.8:1 Volume Output Matlab Sag Curve

This program forms part of the engineering report into the accuracy of volume calculation from MX. This program is calculates the mathematical volume of the simulated profile so further analysis can be undertaken in MX.

Two types of profiles are common, the use must make a choice of which profile is to be simulated
 For Sag Curves enter '1'
 For Crest Curves enter '2'
 2
 Base 1(m)Crest =100
 Base 2(m)Crest =462.52
 Base 3(m)Crest =100
 Vertical 1(m)Crest =20
 Vertical 2(m)Crest =28
 Vertical 3(m)Crest =28
 Vertical 4(m)Crest =20
 Width(m)Crest =20
 rad(m)Crest =2900
 alpha(deg)Crest =9.14784

VOL =
 298495.261

The mathematical volume of the crest curve is 298495.261m³.

5.9 Summary

Calculated volumes to the models shown in Appendix B: Model Profiles are shown below in Table 5.9:1.

Table 5.9:1 Mathimatical Model Volumes Summary

Model	Volume m ³
Flat straight alignment	300000.000
At grade Alignment	1333333.33
Crest Curve	1052477.806
Sag Curve	298495.261

The next section will model and volume the above models in MX(moss).

6 MX MODEL

6.1 Model specifications

This section will discuss the production and volume the profiles shown in Appendix B: Model Profiles. This will be done using linemode design methods.

Applying this theory to the end area calculations presented in Section 4, this paper will cut sections at five (5), ten (10) and twenty (20) metre intervals. The expected result is that the smaller interval will shift the volume output closer towards the mathematical value.

6.2 Ground Triangulation

For simplify this paper will triangulate a flat plat to represent the survey DTM. The DTM was created in AutoCAD creating a twenty (20) x twenty (20) metre grid of node points. As discussed previously a real life situation may have errors in the survey DTM translate to errors in volume calculations.

6.3 MX Model: Flat Straight Alignment

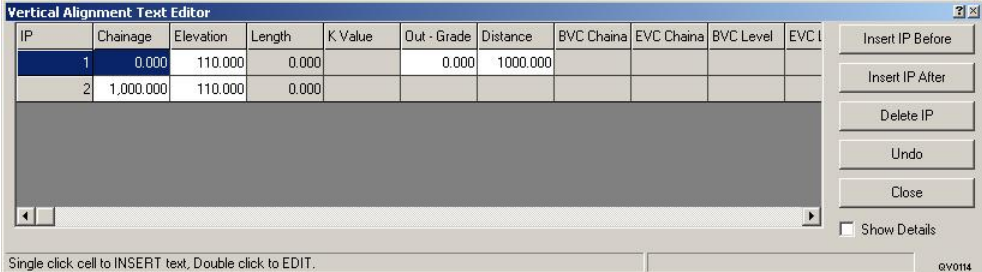
6.3.1 Flat Grade MX Model

MX linemode coding for the flat grade straight alignment model is shown in Appendix E: MX Linemode Alignments.

6.3.2 Flat Grade MX Model: Vertical

Vertical geometry for this model is shown below in Figure 6.3:1.

Figure 6.3:1: MX Flat Straight Alignment Data



IP	Chainage	Elevation	Length	K Value	Out - Grade	Distance	BVC Chaina	EVC Chaina	BVC Level	EVC L
1	0.000	110.000	0.000		0.000	1000.000				
2	1,000.000	110.000	0.000							

Vertical Alignment Text Editor

Buttons: Insert IP Before, Insert IP After, Delete IP, Undo, Close, Show Details

Single click: cell to INSERT text, Double click to EDIT.

GV0114

Note: the natural surface level is set to reduced level 100m; this profile has been modelled with a longitudinal reduced level of 110m, 10m above natural surface.

6.3.3 Flat Grade MX Model: End Area

End area volume calculations at five (5), ten (10) and twenty (20) intervals are shown in Table 6.3:1, Table 6.3:2 & Table 6.3:3. A linemode script for these end area calculations can be viewed in Appendix F: MX Linemode Code End Area Calculations.

Table 6.3:1 MX Volume Output 20m Intervals, Flat Grade

```

MX Software for infrastructure design   Licensed to :
DATE : 20FEB06  TIME : 08:54:49

VOLU  SECT FLAT          DESIGN FLAT
051           1              1
001VOLUME FLAT
056MCF0X  D              0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  51
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  51

-CHAINAGE-      ----SECTIONAL AREAS----      -INTERMEDIATE VOLUMES-      -
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-      ---CUT---  ---FILL---      ---CUT---  ---FILL---  ---CUT---  ---
FILL---

      0.000      0.000  -300.000              0.000      0.000
              0.000  -6000.000
      20.000      0.000  -300.000              0.000  -6000.000
              0.000  -6000.000
BALANCE REMOVED
              0.000  -6000.000
      980.000      0.000  -300.000              0.000  -294000.000
              0.000  -6000.000
      1000.000      0.000  -300.000              0.000  -300000.000

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  51
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  51

START CHAINAGE   :      0.000
END CHAINAGE     :     1000.000

LENGTH OF SECTION :     1000.000

CUT VOLUME       :      0.000
FILL VOLUME    :    -300000.000
TOPSOIL VOLUME   :      0.000
999
OUTP
    
```

Table 6.3:2 MX Volume Output 10m Interval, Flat Grade

```

MX Software for infrastructure design   Licensed to :
DATE : 20FEB06  TIME : 08:54:41

VOLU  SECT FLAT          DESIGN FLAT
051           1              1
001VOLUME FLAT
056MCF0X  D              0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 101

-CHAINAGE-      ----SECTIONAL AREAS----      -INTERMEDIATE VOLUMES-      -
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-      ---CUT---  ---FILL---      ---CUT---  ---FILL---      ---CUT---  ---
FILL---

      0.000      0.000  -300.000              0.000  0.000
              0.000  -3000.000
      10.000      0.000  -300.000              0.000  -3000.000
              0.000  -3000.000

BALANCE REMOVED

              0.000  -3000.000
      990.000      0.000  -300.000              0.000  -297000.000
              0.000  -3000.000
      1000.000      0.000  -300.000              0.000  -300000.000

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 101

START CHAINAGE   :    0.000
END CHAINAGE     :   1000.000

LENGTH OF SECTION :    1000.000

CUT VOLUME       :    0.000
FILL VOLUME    : -300000.000
TOPSOIL VOLUME   :    0.000

999

OUTP
    
```


Table 6.3:3 MX Volume Output 5m Interval, Flat Grade

```

MX Software for infrastructure design   Licensed to :
DATE : 20FEB06  TIME : 08:54:58

VOLU  SECT FLAT          DESIGN FLAT
051           1              1
001VOLUME FLAT
056MCF0X  D              0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 201
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 201

-CHAINAGE-      ----SECTIONAL AREAS----  -INTERMEDIATE VOLUMES-  -
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-      ---CUT---  ---FILL---      ---CUT---  ---FILL---  ---CUT---  ---
FILL---

      0.000      0.000  -300.000              0.000      0.000
              0.000  -1500.000
      5.000      0.000  -300.000              0.000  -1500.000
              0.000  -1500.000
BALANCE REMOVED
              0.000  -1500.000
      995.000      0.000  -300.000              0.000  -298500.000
              0.000  -1500.000
      1000.000      0.000  -300.000              0.000  -300000.000

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 201
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 201

START CHAINAGE   :    0.000
END CHAINAGE     :   1000.000

LENGTH OF SECTION :    1000.000

CUT VOLUME       :    0.000
FILL VOLUME    : -300000.000
TOPSOIL VOLUME   :    0.000

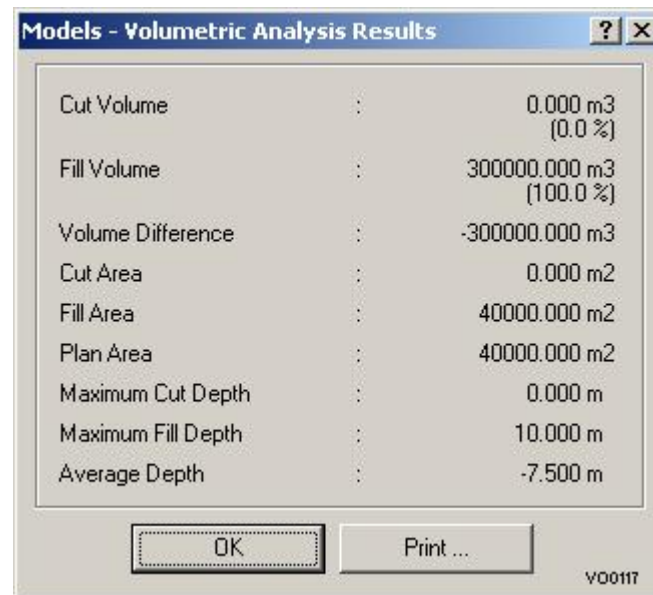
999

OUTP
    
```

6.3.4 Flat Grade MX Model: Volumetric Analysis

Initial volumetric using quick MX Model volumetric analysis yields the following output shown in Figure 6.4:2 for the flat alignment.

Figure 6.3:2: MX Volumetric Analysis: Flat Grade



The Model volumetric analysis Volume fore the Flat Grade is 300000m³.

6.3.5 Flat Grade MX Model: Isopachyte Analysis

Isopachyte volume calculations using the linemode script shown below in Appendix G: MX Linemode Code End Isopachyte Analysis.

Volume output for the isopachyte analysis is shown Table 6.3:4.

Table 6.3:4 MX Output: Isopachyte Analysis Flat Grade

MX Software for infrastructure design Licensed to :	
Version - 20358	GHD Pty Ltd - Brisbane
DATE : 25FEB06 TIME : 09:01:46	
PRISM VOL TRIA	DESIGN FLAT
911TI00	
THE TRUE VOLUMETRIC DIFFERENCE BETWEEN THE TWO SURFACES	
CUT VOLUME =	0.000 (CU. M.)
FILL VOLUME =	300000.000 (CU. M.)
912TI00	
OUTPU	

Isopachyte volume analysis 300,000.000 m3.

6.4 MX Model: At Grade Straight Alignment

6.4.1 At Grade MX Model

MX linemode coding for the at grade straight alignment model is shown in Appendix E: MX Linemode Alignments.

6.4.2 At Grade MX Model: Vertical

Data input for the at grade design is shown below in Figure 6.4:1.

Figure 6.4:1: MX At Grade Straight Alignment Data

IP	Chainage	Elevation	Length	K Value	Out - Grade	Distance	BVC Chaina	EVC Chaina	BVC Level	EVC L
1	0.000	110.000	0.000		5.000	1000.000				
2	1,000.000	160.000	0.000							

6.4.3 At Grade MX Model: End Area

End area volume calculations at five (5), ten (10) and twenty (20) intervals are shown in Table 6.4:1, Table 6.4:2 & Table 6.4:3. A linemode script for these end area calculations can be viewed in Appendix F: MX Linemode Code End Area Calculations.

Table 6.4:1 MX Volume Output 20m Interval, At Grade

MX Software for infrastructure design Licensed to :							
Version - 20358				GHD Pty Ltd - Brisbane			
DATE : 23FEB06 TIME : 08:34:29							
VOLU	SECT	ATGRADE		DESIGN	ATGRADE		
051		1		1			
001 VOLUME AT GRADE							
056MCAOX	D			0.0			
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 51							
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 51							
-CHAINAGE-		---SECTIONAL AREAS---		-INTERMEDIATE VOLUMES-		-	
ACCUMULATIVE VOLUMES-							
		(SQ. M.)		(CU. M.)		(CU. M.)	
-DISTANCE-	---	CUT---	---	FILL---	---	CUT---	---
FILL---							
0.000	0.000	0.000				0.000	0.000
			0.000	-210.000			
20.000	0.000	-21.000				0.000	-210.000
			0.000	-650.000			
BALANCE REMOVED							
980.000	0.000	-3381.000				0.000	-1264690.000
			0.000	-68810.000			
1000.000	0.000	-3500.000				0.000	-1333500.000
-- VOLUME SUMMARY --							
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 51							
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 51							
START CHAINAGE : 0.000							
END CHAINAGE : 1000.000							
LENGTH OF SECTION : 1000.000							
CUT VOLUME : 0.000							
FILL VOLUME : -1333500.000							
TOPSOIL VOLUME : 0.000							

Table 6.4:2 MX Volume Output 10m Interval, At Grade

```

MX Software for infrastructure design   Licensed to :
Version - 20358                        GHD Pty Ltd - Brisbane
DATE : 23FEB06 TIME : 08:34:23

VOLU  SECT ATGRADE      DESIGN ATGRADE
051    1                1
001 VOLUME AT GRADE
056MCAOX  D              0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 101

-CHAINAGE-      ----SECTIONAL AREAS----    -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
(SQ. M.)        (CU. M.)          (CU. M.)
-DISTANCE-      ---CUT---  ---FILL---   ---CUT---  ---FILL---  ---CUT---
FILL---

    0.000      0.000      0.000                0.000      0.000
                0.000      -51.250
10.000      0.000      -10.250                0.000      -51.250
                0.000      -156.250
BALANCE REMOVED
990.000      0.000      -3440.250                0.000      -1298673.750
                0.000      -34701.250
1000.000      0.000      -3500.000                0.000      -1333375.000

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 101

START CHAINAGE   :    0.000
END CHAINAGE     :   1000.000

LENGTH OF SECTION :   1000.000

CUT VOLUME       :    0.000
FILL VOLUME     : -1333375.000
TOPSOIL VOLUME   :    0.000
    
```

Table 6.4:3 MX Volume Output 5m Interval, At Grade

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 23FEB06 TIME : 08:34:37

VOLU  SECT ATGRADE          DESIGN ATGRADE
051   1                    1
001VOLUME AT GRADE
056MCA0X  D                0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 201
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 201

-CHAINAGE-      ---SECTIONAL AREAS---    -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-    ---CUT---  ---FILL---    ---CUT---  ---FILL---  ---CUT---  ---
FILL---

      0.000      0.000      0.000              0.000      0.000
      5.000      0.000      -5.063      0.000      -12.656      0.000      -12.656
      10.000      0.000      -10.126      0.000      -25.312      0.000      -25.312
      15.000      0.000      -15.189      0.000      -38.281      0.000      -38.281
      20.000      0.000      -20.252      0.000      -51.244      0.000      -51.244
      25.000      0.000      -25.315      0.000      -64.207      0.000      -64.207
      30.000      0.000      -30.378      0.000      -77.170      0.000      -77.170
      35.000      0.000      -35.441      0.000      -90.133      0.000      -90.133
      40.000      0.000      -40.504      0.000      -103.096      0.000      -103.096
      45.000      0.000      -45.567      0.000      -116.059      0.000      -116.059
      50.000      0.000      -50.630      0.000      -129.022      0.000      -129.022
      55.000      0.000      -55.693      0.000      -141.985      0.000      -141.985
      60.000      0.000      -60.756      0.000      -154.948      0.000      -154.948
      65.000      0.000      -65.819      0.000      -167.911      0.000      -167.911
      70.000      0.000      -70.882      0.000      -180.874      0.000      -180.874
      75.000      0.000      -75.945      0.000      -193.837      0.000      -193.837
      80.000      0.000      -81.008      0.000      -206.800      0.000      -206.800
      85.000      0.000      -86.071      0.000      -219.763      0.000      -219.763
      90.000      0.000      -91.134      0.000      -232.726      0.000      -232.726
      95.000      0.000      -96.197      0.000      -245.689      0.000      -245.689
      100.000     0.000     -101.260      0.000     -258.652      0.000     -258.652
BALANCE REMOVED
      995.000     0.000    -3470.062              0.000    -1315918.594
      1000.000     0.000     -3500.000              0.000     -17425.156
      1000.000     0.000    -3500.000              0.000    -1333343.750

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 201
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 201

START CHAINAGE   :    0.000
END CHAINAGE     :   1000.000

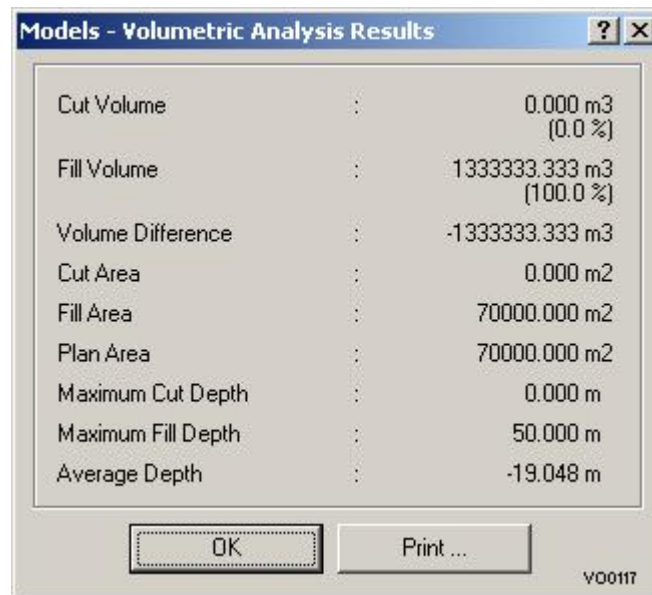
LENGTH OF SECTION :    1000.000

CUT VOLUME       :    0.000
FILL VOLUME      :  -1333343.750
    
```

6.4.4 At Grade MX Model: Volumetric Analysis

Initial volumetric using quick MX Model volumetric analysis yields the following output shown in Figure 6.4:2 for the at grade alignment.

Figure 6.4:2: MX Volumetric Analysis: At Grade



6.4.5 At Grade MX Model: Isopachyte Analysis

Isopachyte volume calculations using the linemode script shown below in Appendix G: MX Linemode Code End Isopachyte Analysis.

Volume output for the isopachyte analysis is shown below in Table 6.4:4.

Table 6.4:4 MX Output: Isopachyte Analysis At Grade

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 25FEB06  TIME : 09:40:17

PRISM  VOL TRIA           DESIGN ATGRADE
911TI00

THE TRUE VOLUMETRIC DIFFERENCE BETWEEN THE TWO SURFACES

CUT VOLUME =      0.000 (CU. M.)

FILL VOLUME = 1333333.333 (CU. M.)

OUTPU

```

Isopachyte volume is 1,333,333.333 m³.

6.5 MX Model: Crest Curve

6.5.1 Crest Curve MX Model

MX linemode coding for the at grade straight alignment model is shown in Appendix E: MX Linemode Alignments.

6.5.2 Crest Curve MX Model: Vertical Data

Data input for the crest curve straight design is shown below in Figure 6.5:1.

Figure 6.5:1: MX Crest Vertical Data

IP	Chainage	Elevation	Length	K Value	Out - Grade	Distance	BVC Chaina	EVC Chaina	BVC Level	EVC L
1	0.000	120.000	0.000		8.000	331.261				
2	331.261	146.501	462.522	28.908	-8.000	331.261	0+100.000	0+562.522	128.000	1:
3	662.522	120.000	0.000							

6.5.3 Crest Curve MX Model: End Area

End area volume calculations at five (5), ten (10) and twenty (20) intervals are shown in Table 6.5:1, Table 6.5:2 & Table 6.5:3. A linemode script for these end area calculations can be viewed in Appendix F: MX Linemode Code End Area Calculations.

Table 6.5:1 MX Volume Output 20m Interval, Crest Curve

MX Software for infrastructure design Licensed to :							
Version - 20358				GHD Pty Ltd - Brisbane			
DATE : 7FEB06 TIME : 13:42:32							
VOLU	SECT	CREST	DESIGN CREST				
051		1	1				
001 VOLUME CREST							
056MCOCX	D		0.0				
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 35							
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 35							
-CHAINAGE-		----SECTIONAL AREAS----		-INTERMEDIATE VOLUMES-		-	
ACCUMULATIVE VOLUMES-							
		(SQ. M.)	(CU. M.)		(CU. M.)		
-DISTANCE-	---	CUT---	---	FILL---	---	CUT---	---
FILL---							
0.000	0.000	-800.000	0.000	-16985.600	0.000	0.000	
20.000	0.000	-898.560	0.000	-19008.000	0.000	-16985.600	
BALANCE REMOVED							
			0.000	-17234.983			
660.000	0.000	-812.146	0.000	-2032.917	0.000	-1069431.107	
662.522	0.000	-800.000			0.000	-1071464.024	
-- VOLUME SUMMARY --							
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 35							
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 35							
START CHAINAGE	:	0.000					
END CHAINAGE	:	662.522					
LENGTH OF SECTION	:	662.522					
CUT VOLUME	:	0.000					
FILL VOLUME	:	-1071464.024					
TOPSOIL VOLUME	:	0.000					

Table 6.5:2 MX Volume Output 10m Interval, Crest Curve

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 3FEB06 TIME : 09:20:24

VOLU SECT CREST          DESIGN CREST
051          1          1
001 VOLUME CREST
056MCOX D          0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 68
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 68

-CHAINAGE-      ---SECTIONAL AREAS---      -INTERMEDIATE VOLUMES-      -
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-      ---CUT--- ---FILL---      ---CUT--- ---FILL---      ---CUT--- ---
FILL---

      0.000      0.000      -800.000              0.000      0.000
      10.000      0.000      -848.640              0.000      -8243.200
              0.000      -8736.000
BALANCE REMOVED
              0.000      -8366.277
      660.000      0.000      -812.146              0.000      -1069670.733
              0.000      -2032.917
      662.522      0.000      -800.000              0.000      -1071703.649

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 68
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 68

START CHAINAGE      :      0.000
END CHAINAGE        :      662.522

LENGTH OF SECTION   :      662.522

CUT VOLUME          :      0.000
FILL VOLUME       : -1071703.649
TOPSOIL VOLUME      :      0.000

999

OUTP
    
```

Table 6.5:3 MX Volume Output 5m Interval, Crest Curve

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 3FEB06 TIME : 09:20:30

VOLU SECT CREST          DESIGN CREST
051          1          1
001 VOLUME CREST
056MCOX D          0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 134
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 134

-CHAINAGE-      ---SECTIONAL AREAS---      -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
              (SQ. M.)          (CU. M.)          (CU. M.)
-DISTANCE-      ---CUT--- ---FILL---      ---CUT--- ---FILL--- ---CUT---
FILL---

    0.000      0.000  -800.000
                   0.000  -4060.400
    5.000      0.000  -824.160
                   0.000  -4182.000
BALANCE REMOVED
                   0.000  -4121.535
    660.000      0.000  -812.146
                   0.000  -2032.917
    662.522      0.000  -800.000
                   0.000  -1071763.648

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 134
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 134

START CHAINAGE   :    0.000
END CHAINAGE     :    662.522

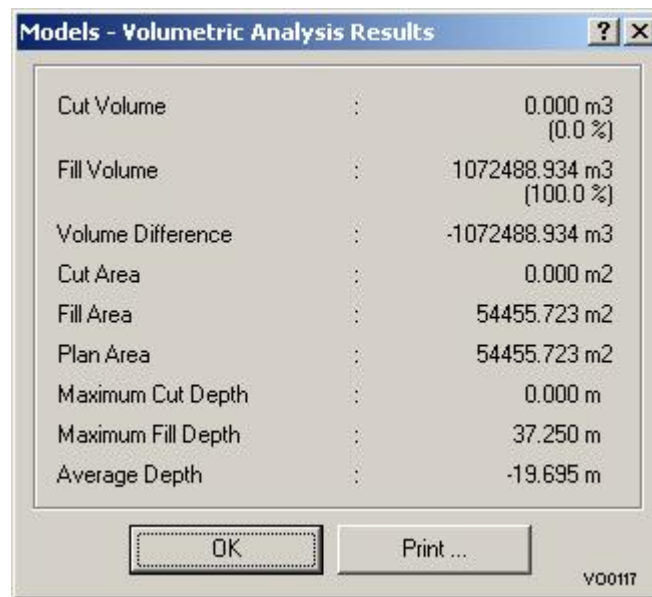
LENGTH OF SECTION :    662.522

CUT VOLUME       :    0.000
FILL VOLUME    : -1071763.648
TOPSOIL VOLUME   :    0.000
OUTP
    
```

6.5.4 Crest Curve MX Model: Volumetric Analysis

Initial volumetric using quick MX Model volumetric analysis yields the following output shown in Figure 6.5:2 for the crest curve straight alignment.

Figure 6.5:2: MX Volumetric Analysis: Crest Curve



6.5.5 Crest Curve MX Model: Isopachyte Analysis

Isopachyte volume calculations using the linemode script shown in Appendix G: MX Linemode Code End Isopachyte Analysis.

Volume output for the isopachyte analysis is shown below in Table 6.5:4

Table 6.5:4 MX Output: Isopachyte Analysis Crest

```

MX Software for infrastructure design   Licensed to :
Version - 20358                        GHD Pty Ltd - Brisbane
DATE : 25FEB06  TIME : 09:33:20

PRISM VOL TRIA          DESIGN CREST
911TI00

THE TRUE VOLUMETRIC DIFFERENCE BETWEEN THE TWO SURFACES

CUT VOLUME =      0.000 (CU. M.)

FILL VOLUME = 1071754.550 (CU. M.)

OUTPU
    
```

Isopachyte volume for the crest curve is 1,071,754.550m³.

6.6 MX Model: Sag Curve

6.6.1 Sag Curve MX Model

MX linemode coding for the sag curve straight alignment model is shown in Appendix B: Model Profiles.

6.6.2 Sag Curve MX Model: Vertical Data

Data input for the sag curve straight alignment design is shown below in Figure 6.6:1.

Figure 6.6:1: MX Sag Vertical Data

IP	Chainage	Elevation	Length	K Value	Out - Grade	Distance	BVC Chaina	EVC Chaina	BVC Level	EVC L
1	0.000	128.220	0.000		-5.004	156.890				
2	156.890	120.370	113.850	23.943	-0.248	156.960	0+099.965	0+213.815	123.218	1:
3	313.850	119.980	0.000							

6.6.3 Sag Curve MX Model: End Area Script

End area volume calculations at five (5), ten (10) and twenty (20) intervals are shown in Table 6.6:1, Table 6.6:2 & Table 6.6:3. A linemode script for these end area calculations can be viewed in Appendix F: MX Linemode Code End Area Calculations.

Table 6.6:1 MX Volume Output 20m Interval, Sag Curve

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 17JUL06  TIME : 16:34:47

VOLU  SECT SAG          DESIGN SAG
051           1              1
001 VOLUME SAG CURVE
056MCO SX D              0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  26
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  16

-CHAINAGE-      ---SECTIONAL AREAS---      -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-    ---CUT---  ---FILL---  ---CUT---  ---FILL---  ---CUT---  ---FILL---
  0.000      0.000  -1360.768              0.000  -26460.807
              0.000  -1285.312              0.000  -26460.807
  20.000      0.000  -1285.312              0.000  -24971.693
              0.000  -803.900
BALANCE REMOVED
280.000      0.000  -803.900              0.000  -271487.204
              0.000  -16047.850
 300.000      0.000  -800.885              0.000  -287535.054
              W822 End of sections in model 2

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  26
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  16

START CHAINAGE   :    0.000
END CHAINAGE     :   320.000

LENGTH OF SECTION :   320.000

CUT VOLUME       :    0.000
FILL VOLUME    : -287535.054
TOPSOIL VOLUME   :    0.000

OUTP
    
```

Table 6.6:2 MX Volume Output 10m Interval, Sag Curve

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 18JUL06  TIME : 07:58:51

VOLU  SECT SAG          DESIGN SAG
051          1          1
001 VOLUME SAG CURVE
056MCOSX  D          0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  51
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  32

-CHAINAGE-      ---SECTIONAL AREAS---      -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
              (SQ. M.)          (CU. M.)          (CU. M.)
-DISTANCE-    ---CUT---  ---FILL---      ---CUT---  ---FILL---  ---CUT---  ---FILL---
0.000      0.000  -1360.768          0.000  0.000
10.000     0.000  -1322.784          0.000  -13417.764
              0.0  -13040.426
BALANCE REMOVED
300.000     0.000  -800.878          0.000  -287434.300
              0.000  -8001.281
310.000     0.000  -799.378          0.000  -295435.581
              W822 End of sections in model 2

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS  51
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS  32

START CHAINAGE   :    0.000
END CHAINAGE     :   320.000

LENGTH OF SECTION :   320.000

CUT VOLUME       :    0.000
FILL VOLUME    : -295435.581
TOPSOIL VOLUME   :    0.000

999

OUTP
    
```

Table 6.6:3 MX Volume Output 5m Interval, Sag Curve

```

MX Software for infrastructure design   Licensed to :
Version - 20358                       GHD Pty Ltd - Brisbane
DATE : 30OCT06 TIME : 08:47:37

VOLU SECT SAG          DESIGN SAG
051          1          1
001 VOLUME CREST
056 MCOSX D          0.0
NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 63

-CHAINAGE-      ---SECTIONAL AREAS---      -INTERMEDIATE VOLUMES-
ACCUMULATIVE VOLUMES-
              (SQ. M.)              (CU. M.)              (CU. M.)
-DISTANCE-      ---CUT---  ---FILL---      ---CUT---  ---FILL---  ---CUT---  ---
FILL---

      0.000      0.000  -1360.768              0.000      0.000
      5.000      0.000  -1341.717              0.000  -6756.213
              0.000  -6661.268
BALANCE REMOVED
              0.000  -4002.543
      305.000      0.000  -800.132              0.000  -291421.554
              0.000  -3998.780
      310.000      0.000  -799.380              0.000  -295420.334
                                         W822 End of sections in model 2

-- VOLUME SUMMARY --

NUMBER OF SECTIONS WITH INITIAL LETTER 'X' IS 101
NUMBER OF SECTIONS WITH INITIAL LETTER 'D' IS 63

START CHAINAGE   :    0.000
END CHAINAGE    :   315.000

LENGTH OF SECTION :   315.000

CUT VOLUME      :    0.000
FILL VOLUME   : -295420.334
TOPSOIL VOLUME  :    0.000

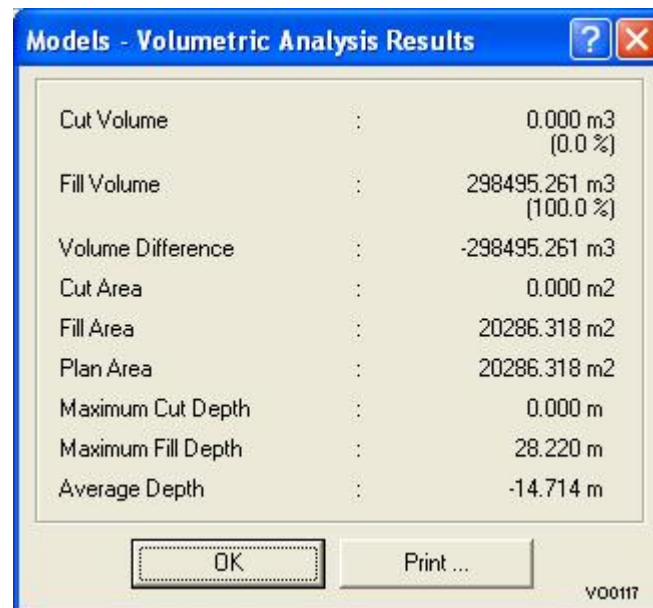
999

OUTP
    
```


6.6.4 Sag Curve MX Model: Volumetric Analysis

Initial volumetric using quick MX Model volumetric analysis yields the following output shown in Figure 6.6:2 for the sag curve straight alignment.

Figure 6.6:2: MX Volumetric Analysis: Sag Curve



6.6.5 Sag Curve MX Model: Isopachyte Analysis

Isopachyte volume calculations using the linemode script shown in Appendix G: MX Linemode Code End Isopachyte Analysis. Volume output for the isopachyte analysis is shown below in Table 6.6:4.

Table 6.6:4 MX Output: Isopachyte Analysis Sag

MX Software for infrastructure design		Licensed to :	
Version - 20358		GHD Pty Ltd - Brisbane	
DATE : 17JUL06 TIME : 16:31:51			
PRISM	VOL TRIA	DESIGN SAG	
911TI00			
THE TRUE VOLUMETRIC DIFFERENCE BETWEEN THE TWO SURFACES			
CUT VOLUME =		0.000 (CU. M.)	
FILL VOLUME =		298495.261 (CU. M.)	

Isopachyte volume is 298,495.261m³.

6.7 Summary

A summary of the calculated volumes is shown in Table 6.7:1.

Table 6.7:1 MX(Moss) Model Volumes Summary

Model	Flat straight alignment	At grade Alignment	Crest Curve	Sag Curve
End Area 20m interval	300000.00	1333500.00	1071464.024	287527.349
End Area 10m interval	300000.00	1333375.00	1071703.649	295435.581
End Area 5m interval	300000.00	1333343.75	1071763.648	295420.334
Model Volumetric Analysis	300000.00	1333333.33	1072488.934	298495.261
Isopachyte triangulation Slow	300000.00	1333333.33	1071754.550	298495.261

7 MODEL CONCLUSIONS

This section will present data of the mathematical and MX volumes produced previously. The end area calculations at different intervals will be analysed against the theory presented by Hughes-Hallett (2002), which states that the step size of sections will affect the accuracy of the calculated volume, i.e. the smaller the step the greater the accuracy (Hughes-Hallett 2002).

7.1 Error Calculations: Flat Grade

The error calculations for the flat straight grade are shown below in Table 7.1:1.

Table 7.1:1 Volumes: Flat Straight Alignment

Type of estimate	Calc Volume	MX Volume m2	Error %
End Area 20m interval	300000.00	300000.00	0.00%
End Area 10m interval	300000.00	300000.00	0.00%
End Area 5m interval	300000.00	300000.00	0.00%
Model Volumetric Analysis	300000.00	300000.00	0.00%
Isopachyte triangulation Slow	300000.00	300000.00	0.00%

Analysis of the results above shows that all methods yield a zero (0) percent error for all volume techniques. This is consistent with the mathematical theory presented in Section 4. The zero (0) percentage error represents that MX(moss) accuracy is perfect.

7.2 Error Calculations: At Grade Alignment

Error calculations for the at grade straight alignment are shown in Table 7.2:1.

Table 7.2:1 Volumes: At Grade Alignment

Type of estimate	Calc Volume	MX Volume m2	Error %
End Area 20m interval	1333333.33	1333500.00	0.013%
End Area 10m interval	1333333.33	1333375.00	0.003%
End Area 5m interval	1333333.33	1333343.75	0.001%
Model Volumetric Analysis	1333333.33	1333333.33	0.000%
Isopachyte triangulation Slow	1333333.33	1333333.33	0.000%

Analysis of the results above shows that the maximum error of 0.013 percent error is achieved for end area calculations at twenty (20) metre intervals. This is not consistent with the mathematical theory presented in section 4. The error reduces as the end area interval is reduced which is consistent with Hughes-Hallett's (2002) theory that accuracy is improved when the step size is reduced. Possible reason for this error is rounding of the results.

7.3 Error Calculations: Crest Curve Alignment

Error calculations for the crest curve straight alignment are shown in Table 7.3:1.

Table 7.3:1 Volumes: Crest Curve

Type of estimate	Calc Volume	MX Volume m2	Error %
End Area 20m interval	1052477.806	1071464.024	1.804%
End Area 10m interval	1052477.806	1071703.649	1.827%
End Area 5m interval	1052477.806	1071763.648	1.832%
Model Volumetric Analysis	1052477.806	1072488.934	1.901%
Isopachyte triangulation Slow	1052477.806	1071754.550	1.832%

Analysis of the results in Table 7.3:1 is not consistent with the theory that a convex down function produces an underestimate for end area calculations. Results for end area calculations at twenty (20) metre and ten (10) metre intervals are both underestimates, however decreases as the interval is reduced. The largest error is the Model Volumetric Analysis, which has an error of 1.90 percent. The triangulation methods also being an overestimate it can be assumed that the triangles between points are formed above the true plane, thus overestimating the volume calculation. The difference between the two triangulation methods is not significant in this case. Possible reason for this is that the profile has a very low algebraic difference between grades.

7.4 Error Calculations: Sag Curve Alignment

Error calculations for the sag curve straight alignment are shown in Table 7.4:1.

Table 7.4:1 Volumes: Sag Curve

Type of estimate	Calc Volume	MX Volume m2	Error %
End Area 20m interval	298495.261	287535.054	-3.672%
End Area 10m interval	298495.261	295443.136	-1.023%
End Area 5m interval	298495.261	295420.334	-1.030%
Model Volumetric Analysis	298495.261	298495.261	0.000%
Isopachyte triangulation Slow	298495.261	298495.261	0.000%

Analysis of the results in Table 7.4:1 is not consistent with the theory that a concave up function produces an overestimate for end area calculations. Results for end area calculations at twenty (20) metre and ten (10) metre intervals are both overestimate, however decreases as the interval is reduced. The largest area is the End Area 20m interval, which has an error of -3.672 percent.

7.5 Summary of Volume Errors

A summary of the calculated errors is shown below in Table 7.5:1.

Table 7.5:1 Summary of Error Calculations

Type of estimate	Error Flat %	Error At Grade %	Error Crest %	Error Sag %
End Area 20m interval	0.000%	0.013%	1.804%	-3.674%
End Area 10m interval	0.000%	0.003%	1.827%	-1.025%
End Area 5m interval	0.000%	0.001%	1.832%	-1.033%
Model Volumetric Analysis	0.000%	0.000%	1.901%	0.000%
Isopachyte triangulation Slow	0.000%	0.000%	1.832%	0.000%

Analysis of the results in Table 7.5:1 shows that the over and underestimation theory presented by Hughes-Hallett et al. 2002 has not been verified. Possible reasons for this may include errors in the mathematical calculations. However the consistent nature and small errors of the results means they can be used for further analysis.

These results have been used to rank the volume methods from least accurate to most accurate in Table 7.5:2. The least accurate method of determining volumes is the Model Volumetric Analysis. The end area results presents that the twenty (20)

metre interval presents the largest errors with a significant improvement for a reduction to a ten (10) metre interval was observed. A further reduction to a five (5) metre interval did not significantly improve the accuracy of the results.

Table 7.5:2 Ranking of Volume Calculations

Type of estimate	Ranking
Model Volumetric Analysis	5
End Area 20m interval	4
End Area 10m interval	3
End Area 5m interval	2
Isopachyte triangulation Slow	1

While the results are well below Turner's (1999) errors shown in Table 8.3:1 (shown in the next section). Making the assumption that the specified models analysed in this paper are too simplistic compared to a real life situation, the results presented in this paper should be considered as an absolute minimum. For this reason this paper has focused on the trends present in the different error volume calculations.

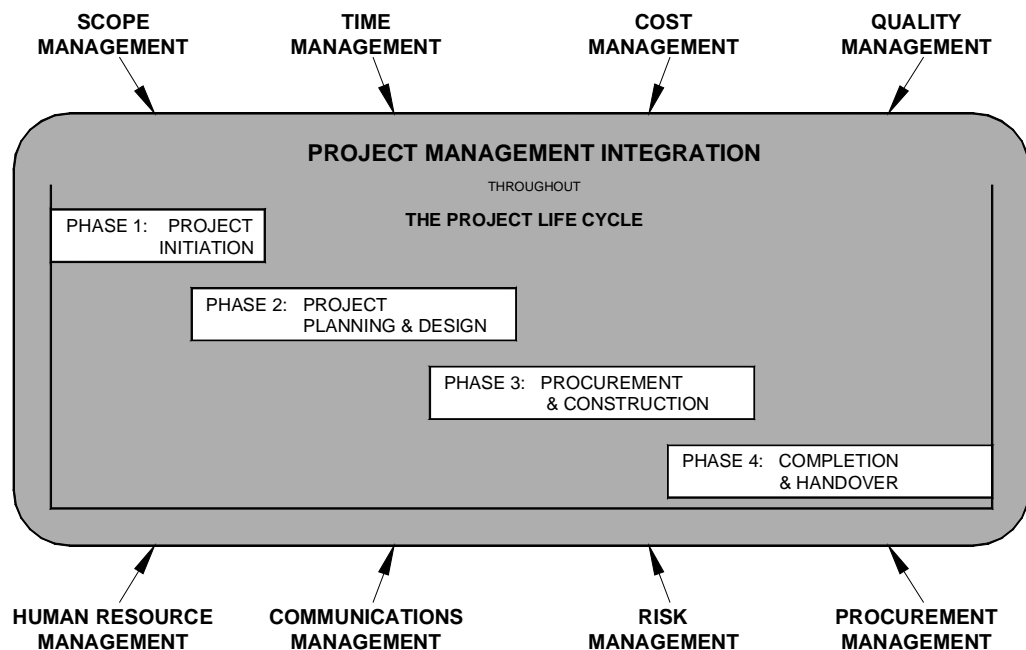
8 PROJECT MANAGEMENT

Now we have some idea regarding the accuracy of volumes. How do they affect the management of a project? We have already discussed that inaccurate volumes could have a significant legal affects (Said 2003), however projects have many different phases that don't require high accuracy at all stages. This section will give basic background into project phasing and estimating so we can rationalise the required degree of accuracy and methods to be undertaken.

8.1 Project Management Summary

The process of project management is best summarised by the Project Management Body of Knowledge (PMBoK) (AIPM 1995), as shown below in Figure 8.1:1.

Figure 8.1:1: Project Management Integration



(Source: AIPM 1995, p. 27).

Shown above are the nine (9) knowledge areas and phases. Volumes form such a large component of a road design that they influence scope, time, cost, quality, risk

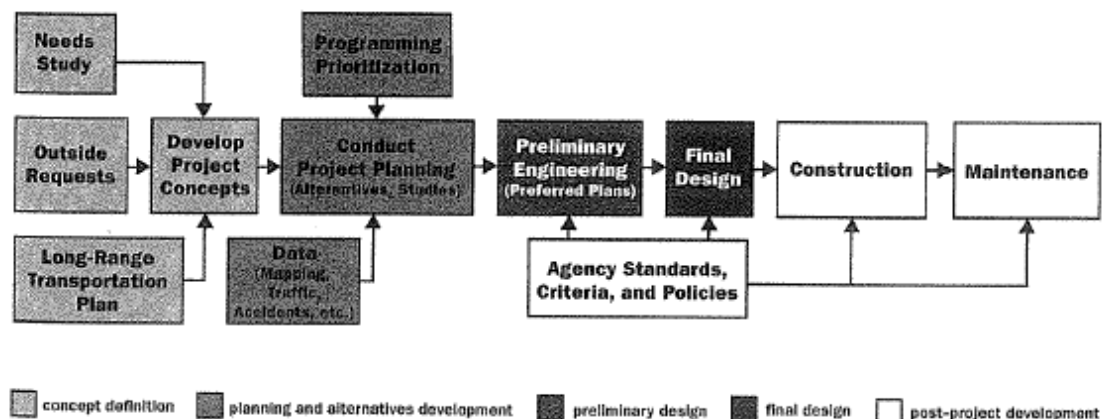
and procurement of the project. For example a poor quality road design model will result in a poor determination in volumes.

8.2 Project Stages

Further to the PMBoK (AIMP 1995), AASHTO (2004) has further developed the typical project management process for highways as shown in Figure 8.2:1. 'The four stages:

- Concept definition, (Feasibility Design);
- Planning and alternative development, (Preliminary Sketch Plan (PSP) & Final Sketch Plan (FSP);
- Preliminary design (80% Design); and
- Final design (Tender).

Figure 8.2:1: Typical Project Development Process



(Source: AASHTO 2000, p. 1)

8.3 Project Estimates

Project management theory presented by Turner (1999) contents that a typical project has five types of estimates with varying accuracy, refer Table 8.3:1.

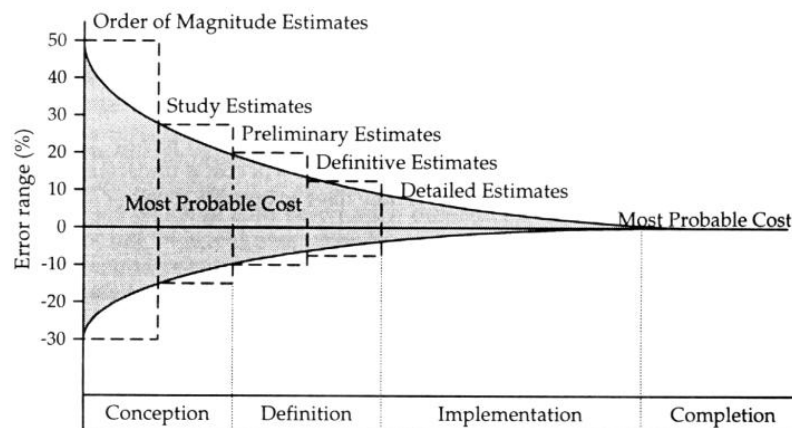
Table 8.3:1 Turner, Types of Estimate, Purpose and Accuracy

<i>Type of estimate</i>	<i>Deliverable</i>	<i>Range of accuracy (%)</i>	<i>Purpose</i>
Proposal	Feasibility	± 50	Appraisal viability to start, feasibility study
Design (Feasibility)	Design		
Budget	Preliminary Sketch Plan	± 20	Appraisal viability to start, system design
Sanction	Final Sketch Plan	± 10	Appraisal viability to approve project, obtain funding, allocate resources
Control	80% Design	± 5	Measure progress, assign resources
Tender	100% Design	± 2	Prepare tender

(Source: Adapted from Turner 1999, p. 174)

This paper will undertake analysis of the estimate theory presented by Turner (1999), as they appear not to be a reasonably applicable to civil construction works. Other theories, such as that presented by Hamilton (1997) state that tender estimation can range from ten percent plus to minus five percent at tender, refer Figure 8.3:1. Estimate accuracy is related to the complexity of the project (Hamilton 1997). Either way the theory presented by both Turner (1999) and Hamilton (1997) states that estimate requirements in the early stages of a project are not very high and the range at tender is very low.

Figure 8.3:1 Accuracy Range of Estimates



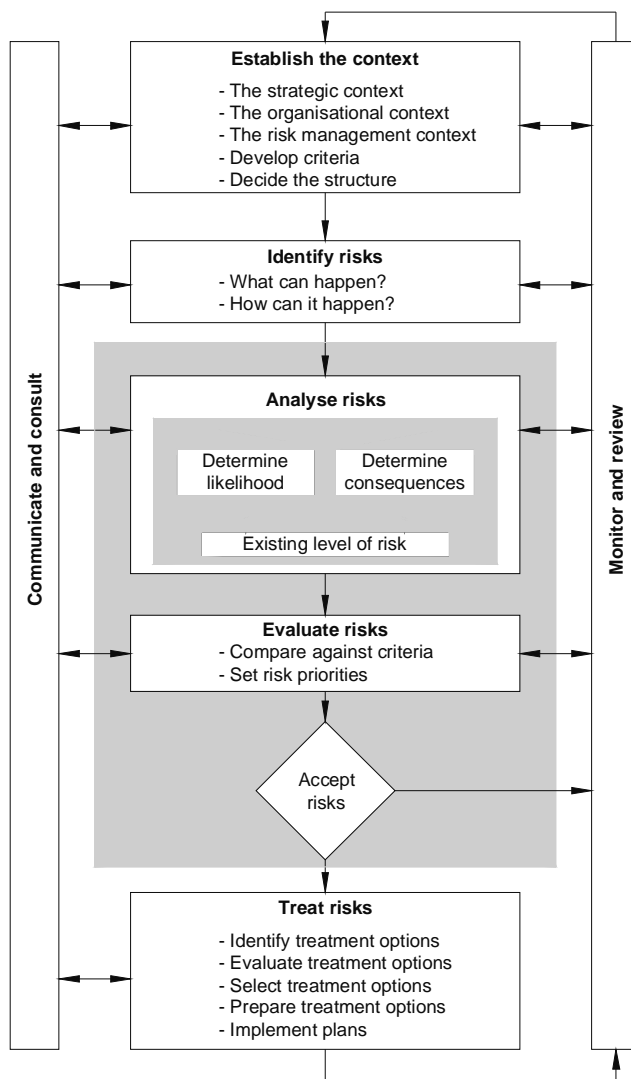
(Source: Hamilton 1997, p. 252)

These points will be critically analysed in Section 9 when the results of a survey of senior engineers and project managers will be presented.

8.4 Risk Management

‘Risk is the exposure to the possibility of such things as economic or financial loss or gain, physical damage, injury or delay, as a consequence of pursuing or not pursuing a particular action’ (Knight 1999). It is encapsulating three components, the perception that something could, the likelihood of something happening, and the consequence if it happens defines the scope of risk (Standards Australia 2004). The risk identification process can use a wide variety of tools and techniques. A generic risk management process is shown in Figure 8.4:1.

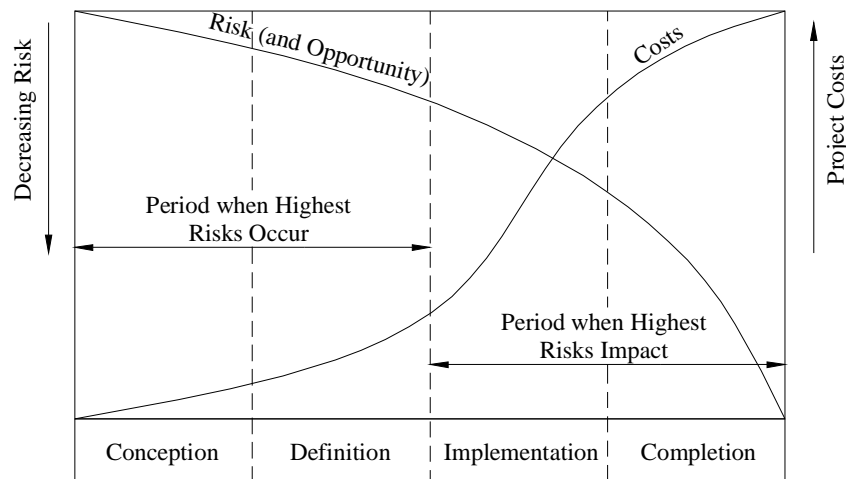
Figure 8.4:1: Risk Management Process



(Source: Knight 1999, p. 16).

The risk management process should begin as early as possible in the project (Knight 1999, p. 13). Kerzner (2003), Turner (1999), Knight (1999) and Standards Australia (2004) all supporting the early identification of risks and involving experienced persons in brainstorming, expert judgements and team oriented group discussions. As shown in Figure 8.4:2, decreasing risks is highest and less costly during the conception and definition stage when significant design work is undertaken.

Figure 8.4:2: Opportunity and Risk versus Project Life Cycle



(Source: Hamilton 1997, p 278)

Further to the academic processes and theory presented, the above important aspects of risk is involved by integrating a risk adverse culture into every day activities (Veith 1998). As shown in Figure 8.4:1 the process is continuous and individual event should be related to the likelihood, which is summarised in Table 8.4:1. Assessment of the likelihood of an event is an important and complex aspect of risk management. This paper will consider the risk of inaccurate volumes as likely and important.

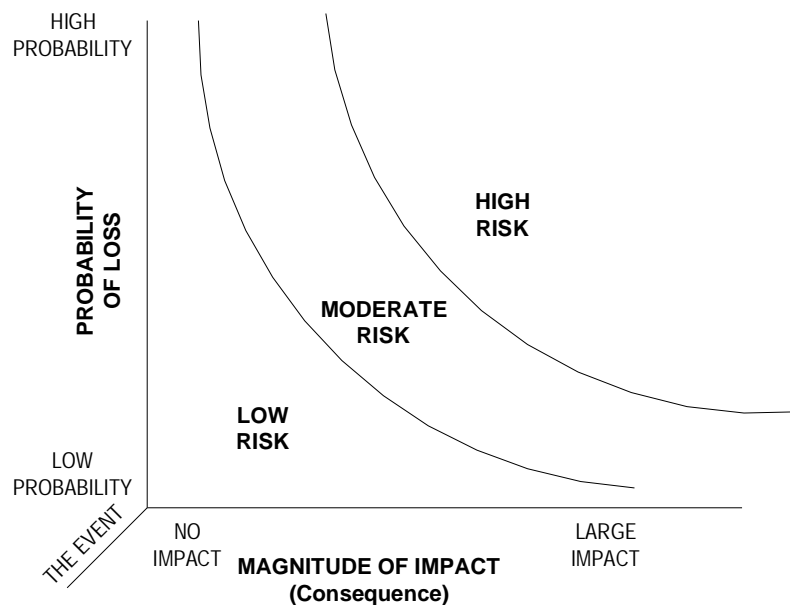
Table 8.4:1 Likelihood Table

Almost certain	The event will occur on an annual basis
Likely	The event has occurred several times or more in your career
Moderate	The event could occur once in your in your career or could occur at any time
Unlikely	The vent has not yet occurred but could occur at some time
Rare	Heard of something like this occurring elsewhere
Very rare	Have never heard of this happening
Almost incredible	One off event in exceptional circumstances

(Source: Knight 1999, p. 26)

Kerzner (2003) contended that at any particular point or decision during the design process can be accessed to its magnitude of impact and probability. This concept is summarised in Figure 8.4:3. At risk level can be determined from this process. This theory presented by Kerzner (2003) will be used later in this paper to access the risk at different stages of the project.

Figure 8.4:3 Overall risk is a function of it components



(Source: Kerzner 2003, p. 654)

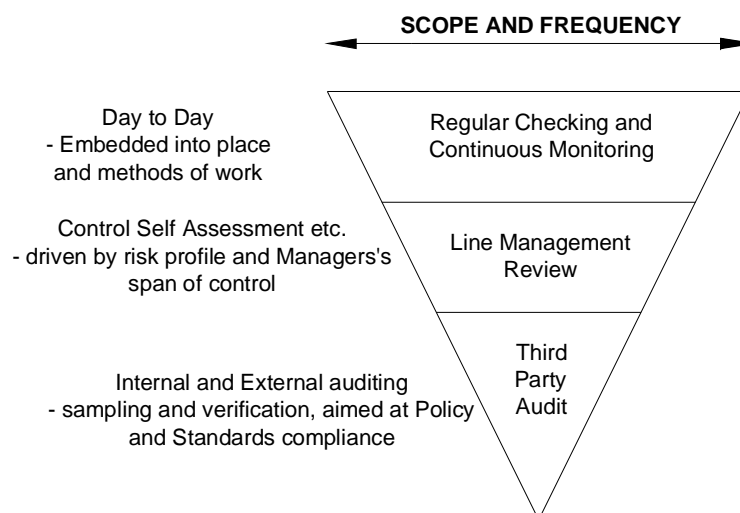
8.5 Auditing

The discussions so far are characteristic of a design office with a risk adverse culture, which is important in the design process of a road. Significant studies outline the benefits of effective risk management in the design process (AASTHO 2004). Auditing of road designs is a risk management technique, which should be incorporated into all projects (Vieth 1998). Austroads (2002) defines a road safety audit as:

“A formal examination of an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner reports on the project’s accident potential and safety performance”.

AS/NZL 4360 :2004 (Standards Australia 2004a) relates risk to the auditing process in Figure 8.5:1. This application of risk adverse behaviour and auditing is important for the calculation of roadwork’s volumes. Management theory would categorise this type of approach to determining the accuracy of work as good culture, which should be developed in a design office by effective leadership and reinforcement (Viljoen, J & Dann, S 2000, p. 27).

Figure 8.5:1 Hierarchy of Assurance Activities



(Source: Standards Australia 2004a, p. 83)

8.6 Procurement: General Conditions of Contract

Standard procurement contract documentation includes a General Conditions of Contract, which are clauses general to the performance of the contract. Tender documentation and the volumes created are important for 'the contractor will gain an appreciation for the scale of the work to be undertaken, and the equipment required' (USQ 2006).

Appendix I: AS2124: Annexure A includes a clause stating the 'Limits of accuracy applying to quantities for which the Principal accepted a rate of rates: for schedule items'. The underling message here is that 'Quantities in a Bill of Quantities or Schedule of Rates are estimated quantities only' (Standards Australia 1992, p 7). Vic Roads (2005) states that a factor of ten (10) percent as appropriate for this type of clause. Clearly this clause is a concession that perfect earthworks volumes are unattainable and some realistic limits of accuracy are needed between parties.

8.7 Cost Management

Understanding the global framework of how different technical methods produce various levels of accuracy and the risks involved at different phases in a project, some discussion can now be made as to the cost of producing volumes.

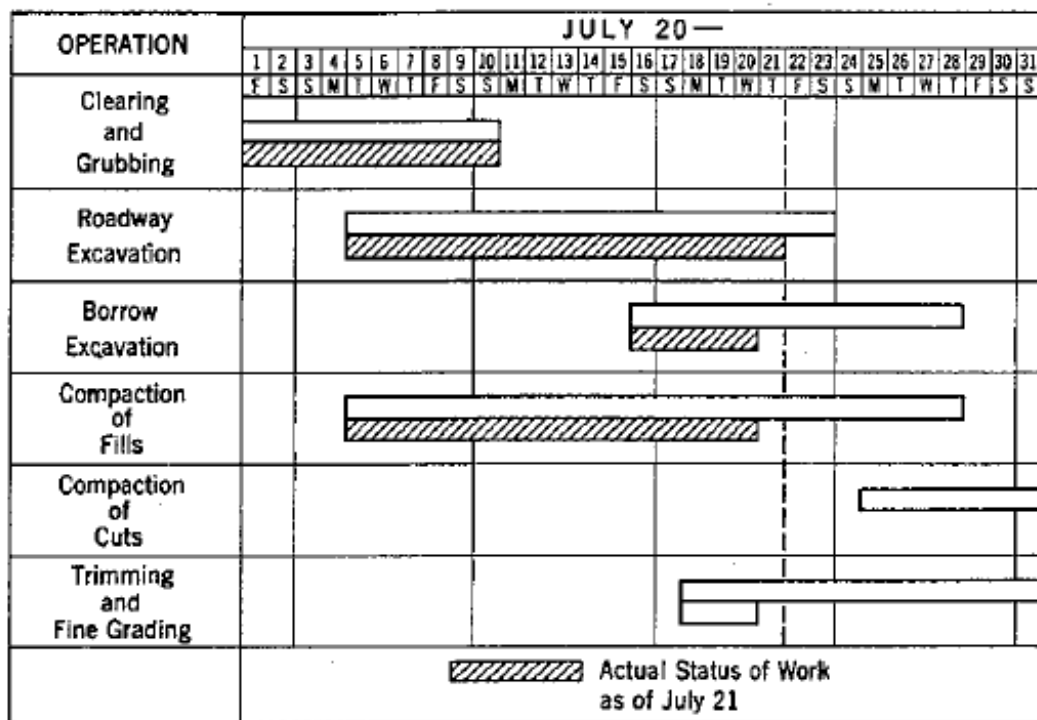
Isopachyte triangulation method is very accurate but time-consuming for larger models (Bentley 2006). However linemode coding for producing end area volume calculations shares text used for other cross sections. The assumption is that it takes four times as long to produce Isopachyte triangulation volumes than end area volume calculations (Watson 2006). The cost of producing high levels of volumes will be considered in this paper. The cost of producing volumes has to be compared to the benefit for doing so.

Prior to tendering contract schedules are not normally produced. Table 8.3:1 has lower limits of twenty (20) percent.

8.8 Planning and Execution

To emphasise the importance that earthworks have on the delivery of a road project this paper will look at some typical project planning techniques. Wright & Dixon (2004) discuss two common project planning techniques, first, the Gantt Chart shown in Figure 8.8:1, will be discussed.

Figure 8.8:1 Schedule of Construction Operations

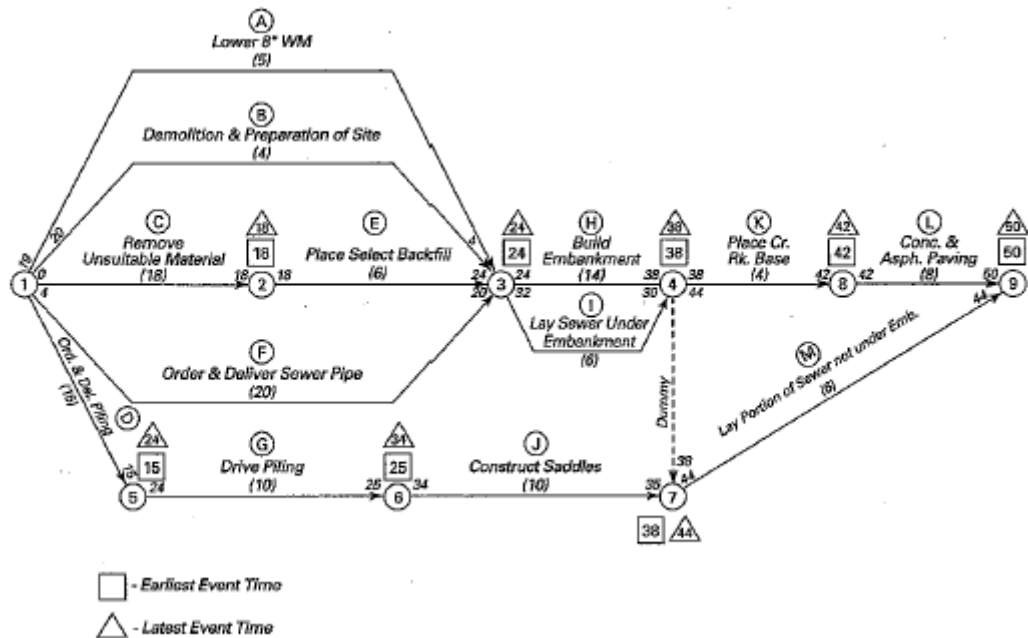


(Source: Wright & Dixon 2004, p. 485)

Figure 8.8:1 is an example of a Gantt chart (Russell & Taylor 2000). Gantt charts are a commonly used because of their simplicity understood. Commonly used software projects use these charts. As compared with building projects, which normally have many more sub jobs, the critical path for civil projects can be easily defined using this method.

A better typical example of the affects of volumes on a roadwork’s program is demonstrated critical path diagram shown in Figure 8.8:2.

Figure 8.8:2 Typical critical path diagram for a simple highway project



(Source: Wright & Dixon 2004, p. 486)

It is common that earthworks are the second most critical item after bridge construction on most typical projects.

8.9 Summary

This section has investigated many areas of the project management delivery of a highway design job. In particular the estimation theory presented by Turner (1999) was discussed. The next Section will discuss the results of the staff survey, which will provide data for Turner's (1990) estimation values to be critically analysed.

9 STAFF SURVEY

The first section of this paper has included a large amount of quantitative analysis, which is data-driven analytical using mathematical & statistical models. This section allows qualitative analysis to be introduced into this paper.

9.1 Survey

A survey was undertaken of key staff within Guttridge Haskins Davey Pty Ltd (GHD), Canberra office. The survey was sent to twenty (20) staff members with three (3) responses. The survey is shown in Table 9.1:1.

Table 9.1:1 Staff Survey

<p>Hi Group</p> <p>Sorry for the inconvenience, however need your help. I have been asked to do the following as part of this USQ engineering project which I am undertaking.</p> <p><i>"Survey major engineering designers and constructors (private consultants, construction companies, government depts, etc) and establish (i) the desirable level of accuracy for earthworks calculations, and (ii) the currently achieved accuracies of earthworks calculations."</i></p> <p>Current work on this area in my report has been focused on project management theory presented by Turner (1999). Which is shown below.</p>		
<i>Phase of Project (Turner 1999)</i>	<i>Deliverable</i>	<i>% Error</i>
FEASIBILITY (Proposal)	Feasibility Design	± 50
PLANNING and DESIGN (Budget)	Preliminary Sketch Plan	± 20
PLANNING and DESIGN (Sanction)	Final Sketch Plan	± 10
CONSTRUCTION (Control)	80% Design	± 5
CONSTRUCTION (Tender)	100% Design	± 2
<p>(Source: Adapted from Turner 1999, p. 174)</p> <p>So further to above I would like your responses to the above issues of earthwork volumes. Any comments regarding your experience with roadwork's volumes would be greatly appreciated, ranging from;</p> <ul style="list-style-type: none"> • Errors which you have trouble with; • What range of error you have been getting (best guess); • What range of error you have got from different methods, eg end area vrs isopachyce triangulation; • Time taken in producing these volumes; • Any comments you have relating to the expectations project managers and the limitations you have as designers in producing roadwork;s volumes; and • Anything else you can think of. <p>Also I have assumed that for limits of accuracy in general conditions of contract documentation is 10%, is this what you have used in other tendering documents????</p>		

Sorry again for the inconvenience because I know this is not work and a pain for you, so the best I can do is offer beer or wine for your trouble.

Regards

Neil Hughes
Project Manager

GHD | CLIENTS | PEOPLE | PERFORMANCE

GHD Pty Ltd Canberra

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neil.hughes@ghd.com.au | T 61 2 6264 0853 | F 61 2 6253 1911

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The respondent's surveys can be viewed in Appendix H: MX Volumes Survey.

9.2 Discussion

Comments received from Faye Powell & Mervyn Cole mentioned pressures from clients to expose projects to tender with the expectation that variations may be in the range of twenty (20) to thirty (30) percent. The possible reasons for this may include:

- Lack of resources with the delivery of engineering design services, the demand of design services is above the markets ability to supply services and this may be lowering the quality across the industry;
- Clients push projects out to tender prior to detailed design;
- Greater pressure on staff, in particular MX designers which are often the critical resource; and
- With increased workload the risk of human error is increased.

The above range of variations will be considered an absolute maximum in this paper.

All respondents have problems with the Turner (1999) estimate percentages at both the feasibility stage and the construction / tender phase of projects. In particular the high error percentage presented at feasibility stage of the project was a concern. The people making decisions at this stage of the project are expecting greater understanding of the magnitude of the decision they are making. Generally this is related to budget processes.

Gardner (2006) further mentions the need to compare volumes against simple volume calculations as a sanity check. Geoff Gardner (2006) further mentioned the need to use different methods as a check against gross errors in the model with the most simplistic generally being adopted because it is easier to understand.

The above discussion will be used determine a revised range of accuracy in the next section.

10 RECOMMENDATIONS

10.1 Recommendations

The recommendation of this paper are summarised in Table 10.1:1, also included is an assessment of risk at the stage of the project. These results have been added to previous academic theory and enhanced using the quantitative analysis of the models analysis of the models, and the qualitative analysis from the staff survey.

Table 10.1:1 Recommended Range of Accuracy, Method with Risk Assessment

<i>Purpose</i>	<i>Recommended Range of accuracy (%)</i>	<i>Recommended Volume Method</i>	<i>Magnitude of impact</i>	<i>Probability of Loss</i>	<i>Risk</i>
Feasibility	$\pm 30^1$	Model Volumetric Analysis	Low	Low	Low
PSP	± 20	End Area 20m interval	Low	Low	Low
FSP	$\pm 15^*1$	End Area 20m interval	Medium	Low	Low
80% Design Review	$\pm 10^{*1}$	End Area 10m interval	Medium	Medium	Medium
Tender	$\pm 5-10^{*1}$	Isopachyte triangulation & End Area 10m interval	High	High	High

(Source: Adapted Turner 1999, p. 174)

Notes:

1. Changed from Tuner (1999) following survey.

Analysis of the end area results showed that a reduction to a five (5) metre interval did not significantly improve the accuracy of the volumes. Adopting a cross section interval of five (5) metre is not recommended in this paper. Note that a general risk assessment has been included in Table 10.1:1, however this is a guide only; risk assessment should be specific to each project.

Recommendations, which should be applied to a design office responsible for design volumes are:

- Survey DTM be verified prior to design;
- That the survey extent be approximately twenty metres longer and wider than the design model;
- Gantt charts used for project planning;
- Cross sections should be verified prior to volume calculations so that MX(moss) interpretation error does not occur, for example; two strings with the same horizontal geometry with different Z values;
- Results are cross referenced with other methods, eg Isopachyte triangulation & End Area ten (10) metre interval;
- Reduce end area calculations to five (5) metre intervals at tender for projects in mountainous terrain and projects with large amounts of superelevated curves;
- Independent auditing of the road design including contract volumes;
- Independent risk assessment;
- Apply management techniques which integrate quality of determining volumes;
- Apply management techniques which integrate risk aversion;
- Apply management techniques, which develop a culture conducive to producing accurate volumes, if needed a cultural change model could be applied; and
- Adopt a value of twenty (20) percent for the contractual 'Limits of accuracy applying to quantities for which the Principal accepted a rate of rates' Annexure shown in Appendix I: AS2124: Annexure A.

The recommendations include items, which could be included into the process manuals for delivering roadwork volumes in a design office. It is important to be practicable in these recommendations because over checking may not be the most practicable method when resources are hard to find in the workplace. The economic reality of present day consulting is that projects are priced at low margins and excessive checking reduces the margin further. However the

financial cost of getting it wrong is large so it should be linked to a risk management process to identify the technical and financial risk.

10.2 Benefits

Benefits from this study include the following:

- Reduced risk;
- Reduction in errors;
- Greater consistency;
- Recommendations could be used to form design checklists;
- Could form part of a Quality Assurance system; and
- Reduced human error.

The finding of this paper could be included in a design office:

- Design checklist; and
- Quality assurance system.

10.3 Future Work

This paper has concluded that for the simplified road profiles analysed produce errors, which are under the recommended limits of accuracy required for the delivery of the project. Greater complexity could be added to these profiles to further examine the volume effects of super elevated curves and existing survey accuracy.

Project management theory appears to be specific to more complex projects. Further research could present theory more related to civil projects.

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Appendices

Appendix A: Project Specification

Project Aim:

To determine the accuracy of MX(moss) road design software volumes calculations and relate them to project management requirements.

Background:

MX is a road design software package which is extensively used throughout the world. The accuracy of calculation algorithms in such software is often determined by benchmarking against other calculation methods. The aim of the project is to determine the accuracy of the volume calculation algorithms used in MX by comparing calculated volumes with actual volumes determined from measurements of a mathematical model.

Research Programme

1. Review the literature relating to road design and road design software, in particular the methods of establishing earthwork volumes and their accuracy.
2. Design suitable models, which can be mathematically measured.
3. Determine the volume of the models.
4. Determine the linear dimensions of the physical model for use as input data for MX modelling.
5. Using MX software, create a computer model of the model and determine its volume by the methods available in MX.
6. Compare real and calculated volumes and hence determine the accuracy of the calculation algorithms in MX.
7. Report findings through oral presentation at the Project Conference, and in the required written format.

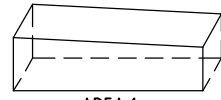
Appendix B: Model Profiles

VOLUME CALCULATIONS

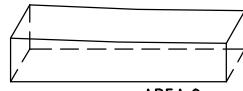
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AREA 2 (BASE 2 x VERT 3 x WIDTH) + $\frac{1}{2}$ (BASE 2 x (VERT 2-VERT 3) x WIDTH) - $R^2/2(\text{pie} \times \text{THETA}/180 - \text{SinTHETA})$

AREA 3 (BASE 3 x VERT 4 x WIDTH) + $\frac{1}{2}$ (BASE 3 x (VERT 3-VERT 4) x WIDTH)



AREA 1

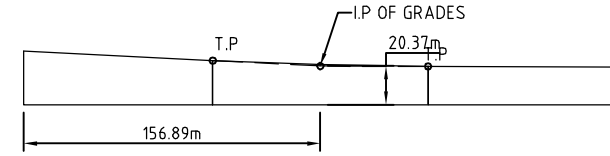


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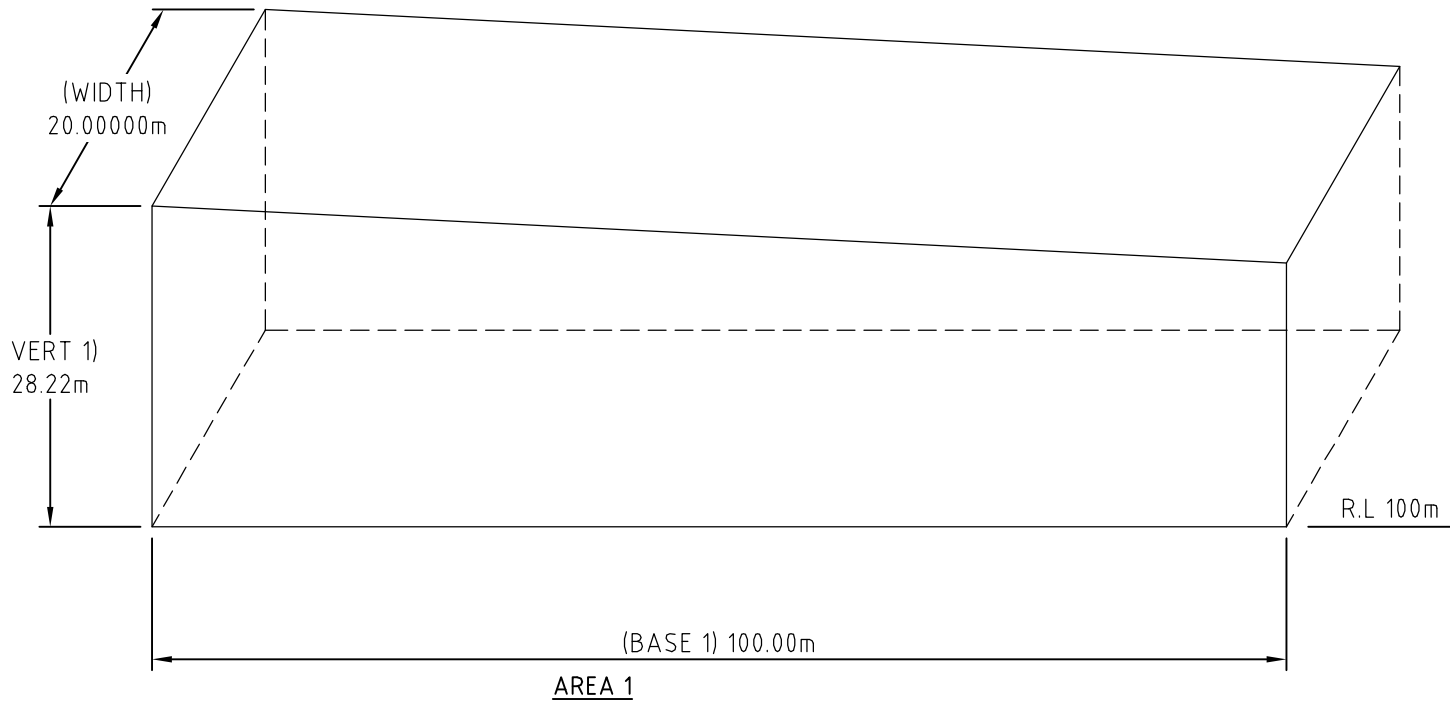


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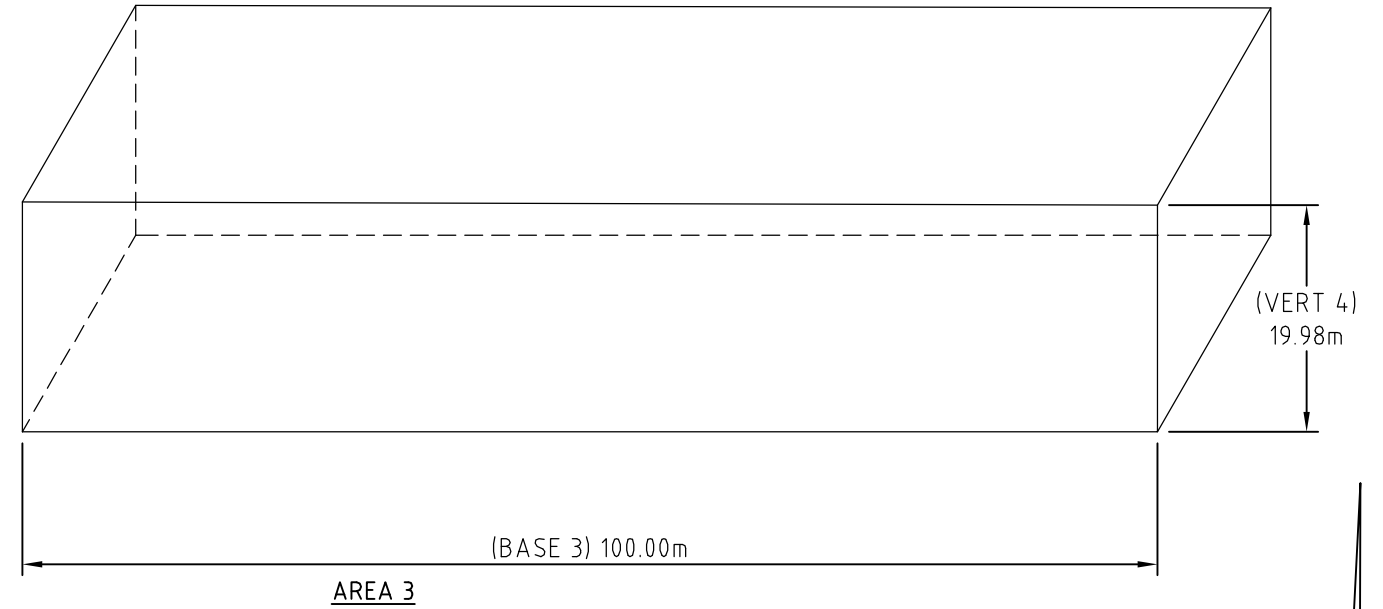
KEY PLAN



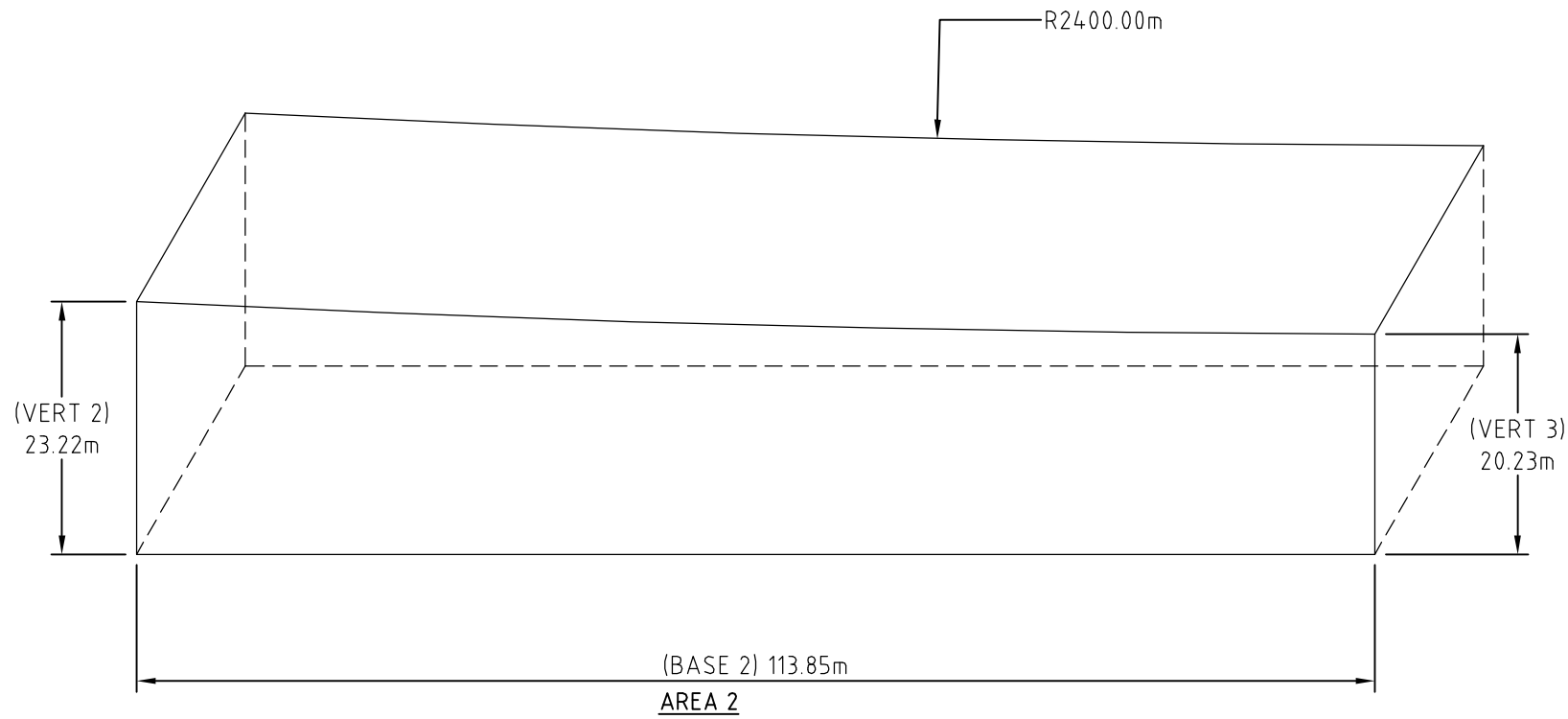
CURVE IP



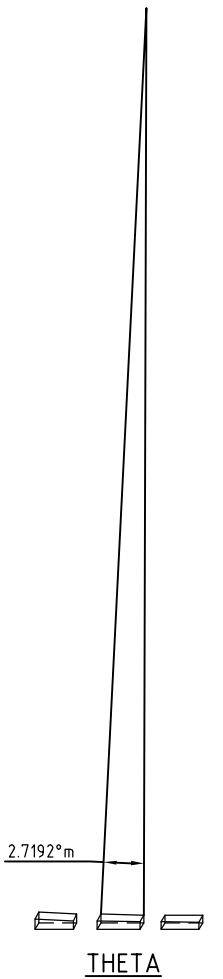
AREA 1



AREA 3



AREA 2



THETA

PRELIMINARY

150 mm ON ORIGINAL
A1

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		DRAFTING CHECK	NEIL HUGHES
		DESIGNER	NEIL HUGHES
		DESIGN CHECK	NEIL HUGHES
		PROJECT MANAGER	NEIL HUGHES
		PROJECT DIRECTOR	NEIL HUGHES

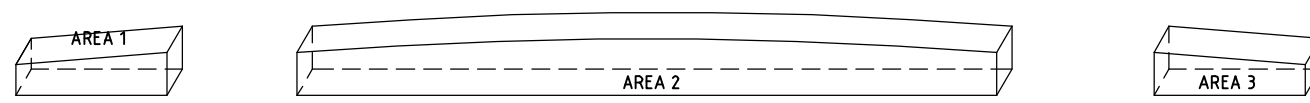
SCALES AT A1 SIZE DRAWING	DESIGNER	CLIENT

PROJECT TITLE	University of Southern Queensland ENG4111 Project MX VOLUMES SAG CURVE SIMULATION
---------------	--

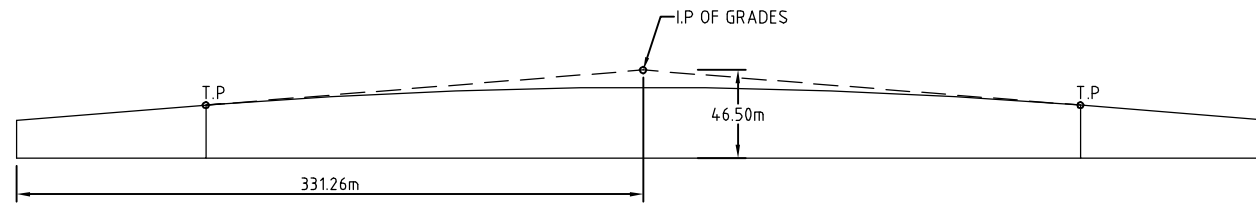
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NTS		SAG	1

VOLUME CALCULATIONS

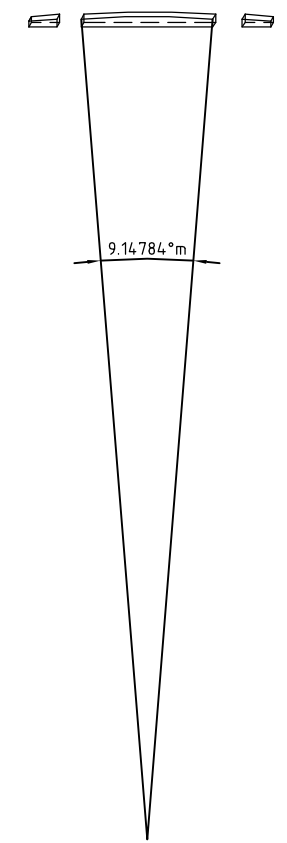
AREA 1 (BASE 1 x VERT 2 x WIDTH) + $\frac{1}{2}$ (BASE 1 x (VERT 1-VERT 2) x WIDTH)
 AREA 2 (BASE 2 x VERT 3 x WIDTH) + $\frac{1}{2}$ (BASE 2 x (VERT 2-VERT 3) x WIDTH) + $R^2/2(\text{pie} \times \text{THETA}/180 - \text{SinTHETA})$
 AREA 3 (BASE 3 x VERT 4 x WIDTH) + $\frac{1}{2}$ (BASE 3 x (VERT 3-VERT 4) x WIDTH)



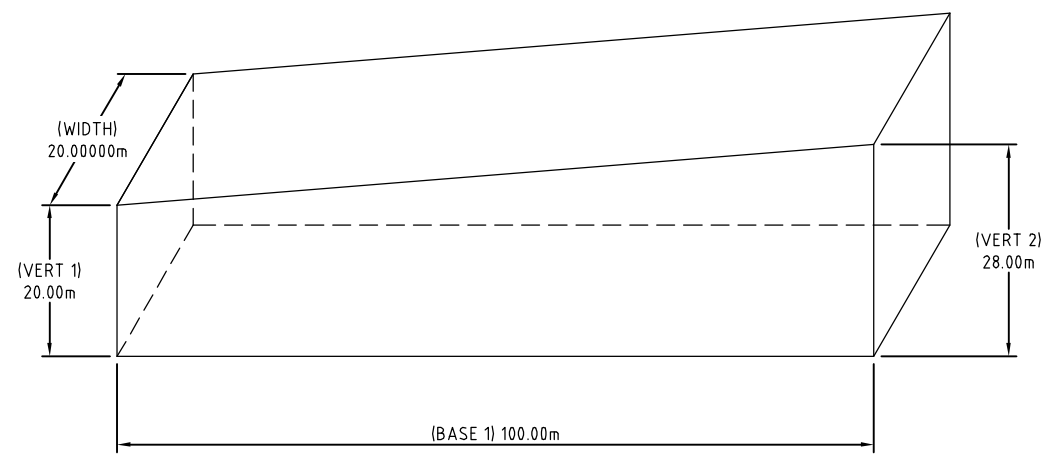
KEY PLAN



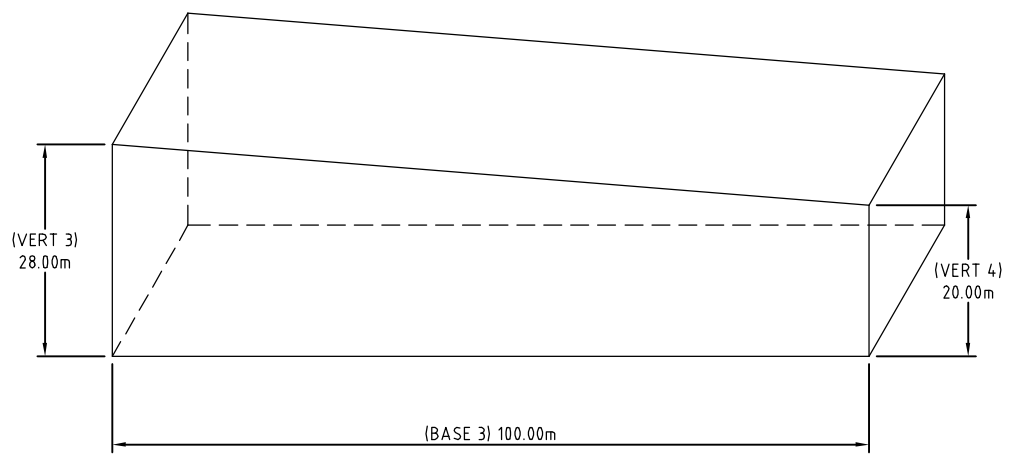
CURVE IP



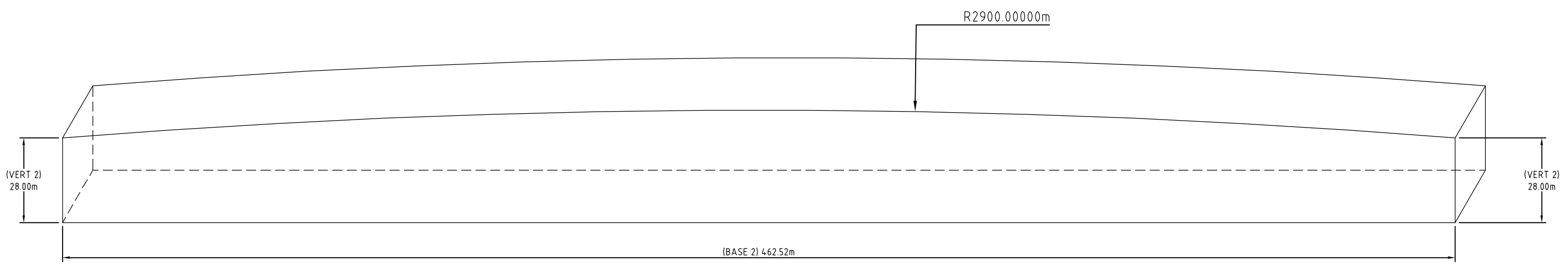
THETA



AREA 1



AREA 3



AREA 2

PRELIMINARY

150 mm ON ORIGINAL
A1

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				DRAFTING CHECK	NEIL HUGHES	
				DESIGNER	NEIL HUGHES	
				DESIGN CHECK	NEIL HUGHES	
	PROJECT MANAGER	NEIL HUGHES				
	PROJECT DIRECTOR	NEIL HUGHES				
PROJECT TITLE University of Southern Queensland ENG4111 Project MX VOLUMES CREST CURVE SIMULATION			SCALE NTS	DRAWING STATUS	PROJECT / DRAWING No. CREST	REVISION 1

Appendix C: Matlab Script: Volume Analysis

```

1 % ENG4111 Project,
2 % Purpose of File: Volume Calculation Script
3 % Prepared By: Neil Hughes
4 % Student Number: d1210173
5 %
6 clear;clc;
7 global pie
8 pie=3.14159265;
9 % Get variable from keyboard for Sag or Crest Curve 1
10 % Displays initial message in command window
11 disp(' ')
12 disp('This program forms part of the engineering report into')%displays message in command window
13 disp('the accuracy of volume calculation from MX. This program is calculates the mathematical volume')
14 disp('of the simulated profile so further analysis can be undertaken in MX.')
15 disp(' ')
16 disp('Two types of profiles are common, the use must make a choice of which profile is to be simulated')
17
18 % Get variable from keyboard for atmospheric effects or for no atmospheric effects
19 check1=0;
20 while check1~=1;
21     disp('For Flat Alignment enter "1" ')
22     disp('For At Grade enter "2" ')
23     disp('For Sag Curves enter "3" ')
24     user=input('For Crest Curves enter "4"\n');
25 % Check if variables input are valid
26 % If user chooses 1, let useratmosph=1
27 if user==1;check1=1;
28     BASE1=input('Base (m) =');
29     VERT1=input('Vertical (m) =');
30     W=input('Width(m) =');
31     area1=(VERT1*W);
32     area2=(VERT1*VERT1);
33     areaT=(area1+area2);
34     VOL=(areaT*BASE1)
35 elseif user==2;check1=1;
36     BASE1=input('Base 1(m) =');
37     VERT1=input('Vertical 1(m) =');
38     VERT2=input('Vertical 2(m) =');
39     W=input('Width(m) =');
40     area1=VERT1*VERT1;
41     area2=VERT2*VERT2;
42     frustum=((area1+sqrt(area1*area2)+area2)/3)*BASE1);
43     VOLM=.5*VERT2*BASE1*W;
44     VOL=frustum+VOLM
45 elseif user==3;check1=1;
46     BASE1=input('Base 1(m) =');
47     BASE2=input('Base 2(m) =');
48     BASE3=input('Base 3(m) =');
49     VERT1=input('Vertical 1(m) =');
50     VERT2=input('Vertical 2(m) =');
51     VERT3=input('Vertical 3(m) =');
52     VERT4=input('Vertical 4(m) =');
53     W=input('Width(m) =');
54     rad=input('rad(m) =');

```

```

55 alpha=input('alpha(deg) =');% Degrees
56 area1=((BASE1*VERT1)+(0.50*((VERT2-VERT1)*BASE1)));
57 area3=((BASE3*VERT4)+(0.50*((VERT3-VERT4)*BASE3)));
58 area2=((BASE2*VERT3)-((rad^2/2)*(((pie*alpha)/180)-sin(alpha*(pie/180)))));
59 areaT=(area1+area2+area3);
60 VOL=(areaT*W)+((areaT/(BASE1+BASE2+BASE3))*areaT)
61 elseif user==4;check1=1;
62 BASE1=input('Base 1(m) =');
63 BASE2=input('Base 2(m) =');
64 BASE3=input('Base 3(m) =');
65 VERT1=input('Vertical 1(m) =');
66 VERT2=input('Vertical 2(m) =');
67 VERT3=input('Vertical 3(m) =');
68 VERT4=input('Vertical 4(m) =');
69 W=input('Width(m) =');
70 rad=input('rad(m) =');
71 alpha=input('alpha(deg) =');% Degrees
72 area1=((BASE1*VERT1)+(0.50*((VERT2-VERT1)*BASE1)));
73 area3=((BASE3*VERT4)+(0.50*((VERT3-VERT4)*BASE3)));
74 area2=((BASE2*VERT3)+((rad^2/2)*(((pie*alpha)/180)-sin(alpha*(pie/180)))));
75 areaT=(area1+area2+area3);
76 VOL=(areaT*W)+((areaT/(BASE1+BASE2+BASE3))*areaT)
77 % If data not valid, ask again
78 else
79 disp(' ')
80 disp('Invalid data entered. Try again.')
81 disp(' ')
82 disp('Press "ENTER" to start again.')
83 pause;
84 end
85 end
86 %
87 %EOF

```

Appendix D: MX Linemode Survey**MX Linemode Code: Survey Triangulation**

```
MOSS

DELETE,SURVEY TRIA
CREATE,SURVEY TRIA

DELETE,CRAP SURVEY
CREATE,CRAP SURVEY

DELETE,SURVEY CONT
CREATE,SURVEY CONT

TRIANGLE,CRAP SURVEY
TRIANGLE,SURVEY TRIA
019,4=1
960,,,3=TX00
961,2=TX00,3=TX00,10=1
999

SURFACE,SURVEY TRIA
SURFACE,SURVEY CONT
970,TX00,X,Y,0.1,7=0.5
999

SUBS
SYSDEL,X_Exis_Cont.dpw
999

NEWD,X_Exis_Cont.dpw

DISPLAY,EMPTY

DRAW,SURVEY CONT
801,OVER
803,PLAN,7=1000
805,YELLOW
808,2= 1,4=0.100,1
814,3=MIN
825,X
815
814,3=MAJ
805,RED
806,RED
825,Y,3=LEVS
815
999

DISPLAY

DELETE,CRAP SURVEY

FINI
```

Appendix E: MX Linemode Alignments
MX Linemode Code: Flat Straight Alignment

```

MOSS

SUBS
SYSDEL,DESIGN FLAT.dpw
999

NEWD,DESIGN FLAT.dpw

DISPLAY,EMPTY

AUTODRAW,ON

DELETE,DESIGN FLAT
CREATE,DESIGN FLAT

HALGN,DESIGN FLAT      ,DESIGN FLAT
300,LB=MCF0,TL=0.100000,CE=5.00,CT=5.00,ME
305,SC=0.000000,CF=0.000000
301,1,SX,X1=720.000000,Y1=900.000000,X2=1720.000000
305,Y2=900.000000
999

VERAT,DESIGN FLAT      ,DESIGN FLAT
MCF0,0.000000,1000.000000,7=2
1=0.000000,110.000000
1=1000.000000,110.000000
999

DESIGN,DESIGN FLAT
100,MCF0,3=EV00,4=0.0,7=0,5=,8=
100,MCF0,3=EV01,4=0.0,7=-20,5=,8=
999

INTERFAC,SURVEY TRIA,DESIGN FLAT
000 ##### LEFT HAND SIDE #####

260,1=MCF0,2=IA01,4=-1,5=,8=
262,1=TX00,2=EV01,7=-1
263

000 ##### RIGHT HAND SIDE #####
INTERFAC,SURVEY TRIA,DESIGN FLAT
260,1=MCF0,2=IA00,4=1,5=,8=
262,1=TX00,2=EV00,7=-1
263
999

FINI

```

MX Linemode Code: At Grade Alignment

```
MOSS

SUBS
SYSDEL,DESIGN ATGRADE.dpw
999

NEWD,DESIGN ATGRADE.dpw

DISPLAY,EMPTY

AUTODRAW,ON

DELETE,DESIGN ATGRADE
CREATE,DESIGN ATGRADE

HALGN,DESIGN ATGRADE      ,DESIGN ATGRADE
300,LB=MCA0,TL=0.100000,CE=5.00,CT=5.00,ME
305,SC=0.000000,CF=0.000000
301,1,SX,X1=720.000000,Y1=900.000000,X2=1720.000000
305,Y2=900.000000
999

VERAT,DESIGN ATGRADE      ,DESIGN ATGRADE
MCA0,0.000000,1000.000000,7=2
1=0.000000,100.000000
1=1000.000000,150.000000
999

DESIGN,DESIGN ATGRADE
100,MCA0,3=EV00,4=0.0,7=0,5=,8=
100,MCA0,3=EV01,4=0.0,7=-20,5=,8=
999

INTERFAC,SURVEY TRIA,DESIGN ATGRADE
000 ##### LEFT HAND SIDE #####

260,1=MCA0,2=IA01,4=-1,5=,8=
262,1=TX00,2=EV01,7=-1
263

000 ##### RIGHT HAND SIDE #####
INTERFAC,SURVEY TRIA,DESIGN ATGRADE
260,1=MCA0,2=IA00,4=1,5=,8=
262,1=TX00,2=EV00,7=-1
263
999

FINI
```

MX Linemode Code: Sag Curve

```
MOSS

SUBS
SYSDEL,DESIGN SAG.dpw
999

NEWD,DESIGN SAG.dpw

DISPLAY,EMPTY

AUTODRAW,ON

DELETE,DESIGN SAG
CREATE,DESIGN SAG

HALGN,DESIGN SAG      ,DESIGN SAG
300,LB=MC0S,TL=0.100000,CE=5.00,CT=5.00,ME
305,SC=0.000000,CF=0.000000
301,1,SX,X1=640.000000,Y1=660.000000,X2=1138.857000
305,Y2=660.000000
999

VERAT,DESIGN SAG      ,DESIGN SAG
MC0S,0.000000,498.857000,7=3
1=0.000000,132.840580
1=249.335000,120.373800,298.857040
1=498.857000,119.750000
999

DESIGN,DESIGN SAG
100,MC0S,3=EV00,4=0.0,7=0,5=,8=
100,MC0S,3=EV01,4=0.0,7=-20,5=,8=
999

INTERFAC,SURVEY TRIA,DESIGN SAG
000 ##### LEFT HAND SIDE #####

260,1=MC0S,2=IA01,4=-1,5=,8=
262,1=TX00,2=EV01,7=-1
263

000 ##### RIGHT HAND SIDE #####
INTERFAC,SURVEY TRIA,DESIGN SAG
260,1=MC0S,2=IA00,4=1,5=,8=
262,1=TX00,2=EV00,7=-1
263
999

FINI
```

MX Linemode Code: Crest Curve

```
MOSS

SUBS
SYSDEL,DESIGN CREST.dpw
999

NEWD,DESIGN CREST.dpw

DISPLAY,EMPTY

AUTODRAW,ON

DELETE,DESIGN CREST
CREATE,DESIGN CREST

HALGN,DESIGN CREST      ,DESIGN CREST
300,LB=MC0C,TL=0.100000,CE=5.00,CT=5.00,ME
305,SC=0.000000,CF=0.000000
301,1,SX,X1=620.000000,Y1=1160.000000,X2=1282.522000
305,Y2=1160.000000
999

VERAT,DESIGN CREST      ,DESIGN CREST
MC0C,0.000000,662.522000,7=3
1=0.000000,120.000000
1=331.261140,146.500890,462.522290
1=662.522000,120.000000
999

DESIGN,DESIGN CREST
100,MC0C,3=EV00,4=0.0,7=0,5=,8=
100,MC0C,3=EV01,4=0.0,7=-20,5=,8=
999

INTERFAC,SURVEY TRIA,DESIGN CREST
000 ##### LEFT HAND SIDE #####

260,1=MC0C,2=IA01,4=-1,5=,8=
262,1=TX00,2=EV01,7=-1
263

000 ##### RIGHT HAND SIDE #####
INTERFAC,SURVEY TRIA,DESIGN CREST
260,1=MC0C,2=IA00,4=1,5=,8=
262,1=TX00,2=EV00,7=-1
263
999

FINI
```

Appendix F: MX Linemode Code End Area Calculations**MX Linemode Code End Area Calculations: Flat**

```
MOSS

DELETE,SECT FLAT
CREATE,SECT FLAT

000 SECTION EXISTING
SECT,SURVEY TRIA,DESIGN FLAT
SECTION,SECT FLAT
178,MCF0,FX00,X,20,7=-100,10=100,5=,8=
999

000 SECTION DESIGN
SECT,DESIGN FLAT,DESIGN FLAT
SECTION,SECT FLAT
174,MCF0,,D,20,7=-100,10=100,5=,8=
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Flat_Volume 20m.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Flat_Volume 20m.prn,TERM

VOLU,SECT FLAT,DESIGN FLAT
051,6=1,10=1
001,VOLUME FLAT
056,MCF0,X,D,7=0.0,5=,8=
999

OUTP

FINI
```


MX Linemode Code End Area Calculations: At Grade

```
MOSS
DELETE,SECT ATGRADE
CREATE,SECT ATGRADE

000 SECTION EXISTING
SECT,SURVEY TRIA,DESIGN ATGRADE
SECTION,SECT ATGRADE
178,MCA0,TX00,X,20,7=-100,10=100,5=,8=
999

000 SECTION DESIGN
SECT,DESIGN ATGRADE,DESIGN ATGRADE
SECTION,SECT ATGRADE
174,MCA0,,D,20,7=-100,10=100,5=,8=
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Atgrade_Volume 20m.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Atgrade_Volume 20m.prn,TERM

VOLU,SECT ATGRADE,DESIGN ATGRADE
051,6=1,10=1
001,VOLUME AT GRADE
056,MCA0,X,D,7=0.0,5=,8=
999

OUTP
FINI
```

MX Linemode Code End Area Calculations: Sag

```
MOSS
DELETE,SECT SAG
CREATE,SECT SAG

000 SECTION EXISTING
SECT,SURVEY TRIA,DESIGN SAG
SECTION,SECT SAG
178,MC0S, TX00,X,20,7=-100,10=100,5=,8=
999

000 SECTION DESIGN
SECT,DESIGN SAG,DESIGN SAG
SECTION,SECT SAG
174,MC0S,,D,20,7=-100,10=100,5=,8=
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Sag_Volume 20m.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Sag_Volume 20m.prn,TERM

VOLU,SECT SAG,DESIGN SAG
051,6=1,10=1
001,VOLUME SAG CURVE
056,MC0S,X,D,7=0.0,5=,8=
999

OUTP

FINI
```

MX Linemode Code End Area Calculations: Crest

```
MOSS
DELETE,SECT CREST
CREATE,SECT CREST

000 SECTION EXISTING
SECT,SURVEY TRIA,DESIGN CREST
SECTION,SECT CREST
178,MC0C,TX00,X,20,7=-100,10=100,5=,8=
999

000 SECTION DESIGN
SECT,DESIGN CREST,DESIGN CREST
SECTION,SECT CREST
174,MC0C,,D,20,7=-100,10=100,5=,8=
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Crest_Volume 20m.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Crest_Volume 20m.prn,TERM

VOLU,SECT CREST,DESIGN CREST
051,6=1,10=1
001,VOLUME CREST
056,MC0C,X,D,7=0.0,5=,8=
999

OUTP

FINI
```

Appendix G: MX Linemode Code End Isopachyte Analysis

MX Linemode Code: Isopachyte Analysis Flat Grade

```

MOSS

DELE,VOL TRIA
CREA,VOL TRIA

DELE,DES TRIA
CREA,DES TRIA

TRIANGLE,SURVEY DTM,DESIGN FLAT
TRIANGLE,DES TRIA,
960,,3=TX00
961,2=TX00,3=TX00,10=1.
999

TRIANGLE,DESIGN FLAT,BDY DESIGN FLAT
TRIANGLE,DES TRIA,
960,BDYF,3=TD00
999

TRIANGLE,DES TRIA,DES TRIA
TRIANGLE,VOL TRIA,
964,TX00,2=TD00,3=TI00
999

SUBS
SYSDEL,FLAT VOLUME.PRN
999

OUTPU,FLAT VOLUME.PRN
SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\FLAT_IsoVolume.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\FLAT_IsoVolume.prn,TERM
PRISM,VOL TRIA,DESIGN FLAT
911,TI00,3=
912,TI00,3=
999

DELE,COND FLAT
CREA,COND FLAT
SURFACE,DES TRIA
SURFACE,COND FLAT,
970,TD00,2=D,3=0,4=0.1,5=0.5,6=0.1,7=0.5,8=200.
970,TD00,2=x,3=z,4=0.01,5=0.25,6=0.1,7=0.5,8=200.
999
OUTPU

FINI

```

MX Linemode Code: Isopachyte Analysis At Grade

```

MOSS

DELE,VOL TRIA
CREA,VOL TRIA

DELE,DES TRIA
CREA,DES TRIA

TRIANGLE,SURVEY DTM,DESIGN ATGRADE
TRIANGLE,DES TRIA,
960,,3=TX00
961,2=TX00,3=TX00,10=1.
999

TRIANGLE,DESIGN ATGRADE,BDY DESIGN ATGRADE
TRIANGLE,DES TRIA,
960,BDYA,3=TD00
999

TRIANGLE,DES TRIA,DES TRIA
TRIANGLE,VOL TRIA,
964, TX00,2=TD00,3=TI00
999

SUBS
SYSDEL,ATGRADE VOLUME.PRN
999

OUTPU,ATGRADE VOLUME.PRN
SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Atgrade_IsoVolume.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\Atgrade_IsoVolume.prn,TERM

PRISM,VOL TRIA,DESIGN ATGRADE
911, TI00,3=
912, TI00,3=
999

DELE,COND ATGRADE
CREA,COND ATGRADE
SURFACE,DES TRIA
SURFACE,COND ATGRADE,
970,TD00,2=D,3=0,4=0.1,5=0.5,6=0.1,7=0.5,8=200.
970,TD00,2=x,3=z,4=0.01,5=0.25,6=0.1,7=0.5,8=200.
999
OUTPU

FINI

```

MX Linemode Code: Isopachyte Analysis Sag

```
MOSS

DELE,VOL TRIA
CREA,VOL TRIA

DELE,DES TRIA
CREA,DES TRIA

TRIANGLE,SURVEY DTM,DESIGN SAG
TRIANGLE,DES TRIA,
960,,3=TX00
961,2=TX00,3=TX00,10=1.
999

TRIANGLE,DESIGN SAG,BDY DESIGN SAG
TRIANGLE,DES TRIA,
960,BDYS,3=TD00
999

TRIANGLE,DES TRIA,DES TRIA
TRIANGLE,VOL TRIA,
964,TX00,2=TD00,3=TI00
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\SAG_IsoVolume.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\SAG_IsoVolume.prn,TERM

PRISM,VOL TRIA,DESIGN SAG
911,TI00,3=
912,TI00,3=
999

DELE,COND SAG
CREA,COND SAG
SURFACE,DES TRIA
SURFACE,COND SAG,
970,TD00,2=D,3=0,4=0.1,5=0.5,6=0.1,7=0.5,8=200.
970,TD00,2=x,3=z,4=0.01,5=0.25,6=0.1,7=0.5,8=200.
999
OUTPU

FINI
```

MX Linemode Code: Isopachyte Analysis Crest

```
MOSS

DELE,VOL TRIA
CREA,VOL TRIA

DELE,DES TRIA
CREA,DES TRIA

TRIANGLE,SURVEY DTM,DESIGN CREST
TRIANGLE,DES TRIA,
960,,3=TX00
961,2=TX00,3=TX00,10=1.
999

TRIANGLE,DESIGN CREST,BDY DESIGN CREST
TRIANGLE,DES TRIA,
960,BDYC,3=TD00
999

TRIANGLE,DES TRIA,DES TRIA
TRIANGLE,VOL TRIA,
964, TX00,2=TD00,3=TI00
999

SUBS
SYSDEL,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\CREST_IsoVolume.prn
999
OUTP,C:\Documents and Settings\nhughes.000\My Documents\neil hughes
personal\usq\ENG4111 Research Project Part 1\MX\INP files\CREST_IsoVolume.prn,TERM

PRISM,VOL TRIA,DESIGN CREST
911, TI00,3=
912, TI00,3=
999

DELE,COND CREST
CREA,COND CREST
SURFACE,DES TRIA
SURFACE,COND CREST,
970,TD00,2=D,3=0,4=0.1,5=0.5,6=0.1,7=0.5,8=200.
970,TD00,2=x,3=z,4=0.01,5=0.25,6=0.1,7=0.5,8=200.
999
OUTPU

FINI
```

Appendix H: MX Volumes Survey

Faye Powell/Canberra/GHD/AU
27/04/2006 02:56 PM To
Neil Hughes/Canberra/GHD/AU@GHD
cc

bcc

Subject
Re: Fw: MX Volumes Survey

Repository: 239999900 "Misc EMails"

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Neil

From my experience the theoretical orders of accuracy posed by Turner are more in the goal area than in actual results. In the major infrastructure project process those results are what is aimed for, and may have been very achievable in the past when tenders were based on very prescriptive designs and specifications. Today many Governments are moving increasingly toward design and construct contracts, resulting in the order of accuracy at tender stage to be closer to the + or - 30% mark - that is the range I have been used to dealing with. An analysis of typical major project over runs in recent times will support this as well. Where the tender price is closer to the order of accuracy proposed by Turner I believe you will find that a tenderer has priced in the cost of that risk in the tendered price.

Regards

Faye Powell

Manager, Stakeholder Solutions

faye.powell@ghd.com.au | T 61 2 6245 1975 | F 61 2 6253 1911 | M 0418 459 750

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Geoff Gardner/Canberra/GHD/AU
08/05/2006 11:03 AM To
Neil Hughes/Canberra/GHD/AU@GHD
cc

bcc

Subject

Re: Survey. for you only geoff 1 bottle wine or 6 beers

Repository: 239999900 "Misc EMails"

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Neil,

I have put some responses to your survey in bold below.

Regards

Geoff Gardner

Senior Engineer

GHD Pty Ltd Canberra

geoff_gardner@ghd.com.au | T 61 2 6264 0820 | F 61 2 6253 1911

<http://www.ghd.com.au>

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59 Cameron Avenue, Belconnen ACT 2617

Neil Hughes/Canberra/GHD/AU

03/05/2006 04:05 PM

To

Geoff Gardner/Canberra/GHD/AU@GHD

cc

Subject

Survey. for you only geoff 1 bottle wine or 6 beers

Repository: 239999900 "Misc EMails"

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data systems is automatically filtered and may be examined at the discretion of management, without prior notification to the sender or recipient. Confidential information should not be sent by electronic mail as the security of this information cannot be guaranteed.

Hi Group

Sorry for the inconvenience, however need your help. I have been asked to do the following as part of this USQ engineering project which I am undertaking. "Survey major engineering designers and constructors (private consultants, construction companies, government depts, etc) and establish (i) the desirable level of accuracy for earthworks calculations, and (ii) the currently achieved accuracies of earthworks calculations." Current work on this area in my report has been focused on project management theory presented by Turner (1999). Which is shown below.

Type of estimate	Range of accuracy (%)	Purpose
Proposal	±50	Appraisal viability to start, feasibility study
Budget	±20	Appraisal viability to start, system design
Sanction	±10	Appraisal viability to approve project, obtain funding, allocate resources
Control	±5	Measure progress, assign resources
Tender	±2	Prepare tender

(Source: Turner 1999, p. 174)

Then this has been related to highway design as follows;

Table: Phase of Project, Design project Deliverables

Phase of Project (Turner 1999)	Deliverable	Adopted	% Error
FEASIBILITY (Proposal)	Feasibility Design	±50	
PLANNING and DESIGN (Budget)	Preliminary Sketch Plan	±20	
PLANNING and DESIGN (Sanction)	Final Sketch Plan	±10	
CONSTRUCTION (Control)	80% Design	±5	
CONSTRUCTION (Tender)	100% Design	±2	

(Source: Adapted from Turner 1999, p. 174)

So further to above I would like your responses to the above issues of earthwork volumes. Any comments regarding your experience with roadwork's volumes would be greatly appreciated, ranging from;

· Errors which you have trouble with;

In the early phases of design problems are often associated with the following, Design still in development. Changes may occur during design development that has a major impact on the e/w quantities. e.g decisions on batter slopes for safety or geotech reasons, use of retaining walls rather than batters etc. There is no boxing as pavement design may not even have been carried out - hand calculation done by the engineer to correct earthworks volumes for pavement Hand calculations required to allow for structures Initial survey information

may be very coarse - maybe 1 or 2m contours only - data may also be very old and out of date (i.e doesn't include recent works that may impact the project)

Bulking factors

In the detailed phases of design errors may occur due to the following:

Estimate of bulking factors (i.e comparison of material insitu and as compacted fill) Design and thus earthworks volume is to face of barrier/face of wall. Corrections required to allow for fill around structures. These are guesses by the engineer. A lot of fill is generated through trench excavation for services and other miscellaneous works around the site etc. I usually guess this volume and allow a suitable correction in the earthworks volumes Depth of topsoil assumed can have a major impact on earthworks volumes particularly on projects with shallow cuts or fills.

- What range of error you have been getting (best guess);

I usually add around 5% in detailed design in to the earthworks volumes to make sure there is an adequate volume in the Schedule of Rates for construction. I would add 10-20% to earthworks volumes in the preliminary design phases depending on the type of project (e.g 20% for projects with a relatively small earthworks component)

- What range of error you have got from different methods, eg end area vrs isopachyce triangulation; end area can give very large errors on complex projects (e.g GDE Package B) if you are not very careful Model-model comparisons can also give HUGE errors if there is an error in either of the models (e.g Boyd did a model-model comparison on GDE package B which was 1,000,000m³ out - he had an error in the design model. He didn't realise there was a problem. It is easier to check for gross errors in the end area method as there are cross sections along each control line that can be reviewed for anomalies. Not so easy for model-model comparisons as you only get one number out where you get volumes at each cross section for end area method. I like to get quantities done using both methods as a check on each other. However, the model - model comparison always has anomalies and the end area volumes are always adopted as I have more confidence in them.

- Time taken in producing these volumes;

Designers are best to give you Mx times. It usually takes me 1/2 day at the end of each design stage on a big project to do pavement/wall corrections/bulking etc and come up with figures that I have some confidence in from the Mx data.

- Any comments you have relating to the expectations project managers and the limitations you have as designers in producing roadwork;s volumes; and **Uninformed clients often don't understand that the accuracy of the quantities increases with the accuracy of the design, and this has to be explained to them.**

- Anything else you can think of.

Estimation of quantities is an art not a science. It is not as straight forward as it looks and there have been many projects where problems have resulted from quantities from Mx or other package being adopted by a junior (inexperienced) engineer without thought or adjustment. Quantities are often left to junior engineers as it is seen by Project Managers as being straight forward. BIG mistake.

If you think the limit of accuracy of the earthworks in the tender documents is 2% you are living in a dream. Also I have assumed that for limits of accuracy in general conditions of contract documentation is 10%, is this what you have used in other tendering documents???? General Conditions of Contract limits of accuracy in quantities for Schedule of Rates contracts is set in Appendix A by the Principal - normally 25%. If quantities are outside this limit, the Contractor can renegotiate the rate. Under the old NPWC 3 conditions of contract, for a lump sum contract, if the quantities were out by more than 4%, the lump sum could be varied by the contractor.

Sorry again for the inconvenience because I know this is not work and a pain for you, so the best I can do is offer beer or wine for your trouble.

Regards

Neil Hughes
Project Manager

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59 Cameron Avenue, Belconnen ACT 2617 <http://www.ghd.com.au>
neil.hughes@ghd.com.au | T 61 2 6264 0853 | F 61 2 6253 1911

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Q Please consider the environment before printing this email

Mervyn F Cole/Canberra/GHD/AU
02/05/2006 12:33 PM To
Neil Hughes/Canberra/GHD/AU@GHD
cc

bcc

Subject
Re: Fw: MX Volumes Survey

Repository: 239999900 "Misc EMails"

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Neil

I have had very limited experience with straight civil engineering projects and their nature with costs dominated by estimated quantities or schedules of rates as they progress through each phase, but the following comments may help

· Errors which you have trouble with;

Acceptance of +or- 50% may be acceptable for very early stage feasibility civil engineering projects but for the building/civil projects that my experience covers clients and consultants would be seeking or expecting closer tolerances than that even at the earliest phase. For an indicative cost for a major project the range offered by the consultant would be stated as +or- 25 to 30% and even then the client would be expecting a lower error on the upside. For building project that I currently handle, my client expects to set a budget from the feasibility study estimates, that is a budget that will not be exceeded. The error range is therefore more likely to be -20% to +5%. But I believe that this may not be the error that other clients would be prepared to accept. Quantity Surveyors are generally used to provide estimating services for building and building/civil projects drawing on engineering estimates for certain components, e.g. civil and some building services, and they work with the PM and consultant team to provide consolidated estimates at each phase of the job. It is common practice for the QS to build into the overall figure estimates to contingency (for both design and construction) and escalation; these amounts will depend on the phase reached, but typically the figure for combined contingency could be 10-11% at PSP or Budget phase. It is much more common for the estimates to increase rather than achieve the minus error in practice. Clients are more often forced to trim their scope of work than receive the benefits of an overestimation.

We are finding that the market conditions are one of the dominant uncertainties and tend to remain so through most phases in the circumstances of a resource strapped construction industry. So that rather than the 'quantities' being the dominant factor it is increasingly the market climate that is 'a' if not 'the dominant factor. Hence to claim +or- 2% at tender stage is optimistic in the current climate. Market is both time and location dependent which reflect the available tenderers current commitments and willingness to take on work in more difficult or remote locations because of the cost of getting scarce labour, including sub-contractors, to such sites.

· What range of error you have been getting (best guess);

A recent and current major job in Canberra is currently running at some 10% over the budget and pretender estimates, despite the intention at 'sanction' or your 'planning & design' to develop the project within the budget figure Two other similar size projects that I have as PM in different regional locations have performed quite differently, affected largely by the different market conditions prevailing at the precise time tenders were called including workload of the respective selected tenderers. One project had a tender result within the project budget and with variations will be about 5% above the tender price and very slightly higher than the original budget when finished. The other tender outcome was some 24% under budget and with variations should finish better than 21% under that budget.

· What range of error you have got from different methods, eg end area vrs isopachyce triangulation;

No relevant comments

· Time taken in producing these volumes;

No relevant comments

· Any comments you have relating to the expectations project managers and

the limitations you have as designers in producing roadwork;s volumes; and

Covered above to some extent

· Anything else you can think of.

It may be that your assignment is attempting to look very specifically at

the affect of estimating accuracy on achievable level of accuracy on cost estimates; and if so my comments will be of little relevance.

Mervyn

Ph: 02 6245 1935

Fx: 02 6253 1911

Email: mervyn_cole@ghd.com.au

Neil Hughes/Canberra/GHD/AU

26/04/2006 04:36 PM

To

Douglas

Fox/Canberra/GHD/AU@GHD,

Mervyn

F

Cole/Canberra/GHD/AU@GHD, Robert
W Rosenbauer/Canberra/GHD/AU@GHD
cc

Subject
Fw: MX Volumes Survey

Repository: 239999900 "Misc EMails"

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Guys

I am having trouble getting a response on this so i was wondering if i could ask for your comments. I understand that i am looking for feedback on a transport/civil thing, however the project management side is of importance in this report as well.

Regards

Neil Hughes
Project Manager

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neil.hughes@ghd.com.au | T 61 2 6264 0853 | F 61 2 6253 1911

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Q Please consider the environment before printing this email

----- Forwarded by Neil Hughes/Canberra/GHD/AU on 26/04/2006 04:15 PM -----

Neil Hughes/Canberra/GHD/AU

27/02/2006 09:33 AM

To

David Nicholson/Melbourne/GHD/AU, Moya M Watson/Canberra/GHD/AU,
Geoff

Gardner/Canberra/GHD/AU, Shaun O'Brien/Canberra/GHD/AU

cc
 ayers@usq.edu.au
 Subject
 MX Volumes Survey

Repository: 239999900 "Misc EMails"
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Budget	±20	Appraisal viability to start, system design
Sanction	±10	Appraisal viability to approve project, obtain funding, allocate resources
Control	±5	Measure progress, assign resources
Tender	±2	Prepare tender

(Source: Turner 1999, p. 174)

Then this has been related to highway design as follows;

Table: Phase of Project, Design project Deliverables

Phase of Project (Turner 1999)	Deliverable	Adopted	% Error
FEASIBILITY (Proposal)	Feasibility Design	±50	
PLANNING and DESIGN (Budget)	Preliminary Sketch Plan		±20
PLANNING and DESIGN (Sanction)	Final Sketch Plan		±10
CONSTRUCTION (Control)	80% Design	±5	

CONSTRUCTION (Tender) 100% Design ±2

(Source: Adapted from Turner 1999, p. 174)

So further to above I would like your responses to the above issues of earthwork volumes. Any comments regarding your experience with roadwork's volumes would be greatly appreciated, ranging from;

- Errors which you have trouble with;
- What range of error you have been getting (best guess);
- What range of error you have got from different methods, eg end area vrs isopachyte triangulation;
- Time taken in producing these volumes;
- Any comments you have relating to the expectations project managers and the limitations you have as designers in producing roadwork;s volumes; and
- Anything else you can think of.

Also I have assumed that for limits of accuracy in general conditions of contract documentation is 10%, is this what you have used in other tendering documents????

Sorry again for the inconvenience because I know this is not work and a pain for you, so the best I can do is offer beer or wine for your trouble.

Regards

Neil Hughes
Project Manager

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