OPTIMIZATION OF HIGHWAY VERTICAL ALIGNMENT BY DIRECT SEARCH TECHNIQUE

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OPTIMIZATION OF HIGHWAY VERTICAL ALIGNMENT BY DIRECT SEARCH TECHNIQUE

submitted by **ERAY ÖZKAN** in partial fulfillment of the requirements for the degree of **Master Of Science In Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Ahmet Cevdet Yalçıner
Head of Department, **Civil Engineering** _______________

Inst. Dr. Soner Osman Acar
Supervisor, **Civil Engineering Dept., METU** _______________

Examining Committee Members:

Assoc. Prof. Dr. Murat Güler
Civil Engineering Dept., METU _______________

Inst. Dr. Soner Osman Acar
Civil Engineering Dept., METU _______________

Asst. Prof. Dr. Hediye Tüydes Yaman
Civil Engineering Dept., METU _______________

Inst. Dr. Engin Erant
Civil Engineering Dept., METU _______________

Prof. Dr. M. Özdemir Akyılmaz
____

Date: 07 May 2013

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Name, Last Name : Eray ÖZKAN

Signature :

ABSTRACT

OPTIMIZATION OF HIGHWAY VERTICAL ALIGNMENT BY DIRECT SEARCH TECHNIQUE

Özkan, Eray
M.Sc., Department of Civil Engineering
Supervisor: Dr. Soner Osman Acar

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During initial stages of geometric design of highway projects, generally a number of alternative horizontal alignments are developed. For any selected alternative horizontal alignment, the basic features of the geometric design are to be completed by establishing the vertical alignment of the roadway. Since for a given horizontal alignment there would be infinite number of vertical alignments conforming to the specifications, it is essential to use an optimization process in order to achieve the most economic design.

This study is focused on optimizing a vertical alignment already established by the designer. The governing cost item in relation to vertical alignment being the earthwork cost, it should be minimized to reach the optimum solution. Since the problem itself is a multivariable, complex and non-differentiable one, a heuristic search technique; namely the direct search technique is chosen for this purpose. In order to apply the optimization in an efficient and fast manner, AutoCAD Civil 3D software is selected and a program module in Visual Basic programming language is written to optimize the vertical alignment. The program module integrated to AutoCAD Civil 3D software is applied for some virtual projects and for a segment of a real highway project as well. The results showed that the method provides an incredible reduction in the earthwork costs of the projects by adjusting the vertical alignments slightly without changing the basic design features of the project.

Keywords: Highway, Vertical Alignment, Optimization, Earthwork

ÖZ

DİREKT ARAMA TEKNİĞİ İLE KARAYOLU DÜŞEY GÜZERGAH OPTİMİZASYONU

Özkan, Eray
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Karayolu geometrik tasarımının ilk aşamalarında genellikle bir kaç alternatif yatay güzergah oluşturulur. Seçilen herhangi bir alternatif yatay güzergah için geometrik tasarımın ana hatları, yolun düşey güzergahının oluşturulması ile tamamlanır. Seçilen bir yatay güzergah için tasarım kriterlerine uygun sonsuz sayıda düşey güzergah olabileceğinden, en ekonomik tasarıma ulaşmak için bir optimizasyon metodu kullanılması gereklidir.

Bu çalışma tasarımcı tarafından hâlihazırda oluşturulan bir düşey güzergahı optimize etmeye odaklanmıştır. Düşey güzergah ile ilgili ana maliyet kalemi toprak işleri maliyeti olup, optimum çözüme ulaşmak için bunun minimize edilmesi gerekmektedir. Problemin kendisi çok değişkenli, karmaşık ve türevlenebilir olmayan bir problem olduğu için, problemin çözümünde sezgisel bir arama tekniği olan direkt arama tekniği bu amaç için seçilmiştir. Optimizasyonu efektif ve hızlı bir şekilde uygulamak üzere AutoCAD Civil 3D yazılımı seçilmiş ve Visual Basic programlama dili kullanılarak düşey güzergahı optimize etmek için bir program modülü hazırlanmıştır. AutoCAD Civil 3D yazılımına entegre edilen program modülü bazı sanal projeler için olduğu gibi gerçek bir karayolu projesinin bir kesimi için de uygulanmıştır. Sonuçlar, metodun projenin temel tasarım özelliklerini değiştirmeden düşey ekseni bir miktar ayarlayarak toprak işleri maliyetlerinde önemli ölçüde azalma sağladığını göstermiştir.

Anahtar Kelimeler: Karayolu, Düşey Güzergah, Optimizasyon, Toprak İşleri

To my family…

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CHAPTER 1

INTRODUCTION

In our modern age, transportation is vital nearly for all the activities in our daily lives. There are several different modes, namely highway, rail, air and water transportation classified according to the vehicle and the movement type. Today, still the major part of the transportation worldwide is handled by highways.

For sustainable highway systems, land use planning and road network planning are critical concepts and they should be handled together. Different land uses create different demands and there are different network design strategies to be developed for different land uses in order to have sustainable transportation by minimizing congestion and increasing traffic safety. Therefore proper zoning plans and road network should be prepared to distribute the land use patterns, such as residential areas, shopping centers, trade areas, industrial facilities and others.

At the planning stage, land use study and traffic analysis will help the planners to conclude the functional class and geometric class on which the geometric design of the project to be based on. After land use study, traffic demand forecasting should be done to identify the present and the future needs, and to select the geometric class of the highway.

During the planning stage, the needs versus funds are carefully evaluated and for any candidate project the cost items are roughly examined and included in the feasibility study. The cost items to be considered in the economic analysis of highway projects are generally divided into two broad categories: (1) supplier costs, which are directly incurred by highway administrators, and (2) user costs incurred by highway users. The supplier costs are further divided in three categories: (a) construction, pavement, and other costs primarily depending upon the length of the alignment, (b) right-of-way costs including those associated with land and environmental impacts as well as impacts to stream and other water conduits, and (c) earthwork costs. The user costs are divided into three categories: (a) travel-time cost, (b) vehicle-operating cost, and (c) accident cost. The indirect costs associated with environmental damage are considered in order to protect environmentally sensitive regions such as wetlands and floodplains (Jha and Schonfeld 2004).

If a highway project is approved for implementation, it is expected that the corridor, the standards, the pavement type, and most of the geometric features of the project have already been decided during the feasibility study and known before the final design stage. Provided that the basic design features of the project are not changed and the revisions during the final design stage are minor, the changes in user costs and benefits with such revisions will be very small and can be considered negligible. It follows that the economic evaluation of the project during final design stage can be assumed to be controlled only by the construction cost which is subject to change with the minor revisions in the alignment.

During the final design stage, firstly the best locations for the expensive structures like bridges and tunnels are searched and the locations of those structures are fixed after extensive studies. Hence, the start and end points of those structures become control points. For a highway segment between such control points, the main cost factor is the earthwork cost. For finalizing the alignment design of such segments, the designer's purpose is to select the best alignment between those successive control points which would minimize the earthwork cost.

1.1. SCOPE OF THE STUDY

The earthwork cost minimization by changing the vertical alignment is a time consuming trial and error process. The designer first fixes the horizontal alignment and then by studying on the centerline ground profile will try to establish a vertical alignment. If the time permits, the designer would calculate the earthwork volumes and the cost and then reconstruct the vertical alignment and recalculate the volumes and the earthwork cost again. This process could be repeated a number of times but the designer would never be sure whether the vertical alignment with minimum cost would have been achieved or not. The level of success in selecting a satisfactory low cost alignment would be directly dependent on the experience and the skill of the designer. However it is sure that the success cannot be ascertained without using an efficient optimization process.

There are several researches in the literature summarized in Chapter 2 that aim to optimize the vertical alignment for a given horizontal alignment. But, the earthwork volume calculations in all these studies are based on the difference between the centerline ground profile and the grade line profile which is referred as the vertical alignment. Since the calculations of volumes in this manner are very rough, the optimization based on these volumes will also be rough and sometimes be seriously erroneous.

The purpose of this study is to create a useful, fast and applicable vertical alignment optimization method based on precise earthwork volume calculations. As discussed before, the alternative horizontal alignment and the template (cross section assembly) of the highway segment is assumed to be fixed beforehand and there are no highway bridges and tunnels between starting and end points of the alignment. The optimization will start on a base case where the vertical alignment is constructed by the designer. The objective function of the optimization process will only include earthwork costs, namely excavation, embankment and earthwork transportation costs. As discussed above, the variations of other probable cost factors, namely user costs and benefits which may slightly change in relation to the vertical alignment are not considered within the scope of this study.

In order to clarify the parameters and basis of calculations in this study; the geometric design of highway, the highway alignment, and the earthwork cost calculation subjects are summarized in the following sections.

1.2. GEOMETRIC DESIGN OF HIGHWAY

Geometric design of highways includes specifying the horizontal and the vertical alignments and the cross sections conforming to the design class and the selected standards.

1.2.1. HIGHWAY ALIGNMENT

Highway alignment is represented by the centerline of the highway route formed by straight lines and curves. Although highway alignment is a three-dimensional (3D) problem, in practice, it is reduced to two-dimensional (2D) alignments, namely, horizontal and vertical alignments.

For any selected design class and standards, the design speed is fixed and there are well defined design controls and criteria set forth to design a safe and comfortable operating highway.

The horizontal alignment is composed of straight portions and curves connecting them. Figure 1 demonstrates a horizontal alignment between terminal points A and B composed of straight lines and simple circular curves. The task is simply locating the centerline of the proposed highway on the plan view, considering the design standards. The horizontal alignment should also be compatible with the land use and the topography. The curves may be simple circular, or combination of transition curves and circular curves.

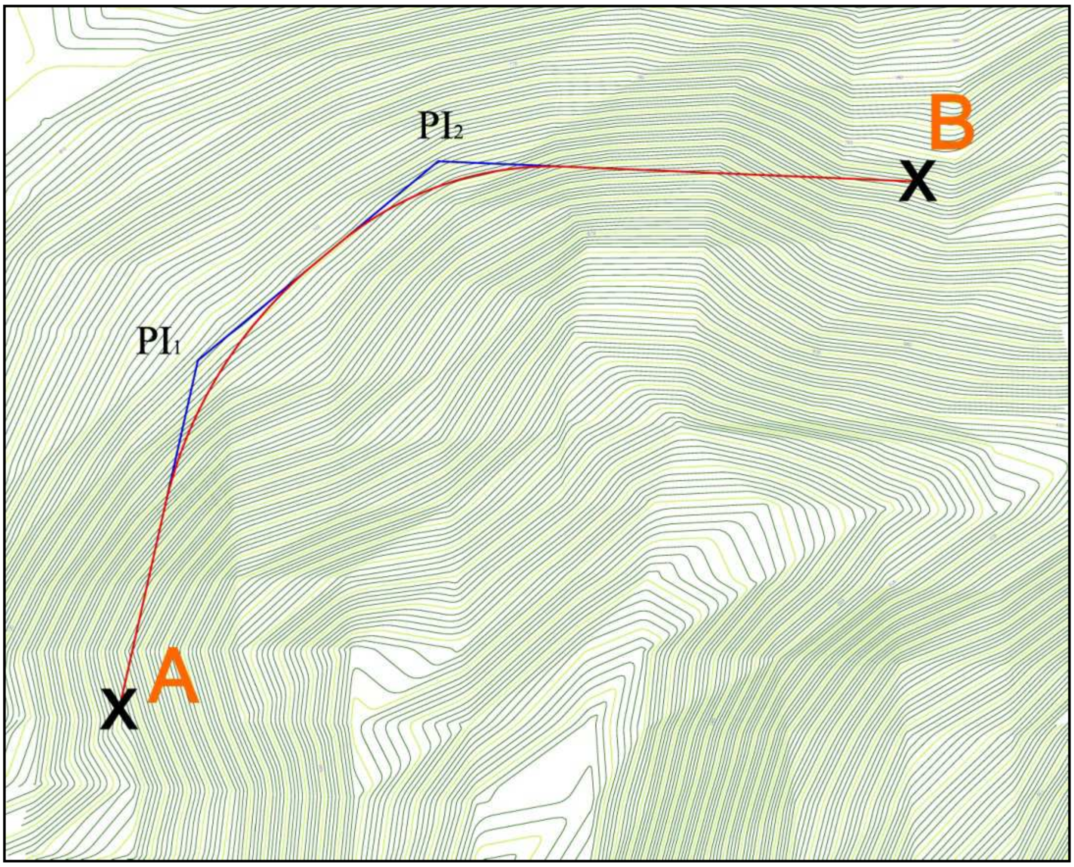

Figure 1: A typical horizontal alignment

On the horizontal curves, the transverse slope of the roadway is superelevated in order to decrease the centrifugal force acting on the vehicle. Figure 2 shows a typical superelevated highway curve segment.

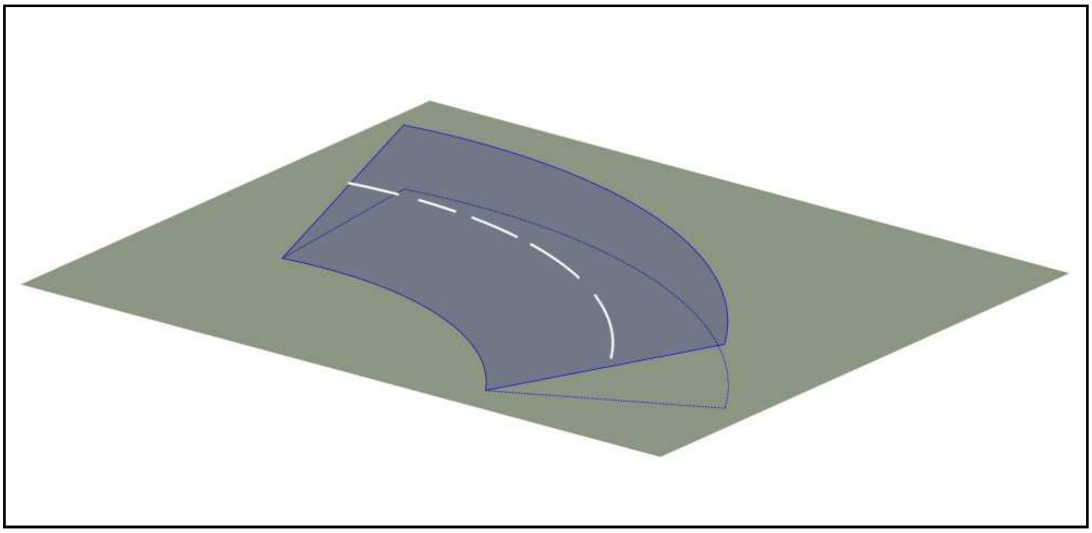

Figure 2: Superelevated highway curve segment

Design criteria are applied for horizontal curves and superelevation applications. In this stage, the designer will establish alternative horizontal alignments conforming to the standards and the constraints of the land use and topography. The efficiency is directly proportional to the designer's talent and experience.

After the horizontal alignment is fixed, the next stage is to establish the vertical alignment. The class and the standards of the project determine the maximum and minimum grades and the limitations for vertical curves. The vertical curves should satisfy the sight distance and comfort requirements for the design speed. For vertical alignment, first the ground profile along the horizontal alignment is created by reflecting the centerline elevations from the topographic map and then the vertical alignment is formed by drawing straight lines and placing parabolic vertical curves between crossing grade lines. These features of vertical alignment are shown in Figure 3 and Figure 4.

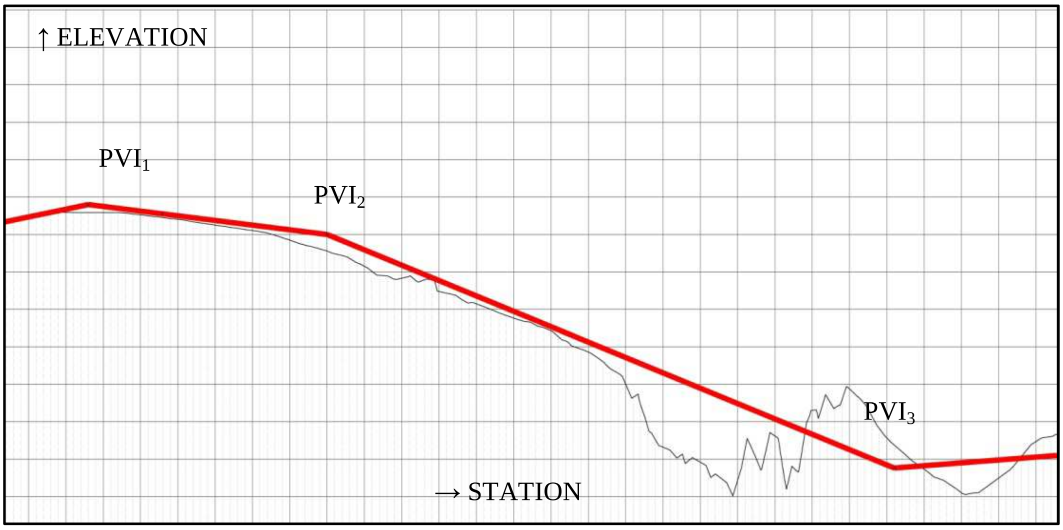

Figure 3: A typical vertical alignment

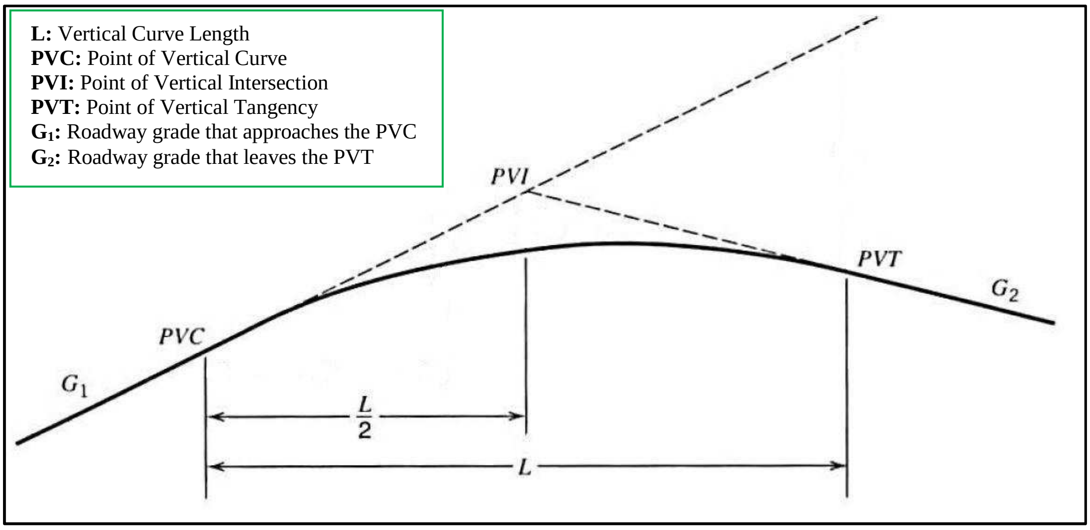

Figure 4: Geometry of parabolic vertical curve

1.2.2. CROSS SECTION

The template specifying the right of way width, the number of lanes, shoulder widths, ditches, cut-fill slopes and walkways are prepared by the designer. A typical cross section for a 4-lane divided highway is illustrated in Figure 5.

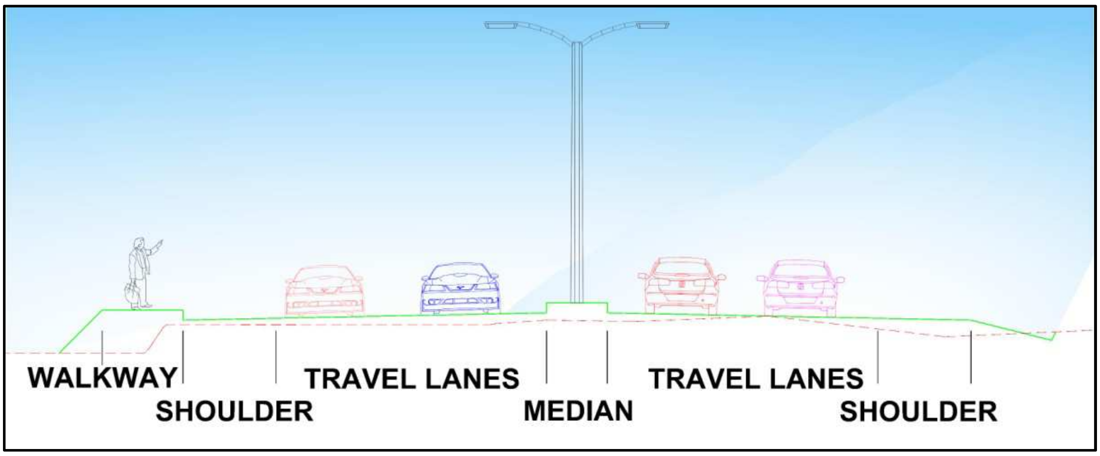

Figure 5: A typical cross section of a 4-lane divided highway

After generating the cross sections at definite intervals along the alignment, earthwork volumes can be calculated. In usual practice, first the cut and fill areas of the cross sections are calculated and then by using appropriate geometric models, the cut and fill volumes from station to station are calculated. Then the designer prepares the volume sheet to calculate the cumulative cut and fill volumes.

1.3. DESIGN SOFTWARE

Complexities of the highway design works and time limitations force the engineers to make use of computer software. The design software provides the designer very high flexibility to modify the design at any time very quickly.

The process of designing a transportation facility with a design software package usually begins with the preparation of the terrain file of the region where the highway is expected to pass. The terrain file is a digital model of the topography of the region. The CAD program can display the digital terrain in different styles as well as a topographic map with contour lines to enable the user to visualize the terrain of the region. Once this file is ready for use, the user can immediately generate trial horizontal and vertical alignments. The user also defines template cross sections by selecting the geometric features of the cross section.

Whenever the horizontal and vertical alignments and the cross section templates are fixed, the three-dimensional model of the project can be formed by the software. The software can also develop the cross-sections at all specified locations. Design software has the capability to revise the design rapidly and this is the main feature of the software. Whenever the design is revised the outputs are recalculated quickly, allowing the designer to try more alternative alignments. An example of highway design model displayed by CAD software is shown in Figure 6.

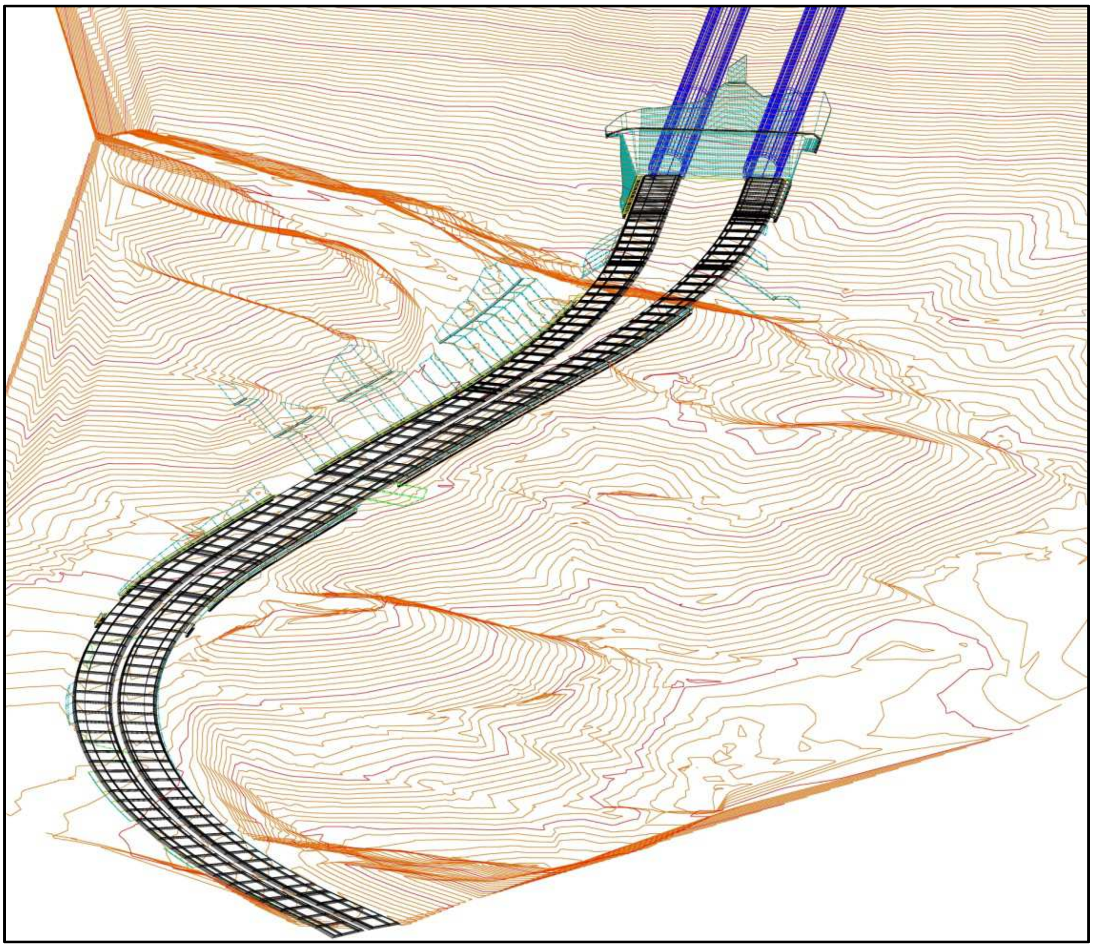

Figure 6: A sample isometric view of a highway design model generated by CAD software

1.4. EARTHWORK COSTS

Earthworks on a highway design contain all the cutting, filling and hauling of soil materials in order to establish the road base platform on the ground surface.

Cutting costs are incurred when the design road profile is lower than the ground profile. Filling costs are the costs of forming the embankments when the road profile is above the ground level. Although the unit price of excavation may vary with depth of cut and soil type, these costs are basically functions of the volume of earth moved. Transportation costs for hauling soil from borrow pits and/or to dumping sites are also involved. (Chew et al. 1989)

Earthwork costs are highly dependent on the soil characteristics at site. In Turkey, cut and fill unit prices are calculated per m^3 of soil for different soil and excavation types. According to the unit price list of General Directorate of Highways (Karayolları Genel Müdürlüğü, 2012), the unit price of cut is exactly the unit price of excavation of the soil, and the unit price of fill covers both the unit price of quenching and compaction of the soil when the cut materials with suitable soil quality are used in embankments. If additional materials are needed in embankment then the excavation cost of material at borrow pit should be added to the fill cost. The price list of General Directorate of Highways for earthworks for the year 2012 is given in Table 1.

Table 1: Price list of General Directorate of Highways, Directorate of Construction and Consultancy Tenders Section (Karayolları Genel Müdürlüğü, 2012) for earthworks

EARTWORKS PRICE LIST			
ITEM NO	**DEFINITION**	**UNIT**	**UNIT PRICE (TL)**
KGM/15.001/A	Cut of all types of soil with excavator and usage (soil from cut or close locations)	m^3	2.19
KGM/15.001/B	Cut of all types of soil with excavator and usage (soil from Borrow pit or to dump)	m^3	1.93
KGM/15.004/A	Cut of all types of soil with bulldozer and usage (soil from cut or close locations)	m^3	1.71
KGM/15.001/B	Cut of all types of soil with bulldozer and usage (soil from Borrow pit or to dump)	m^3	1.45
KGM/15.005	Cut of weak soil (botanik etc.) and usage	m^3	1.33
KGM/15.006/A	Cut of loose rock with excavator and usage (soil from cut or close locations)	m^3	3.04
KGM/15.006/B	Cut of loose rock with excavator and usage (soil from Borrow pit or to dump)	m^3	2.78
KGM/15.009/A	Cut of loose rock with bulldozer and usage (soil from cut or close locations)	m^3	2.91
KGM/15.009/B	Cut of loose rock with bulldozer and usage (soil from Borrow pit or to dump)	m^3	2.65
KGM/15.010/A	Cut of soft rock with excavator and usage (soil from cut or close locations)	m^3	5.40
KGM/15.010/B	Cut of soft rock with excavator and usage (soil from Borrow pit or to dump)	m^3	5.14
KGM/15.013/A	Cut of soft rock with bulldozer and usage (soil from cut or close locations)	m^3	5.31
KGM/15.013/B	Cut of soft rock with bulldozer and usage (soil from Borrow pit or to dump)	m^3	5.05
KGM/15.014/A	Cut of hard rock with excavator and usage (soil from cut or close locations)	m^3	6.04
KGM/15.014/B	Cut of hard rock with excavator and usage (soil from Borrow pit or to dump)	m^3	5.78
KGM/15.017/A	Cut of hard rock with bulldozer and usage (soil from cut or close locations)	m^3	5.95
KGM/15.017/B	Cut of hard rock with bulldozer and usage (soil from Borrow pit or to dump)	m^3	5.69
KGM/15.018/A	Cut of very hard rock with excavator and usage (soil from cut or close locations)	m^3	6.45
KGM/15.018/B	Cut of very hard rock with excavator and usage (soil from Borrow pit or to dump)	m^3	6.19
KGM/15.023/A	Cut of very hard rock with bulldozer and usage (soil from cut or close locations)	m^3	6.36
KGM/15.023/B	Cut of very hard rock with bulldozer and usage (soil from Borrow pit or to dump)	m^3	6.10
KGM/2205	Quenching and compaction of all types of soil	m^3	1.49
KGM/2206	Quenching and compaction of all types of loose rock	m^3	0.80
KGM/2207	Compaction of all types of rock	m^3	0.25

Unit prices of hauling, and transportation of waste and borrow materials are calculated by the relations given by General Directorate of Highways (Karayolları Genel Müdürlüğü, 2012).

The relation for the unit price of hauling up to 10.000m distance is given by:

$$F_{(Haul)} = 1.25x0.00046xKx\sqrt{M} - 0.00575xK \quad (1)$$

Where,

$F_{(Haul)}$: unit price of hauling (TL/m3)

K : unit price constant (yearly published by KGM, 176 for year 2012,

$\sqrt{M}$: is the weighted average of square roots of mean hauling distances determined from mass haul diagram.

The relation for the unit price of transportation of waste and borrow up to 10.000m distance is:

$$F_{(Waste)} = F_{(Barrow)} = 1.25x0.00034xKx\sqrt{M} - 0.00425xK \quad (2)$$

Where, $F_{(Waste)}$ and $F_{(Barrow)}$ define prices of trasnportation of waste and borrow respectively in TL/m^3. K and $\sqrt{M}$ are as defined Eq. 1.

CHAPTER 2

LITERATURE REVIEW

2.1. STUDIES ON HIGHWAY ALIGNMENT OPTIMIZATION

Vertical alignment design of a highway has a major effect on the safety, construction cost and operation cost of a highway. The importance of the optimum design concept was realized and the subject was studied since the 1960s with the increase in the usage of computers.

Theoretically, highway alignment optimization problem involves an infinite number of alternatives to be evaluated. In some previous applications the optimization problem was formulated as a cost minimization problem in which cost functions were non-differentiable, noisy and implicit. Thus, it is inevitable to use fast and efficient search algorithms to solve such a problem (Kim et al., 2005).

At the earlier studies on optimization of horizontal and vertical alignments simultaneously, Chew et al. (1989) has used numerical research while calculating the earth volumes from a basic cross section. Whereas on later studies the earth volumes are calculated from profile view, which do not account any cross sectional areas. Some of these are; Kim et al (2002, 2004, 2007) with stepwise genetic algorithms and with genetic algorithms, Jha and Schonfeld (2004) with genetic algorithms. In the study of Easa (1988) on optimization of vertical alignment of highway, a simple cross-section template was used for calculating the earthwork volumes in the solution with linear programming. Some other vertical alignment optimization studies in which the earth volumes are estimated from profile view are; Goh et al. (1988) with dynamic programming and state parameterization model, Moreb (1995) with linear programming, Fwa et al. (2002) with genetic algorithms and Göktepe et al (2005) with dynamic programming.

The earthwork volumes calculated from profile view can lead the progress to very rough and sometimes seriously wrong alignment analysis. To obtain more efficient results, Göktepe et al. has developed “Weighted Ground Line Method” on vertical alignment optimization studies (Göktepe et al. 2003, 2004, 2005, 2009) by locating the vertical alignment on the volume centers of the cross sections. Still the most precise work can only be supplied by calculating the earthwork volumes from the design templates.

The optimization methods of those studies in literature are successful within their scopes. However, none of them would be adequately used efficiently in a real life design process, because of the complexity of creating the required model assembly, the volume calculation method from centerline profile view and the disadvantages listed in this chapter.

2.2. OPTIMIZATION METHODS

Optimization is the process of maximizing or minimizing a desired objective function while satisfying the prevailing constraints (Belegundu and Chandrupatla, 1999). Optimization of highway alignment is a non differentiable, complex and multivariable problem.

The traditional theoretical optimization techniques require the problem to be formulated mathematically. This requirement presents a severe limitation in applying the techniques to solve the vertical alignment problem. In a real-life highway design problem, not all constraints and requirements can be easily quantified mathematically. Varying ground conditions from one road segment to another and special discrete controls or constraints in specific points make mathematical modeling by the conventional optimization techniques extremely difficult.

Kim at al. (2005) summarized the studies on highway alignment optimization and the deficiencies of the existing highway alignment optimization methods as given in Table 2 and Table 3.

Table 2: Studies on highway alignment optimization (from Kim et al., 2005)

Target for optimizing	Types of approach	References
Horizontal alignment	Calculus of variations	Wan (1995), Howard et al. (1968), Thomson and Skyes (1988), and Shaw and Howard (1981.1982)
	Network optimization	OECD (1973). Turner and Miles (1971), Athanassoulis and Calogero (1973), Parker (1977), and Trietsch (1987a,b)
	Dynamic programming	Hogan (1973) and Nicholson et al. (1976)
	Genetic algorithms	Jong (1998)
Vertical alignment	Enumeration	Easa (1988)
	Dynamic programming	Puy Huarte (1973), Murchland (1973), Goh et al. (1988), and Fwa (1989)
	Linear programming	ReVelle et al. (1997) and Chapra and Canale (1988)
	Numerical search	Hayman (1970), Goh et al. (1988), Robinson (1973), Fwa (1989), and MINERVA (OECD, 1973)
	Genetic algorithms	Jong (1998)
Horizontal and vertical alignment simultaneously	Dynamic programming	Hogan (1973) and Nicholson et al. (1976)
	Numerical research	Chew et al. (1989)
	Two-stage optimization	Parker (1977) and Trietsch (1987a)
	Genetic algorithms	Jong (1998), Jha (2000) and Kim (2001)

Table 3: Deficiencies of the existing highway alignment optimization methods (from Kim et al., 2005)

Methods	Deficiencies
Calculus of variations	●Requires differentiable objective functions ●Not suitable for discontinuous functions ●Tendency to get trapped in local optima
Network optimization	●Outputs are not smooth ●Not suitable for continuous search space
Dynamic programming	●Outputs are not smooth ●Not suitable for continuous search space ●Not applicable for implicit functions ●Requires indepencies among subproblems
Enumeration	●Not suitable for continuous search space ●Inefficient
Linear programming	●Not suitable for non-linear cost functions ●Only covering limited number of points for gradient and curvature constraints
Numerical search	●Tendency to get trapped in local optima ●Complex modeling ●Difficulty in handling discontinuous cost items

The very large number of feasible vertical alignment solutions in a typical highway design problem also renders most conventional optimization techniques unsuitable for practical applications of road alignment analysis (Fwa et al. 2002).

For a real life highway optimization problem, there exists infinite number of possible vertical alignments. Even for a 1km length highway segment within the vertical grade limit of 6%, assuming one PVI at every 200m horizontal distance and 1m elevation grids, there exist 25+49+49+25=148 possible PVI locations. Thus, there exist 25x49x49x25=1,500,625 possible vertical alignments. The possible PVI locations are demonstrated in Figure 7.

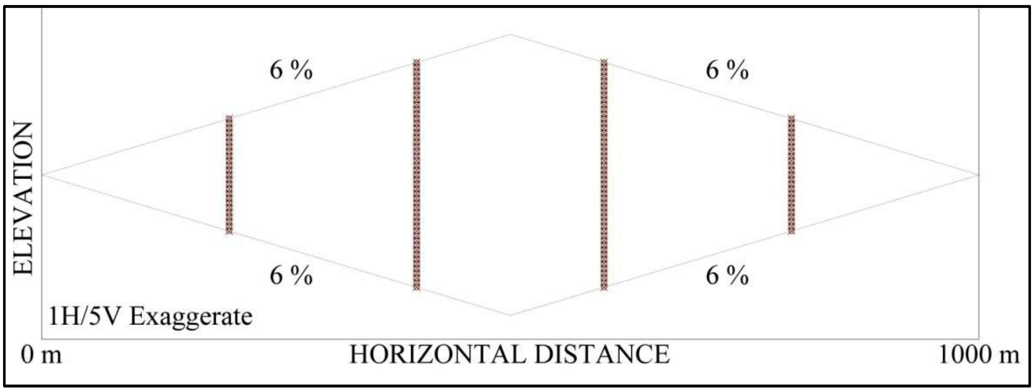

Figure 7: The possible PVI locations for a 1000m highway piece for 6% grade limitation

Because the formulation of the earthwork volume calculation is very complicated, it is not practical and possible to reach the absolute optimal solutions in real life problems. In this respect, heuristic algorithms are considered as the efficient solution tools since they lead to an approximate but often satisfactory solution in tractable time. Genetic Algorithms, Tabu Search and Random Search are some of the well-known heuristic methods. On all of the heuristic methods, samples for comparison are created either by modifying only the first sample or some other samples individually.

In this study, the first sample or the base case vertical alignment is the one that the design engineer constructs. So that the geometric features like the gradients, the locations and lengths of vertical curves and approximate locations of tunnels or intersections are already determined manually. The base case vertical alignment is defined by the locations of PVI's of the designer's initial vertical alignment. To create the sample space, the locations of PVI's are altered within a framework where the neighbor points around old PVI's are defined by shifting them both in station and elevation. By this means a stepwise bounded direct search method is utilized to optimize the vertical alignment.

Direct search algorithm is very generic, simple and any time algorithm. It is iterative and starts from a previous solution, examines all the neighbor sample space and chooses the best one among the new solutions. The algorithm terminates either when it reaches the best among all the neighbors, or when it reaches the specified number of steps. In this study, the algorithm stopped when the best sample is detected.

Besides the advantages of the direct search algorithm, there are some disadvantages like; the result is strongly dependent on the initial sample, and there is a high probability of getting trapped into local minimum or maximum. In this study, the sample space is directly dependent on the initial base case solution of the design engineer but it is not a disadvantage since the purpose is to find the optimum solution close to the designer's initial solution. The sample space searched for the optimum solution is going to be bounded to include the vertical alignment solutions that meet the design criteria. On the other hand the method will be applied in stepwise manner with varying station and elevation shift distances, normally reducing the magnitude of the shift in every successive step in order to minimize the probability of getting trapped into a local minimum.

In order to work on a usable and practical methodology, all the earthwork volumes should have been calculated from the volume difference of highway surface and ground surface; directly or traditionally by cross section work. For that reason; to calculate the volumes and the costs correctly; a CAD program, namely the AutoCAD Civil 3D, is selected as the working platform.

Today in highway design works, designers prefer to use CAD programs by which the highway can be modeled in two-dimensional plan view and two-dimensional profile view and also a three dimensional view and these models can be displayed to the user for interactive working. The AutoCAD Civil 3D software, which is a universally well-known CAD program with the integrated highway design module, is chosen as the working platform for optimization process of this study.

Before and after each step, the mass haul diagram for every solution is to be constructed and earthwork transportation costs are calculated separately by considering economic hauling strategy. By summing up the earthwork transportation cost and the cut and fill costs at the end of each step, the effect of the variation of earthwork transportation is also included as a cost parameter in the optimization process.

CHAPTER 3

METHODOLOGY

To minimize the earthwork costs, the simple direct search is applied in stepwise manner. "The Method of Hooke and Jeeves" (Basic Optimization Methods, 1984) is adopted to the study by repeating the selection and the exploration phases until the solution for the final step is achieved.

First, the initial exploration is carried out for the neighbor points generated around the first Point of Vertical Intersection (PVI) by shifting it with specified horizontal and vertical distances. The first PVI is moved to the neighbor point which releases the lowest cost among all. The same process is applied for all PVI points in sequence. The process is repeated starting from the first PVI every time until no more cost reduction can be achieved for the specified vertical and horizontal shifts. The procedure up to this point is counted as the first step. The earthwork transportation cost is also calculated at the end of the first step to include its effect. After the completion of the first step with the initial vertical and horizontal shift distances, the vertical and horizontal shift distances are reduced and the whole process is repeated. Depending on the accuracy needed the process can be repeated several times. The flow chart for the method is given in Figure 8.

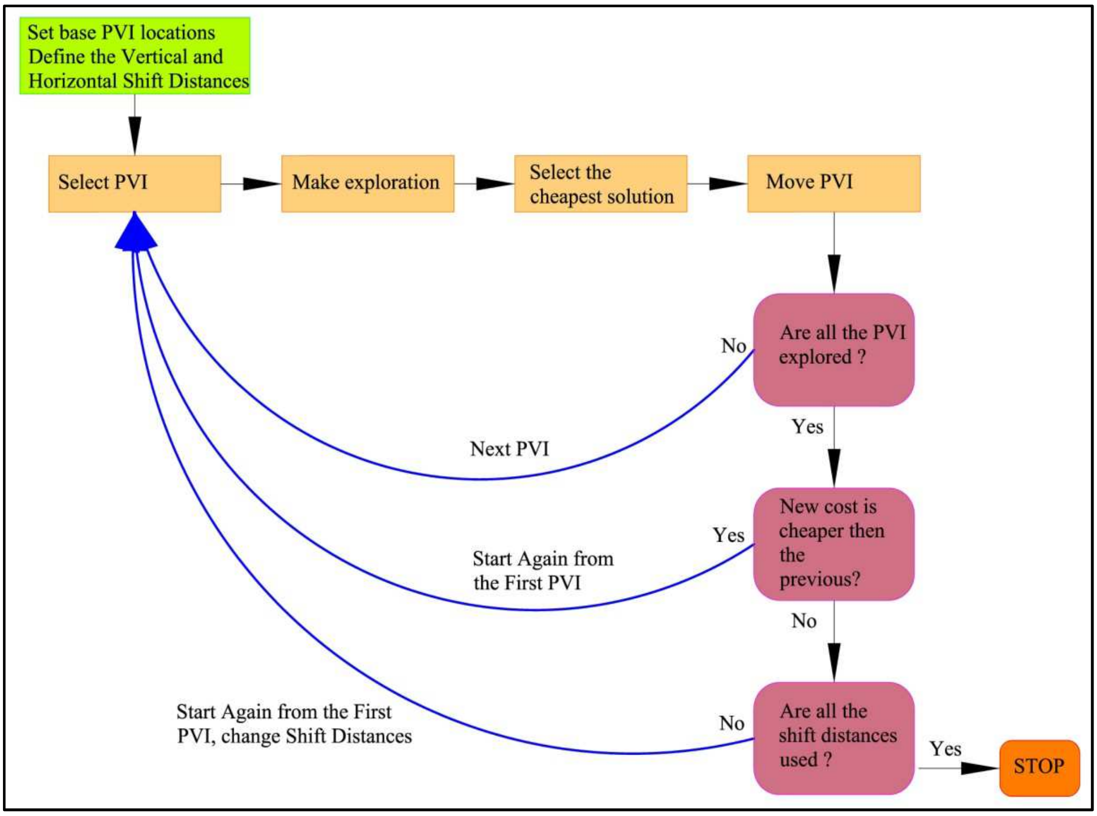

Figure 8: Flowchart of stepwise direct search technique used

3.1. OBJECTIVE FUNCTION

The objective function for the optimization process is to get minimum total earthwork cost. The earthwork costs are calculated by the relations given in Eq.'s 3 to 9.

$$min\ C_{(earthwork)} = min\ [C_{(cut)} + C_{(fill)} + C_{(transport)}] \quad (3)$$

where; $C_{(earthwork)}$ is the earthwork cost,
$C_{(cut)}$ is the cut cost
$C_{(fill)}$ is the fill cost
$C_{(transport)}$ is the earthwork transportation cost

$$C_{(cut)} = V_{(cut)} x\ F_{(cut)} \quad (4)$$

where; $V_{(cut)}$ is the cut volume
$F_{(cut)}$ is the unit price of cut per m^3

$$C_{(fill)} = V_{(fill)} x\ F_{(fill)} + V_{(exc)} x\ F_{(exc)} \quad (5)$$

where; $V_{(fill)}$ is the fill volume
$F_{(fill)}$ is the unit price of fill per m^3
$V_{(exc)}$ is the borrow pit excavation volume
$F_{(exc)}$ is the unit price of borrow pit excavation per m^3

$$C_{(Transport)} = C_{(Haul)} + C_{(Waste)} + C_{(Borrow)} \quad (6)$$

where; $C_{(Haul)}$ is the hauling cost
$C_{(Waste)}$ is the waste material carriage cost
$C_{(Borrow)}$ is the borrow material carriage cost

$$C_{(Haul)} = V_{(Haul)} x\ F_{(Haul)} \quad (7)$$

where; $V_{(Haul)}$ is the hauling material volume
$F_{(Haul)}$ is the unit price of hauling per m^3 (from formula 1)

$$C_{(Waste)} = V_{(Waste)} x\ F_{(Waste)} \quad (8)$$

where; $V_{(Waste)}$ is the waste material volume
$F_{(Waste)}$ is the unit price of carriage per m^3 (from formula 2)

$$C_{(Borrow)} = V_{(Borrow)} x\ F_{(Borrow)} \quad (9)$$

where; $V_{(Borrow)}$ is the borrow material volume
$F_{(Borrow)}$ is the unit price of carriage per m^3 (from formula 2)

The unit prices of cut and fill ($F_{(cut)}$ and $F_{(fill)}$) are selected according to the soil type and excavation type from unit price list. Also borrow pit excavation cost is included to the fill cost in cases when additional material is needed after the consumption of usable cut materials. The transportation cost ($C_{(transport)}$) is calculated by multiplying the transported earth volumes determined from mass-haul diagram by the unit prices calculated by the relations given as Eq.1 and Eq.2 using the overall average haul distance, the average distance to waste area and the average distance to borrow pit.

3.2. VARIABLES

To minimize the objective function, the variables defining the vertical alignments are the locations of PVI determined by their elevations and station Km's. For simplicity, the locations are expressed by the coordinates x and y as shown in Figure 9.

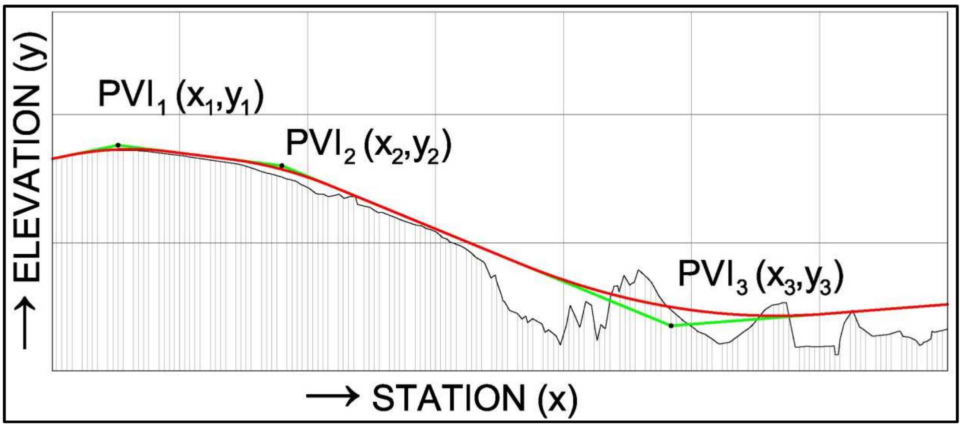

Figure 9: Variables defining vertical alignment; x_i, y_i

3.3. VERTICAL AND HORIOZONTAL SHIFTS

The location of any PVI can be altered by changing its elevation or station, or both. 8 neighbor points are created for each PVI by adding and subtracting the selected vertical and horizontal shift distances, ∆x and ∆y to the coordinates of the PVI. The generated neighbor points around PVI's are demonstrated in Figure 10.

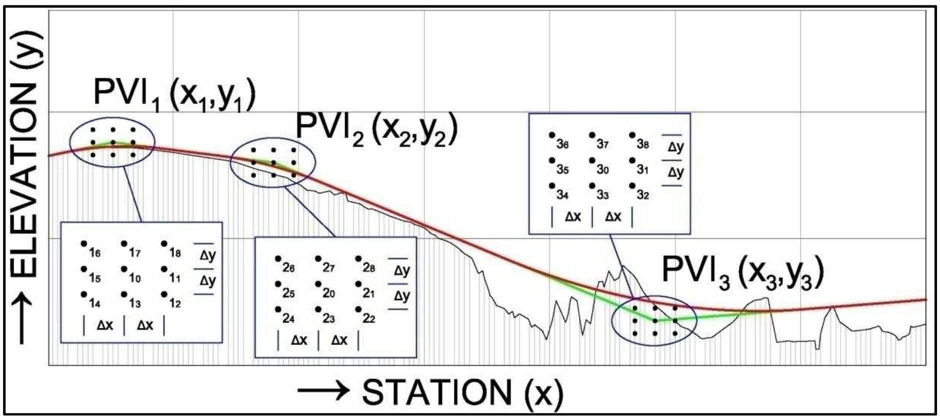

Figure 10: Neighbor points

In order to select efficient and meaningful shift distances, Δx and Δy, for the steps of optimizing process, the variation of earthwork cost by moving the PVI's by different Δx and Δy values should be studied. For this purpose, a virtual highway design of 1 km length with a vertical alignment with 3 PVI's is created. This virtual highway is also studied in detail in CHAPTER 6 as "Virtual Road 1: Flat Terrain" and will be also called as "Study road" throughout this chapter. The horizontal and vertical alignments of the study road are shown in Figure 11 and Figure 12.

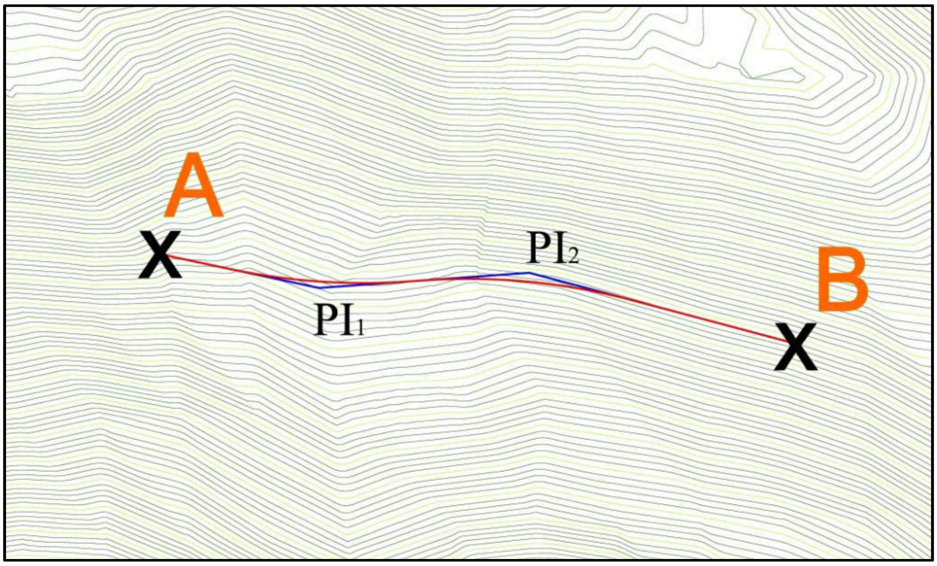

Figure 11: Study road horizontal alignment

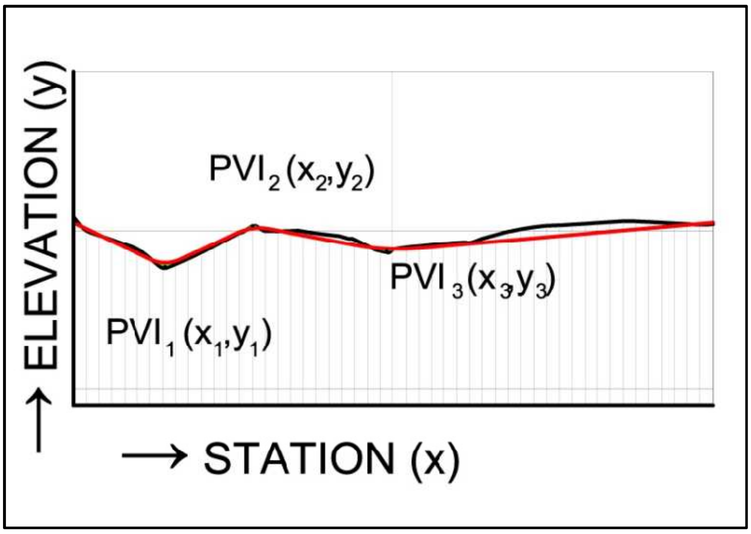

Figure 12: Study road vertical alignment

First, the PVI locations are changed by moving them in negative and positive x directions with the horizontal shift distances sequentially increased by 1m intervals and the earthwork costs are calculated for each new PVI position. The cost variations for all three PVI's are illustrated in Figures 13 to 15. As can be observed from the figures, there are local minimum and maximum points making the graph fluctuating. As a precaution, step size of Δx of the first step should be selected large enough to avoid getting trapped into those local points.

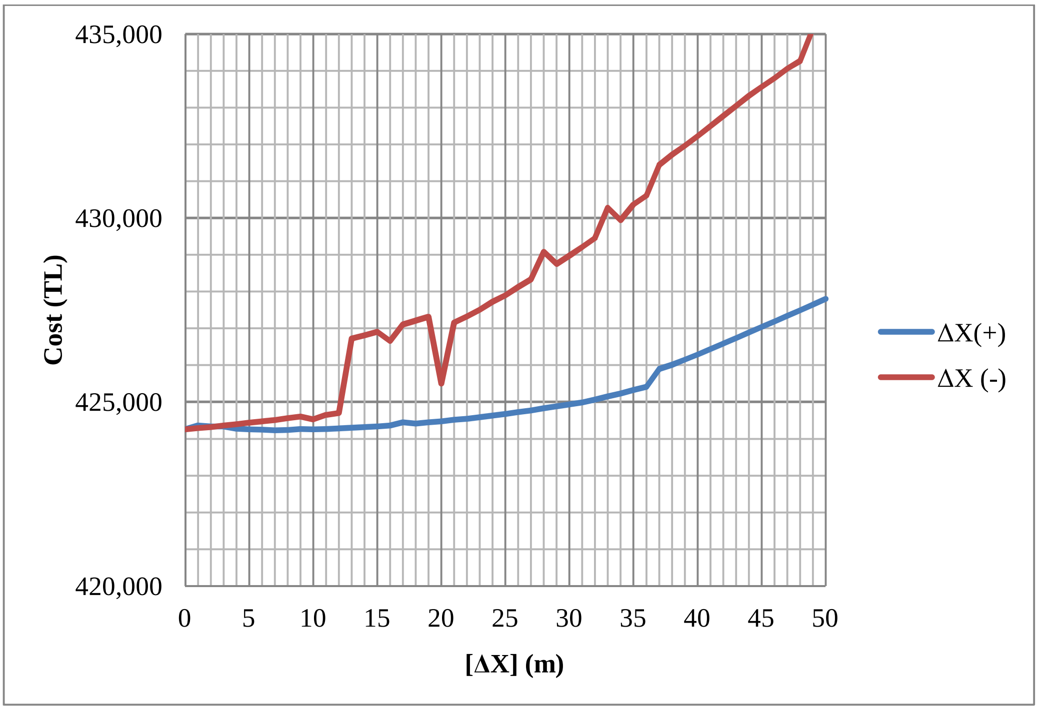

Figure 13: Earthwork cost variation of the study road with the movement of PVI$_1$ in horizontal direction

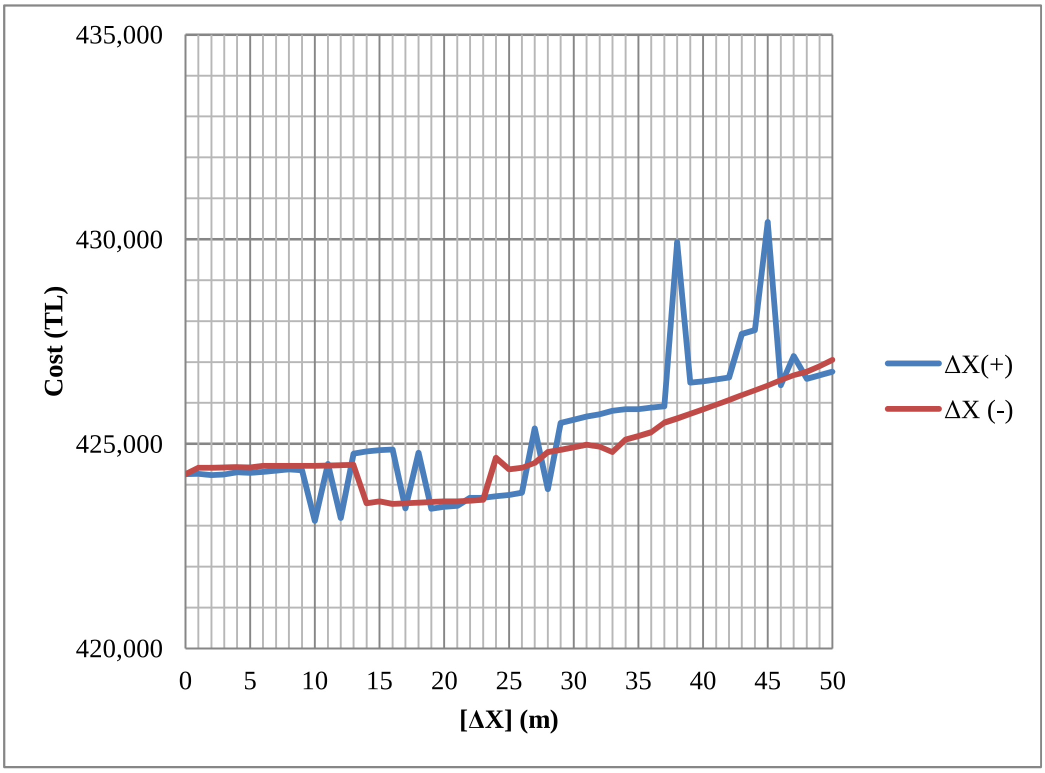

Figure 14: Earthwork cost variation of the study road with the movement of PVI$_2$ in horizontal direction

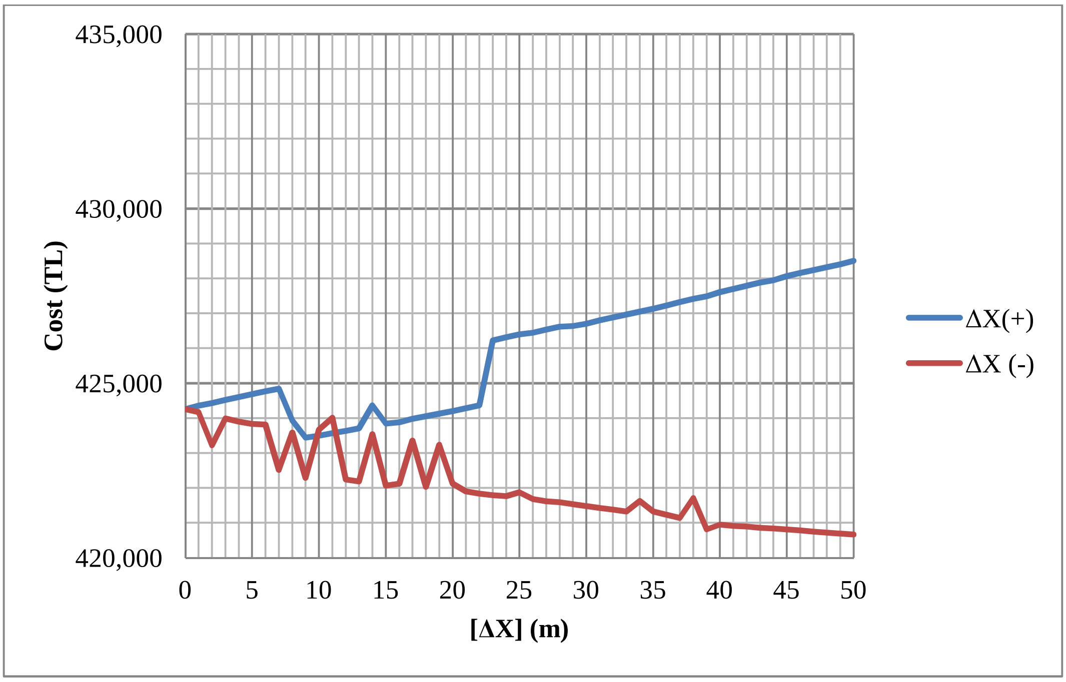

Figure 15: Earthwork cost variation of the study road with the movement of PVI_3 in horizontal direction

The same process is applied to all three PVI's in vertical direction with variable Δy distances also. Similarly, each PVI is relocated by moving both downwards and upwards with increasing Δy distances by 0.1m intervals up to 1m, and 1m intervals up to 10m sequentially. The cost variations for all three PVI's due to change in elevations are illustrated in Figures 16 to 18. Unlike the Δx search, the local minimum and maximum points are nearly not observed within 10m interval.

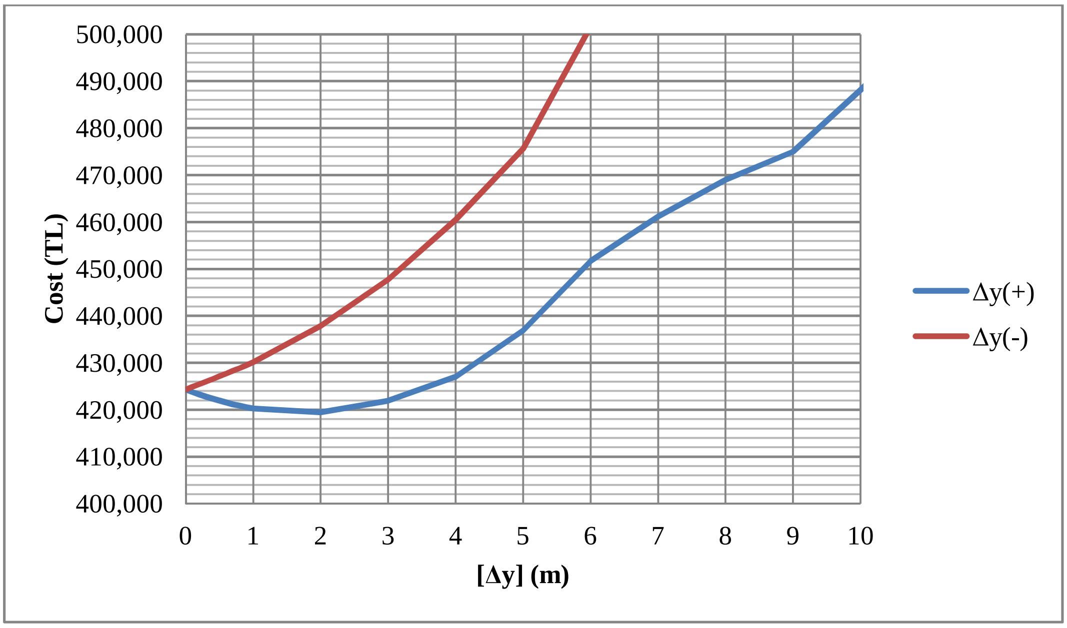

Figure 16: Earthwork cost variation of the study road with the movement of PVI_1 in vertical direction

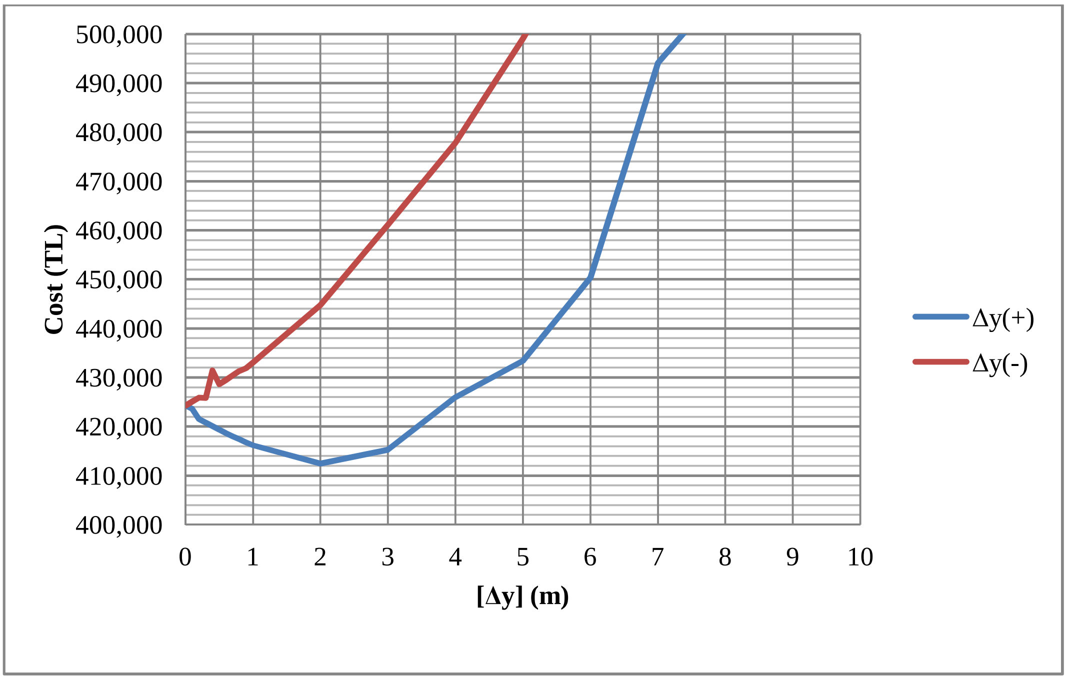

Figure 17: Earthwork cost variation of the study road with the movement of PVI_2 in vertical direction

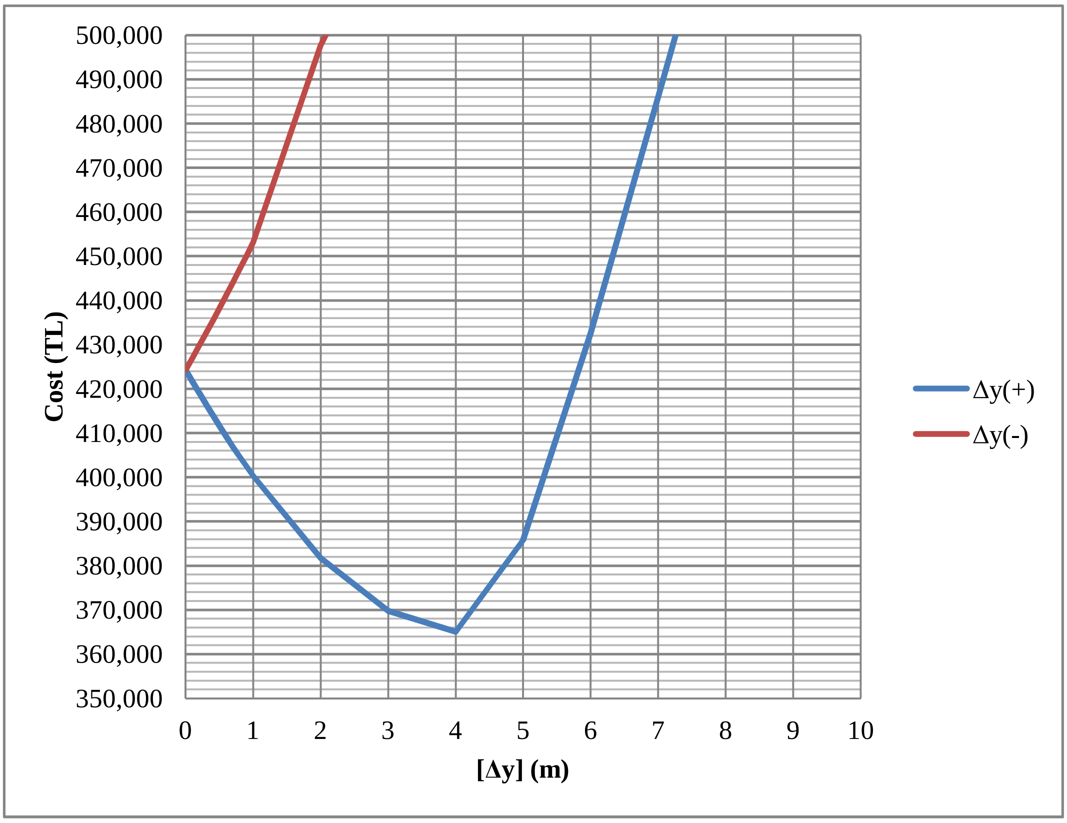

Figure 18: Earthwork cost variation of the study road with the movement of PVI_3 in vertical direction

Results of the investigation on the variation of cut and fill cost with the change of shift distances showed that the change in the elevation (y) of the PVI has a greater effect in comparison to the change in the station (x) of the PVI. For the Δx values up to 50 m, costs varied between 420.000 TL and 435,000 TL. On the other hand, with a change of 8m in elevation results in a cost value exceeding 500,000 TL. Based on these results, it is reasonable to choose Δy values smaller than Δx values.

For the study road, generally the cost is increased when the PVI's are shifted to new locations with Δx greater than 20m and Δy greater than 5m on both positive and negative directions. On the other hand, when PVI's are shifted with Δx smaller than 2m and Δy smaller than 0.1m, the change in the cost is very small and can be considered as negligible.

3.4. SELECTION OF THE VERTICAL AND HORIZONTAL SHIFT COUPLES

Since Δx-Δy couples should be selected for the successive steps of the optimizing process, it is required to investigate the variation of the cut and fill costs by shifting the PVI's both in vertical and horizontal directions simultaneously. For this purpose, based on the results of the prior investigation above, 6 Δx-Δy couples given in Table 4 are chosen to create meshes for every PVI as shown in Figure 19.

Table 4: Trial meshes with various shift couples

	MESH1	MESH2	MESH3	MESH4	MESH5	MESH6
Δx (m)	20.0	15.0	10.0	8.0	5.0	2.0
Δy (m)	4.0	3.0	2.0	1.0	0.5	0.1

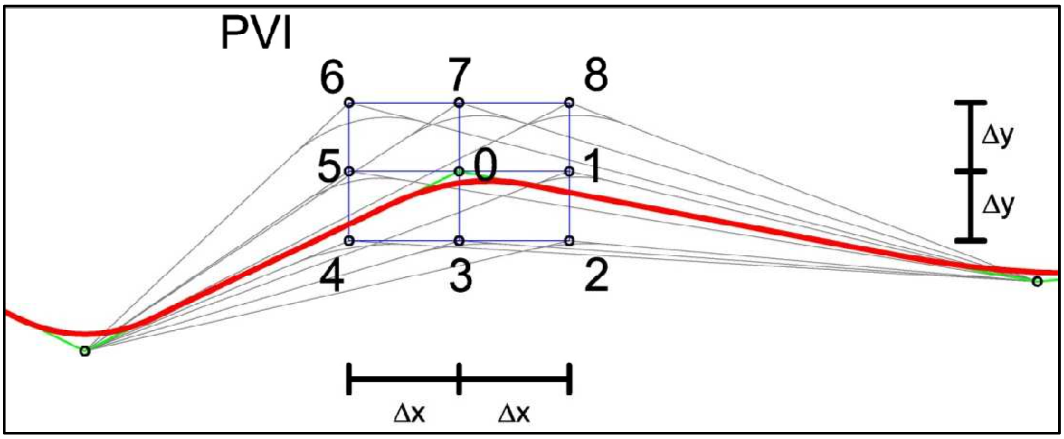

Figure 19: Mesh structure

In Figures 20 to 22, each of the 8 radial directions symbolizes the increasing cost from center to outside for every neighbor point of each PVI. And the costs calculated for each mesh is represented by an octagon with a different color created by connecting the costs observed at neighbor points. Moreover, in order to make a comparison, the initial cost is represented as an extra octagon.

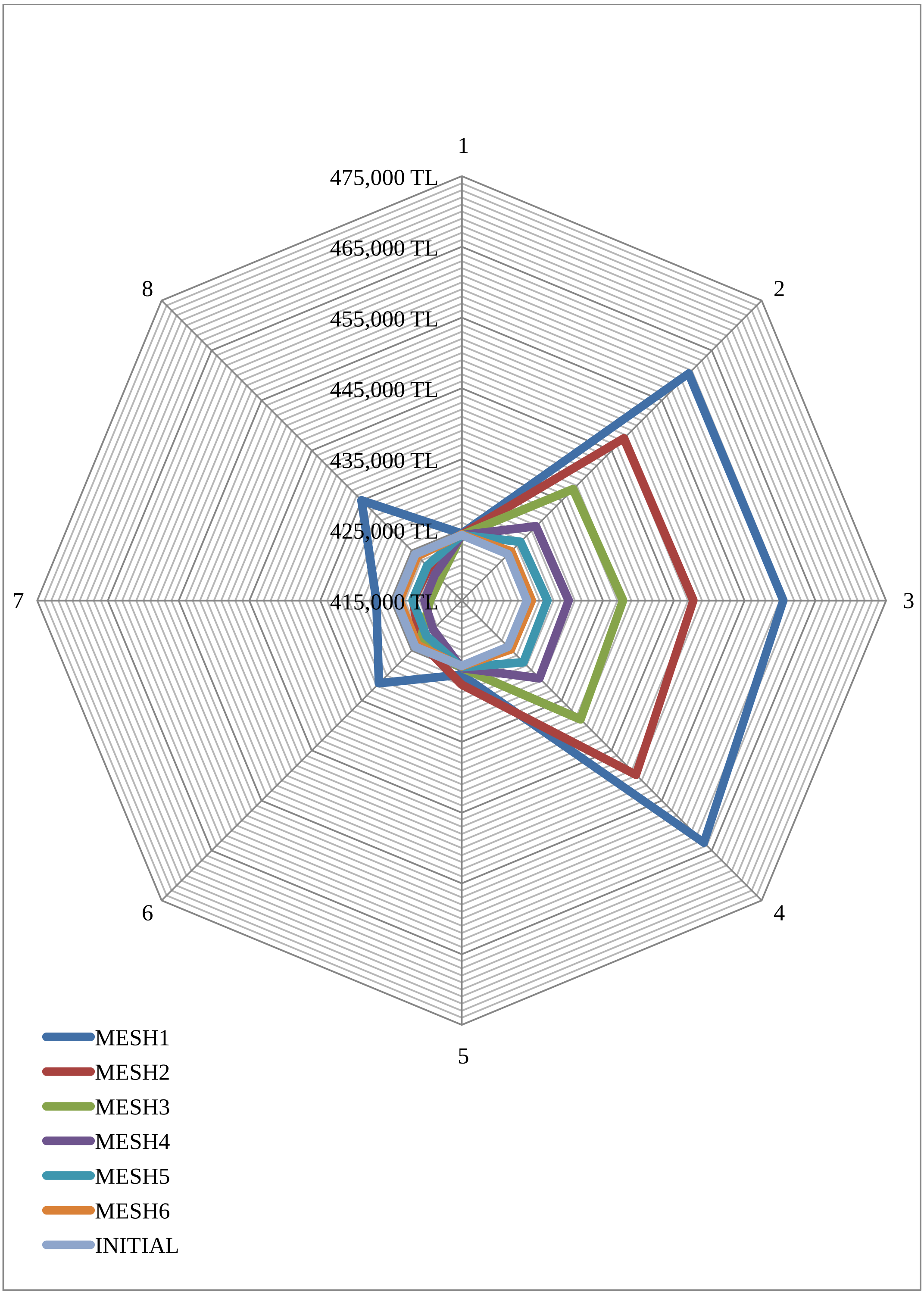

Figure 20: Earthwork cost variation of the study road with the movement of PVI_1 to neighbor points

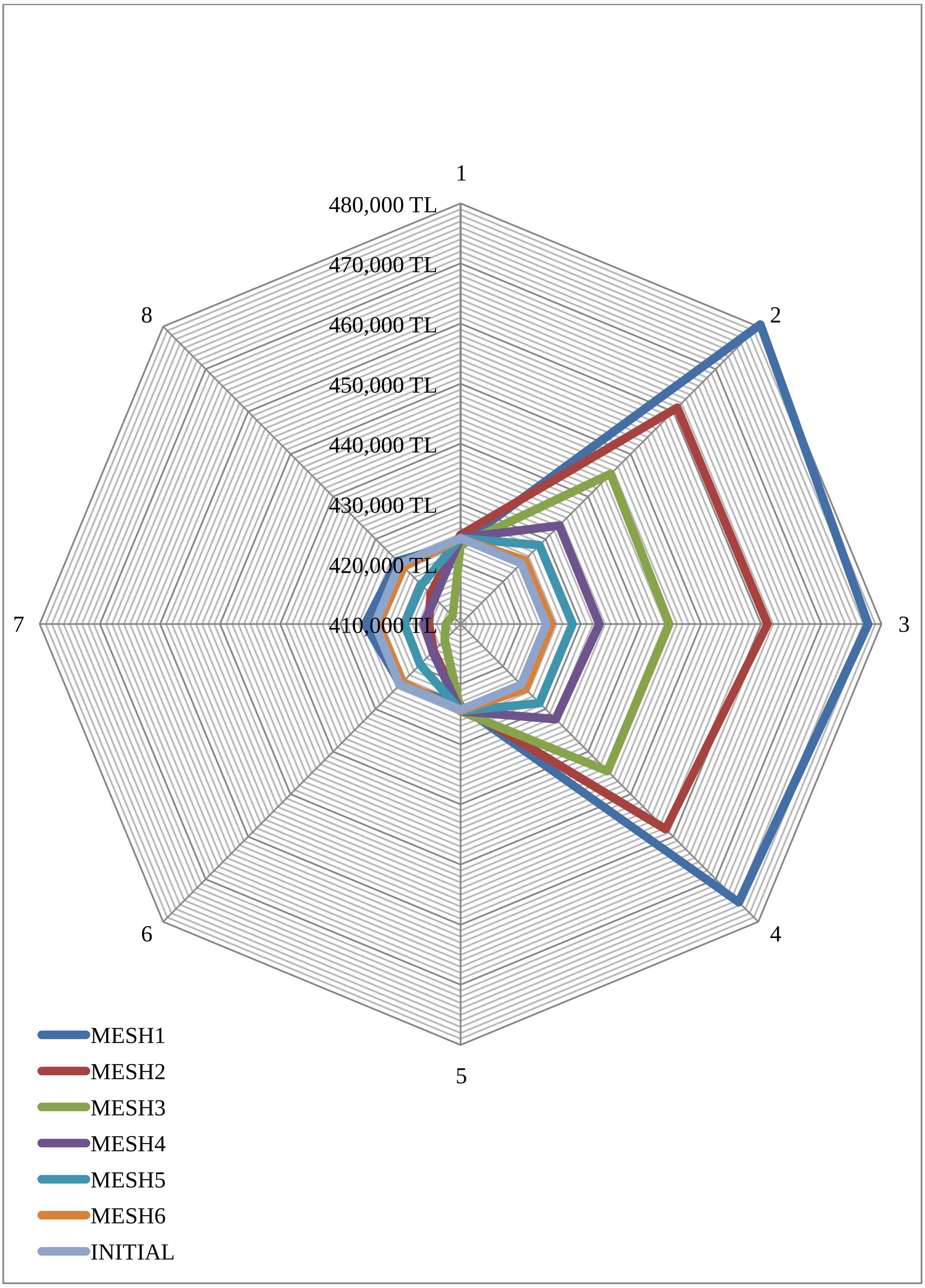

Figure 21: Earthwork cost variation of the study road with the movement of PVI_2 to neighbor points

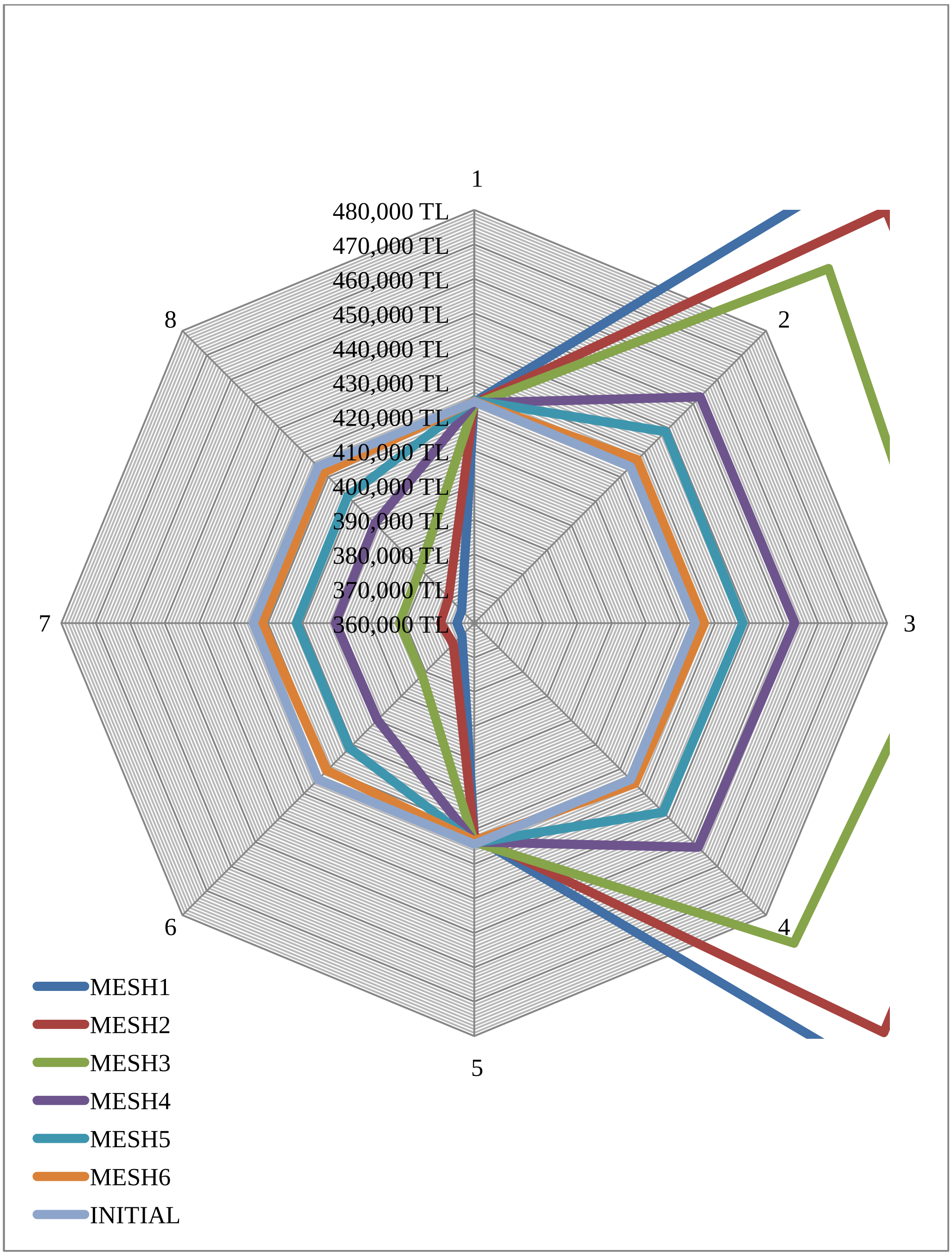

Figure 22: Earthwork cost variation of the study road with the movement of PVI_3 to neighbor points

The results presented in Figures 20 to 22 indicate that with the meshes 1 and 2, there is a possibility to miss the positions of PVI's corresponding to the minimum cost because the shift distances are too big. Therefore mesh 3 is selected for the first step of the optimization in order to not to miss the optimum solution positions of PVI's. Although choosing mesh 3 instead of mesh 1 or 2 may increase the run number for the cases with optimum solution point far from the initial, this will not limit the search space since the exploration process is repeated until the cheapest position is reached.

It is observed that the changes in the excavation and embankment costs for mesh 6 are very low being less than 1% of the initial cost. Such a small change in the cost can be evaluated as insignificant. As a result, for second and third steps, meshes 4 and 5 are selected respectively.

Even though for different problems efficient mesh sizes might come out to be different, meshes 3, 4 and 5 are going to be used for all the vertical alignments in this study. Since the optimizing processes will be applied continuously until no more cost reduction is achieved, the accuracy attained by using the shift distances of mesh 5, namely 5.0m in horizontal direction and 0.5m in vertical direction can be considered as adequate. In case of hesitation, mesh 6 with 2m of Δx and 0.1m of Δy or a completely different mesh can always be used for an additional step (step 4) of the optimizing process. From this point on, meshes 3, 4 and 5 will be called as "Course Mesh", "Fine Mesh" and "Finest Mesh" respectively as identified in Table 5. And these 3 meshes will be used sequentially in 3 steps of the optimization process.

Table 5: Selected meshes with definite shift couples

	COARSE MESH	FINE MESH	FINEST MESH
Δx (m)	10.0	8.0	5.0
Δy (m)	2.0	1.0	0.5

3.5. COMBINATORIAL CASE COMPARISON

The selected PVI moved to the predetermined 8 neighbor points one by one in sequences and the costs are recalculated for all 8 new locations. The one that gives the minimum cost among 9 solutions (initial plus 8 runs) is selected as the new PVI position for the next base vertical alignment. The process is applied for every PVI and the new base vertical alignment is established by the new locations of all PVI's. For the study road, a possible second base vertical alignment that can be achieved after 27 (9+9+9) runs is shown in Figure 23.

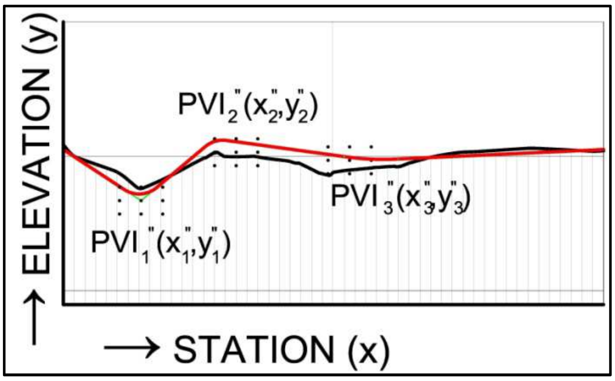

Figure 23: Sample PVI locations of study road after first step

For an alignment with 3 PVI's and the selected mesh, although the total number of possible solutions is 729 (9x9x9) within one step for all neighbors of all PVI's, the number of possible solutions is reduced to 27 (9+9+9) by making the search sequentially as explained above. It was necessary to evaluate the loss in accuracy by reducing the sample space in this manner. For this purpose, the costs for all the 729 combinations of the neighbor points are calculated with the coarse mesh around 3 PVI's of study road. The solutions are presented in Figure 24 so that the cost effect of the movement of 3 PVI's can be examined.

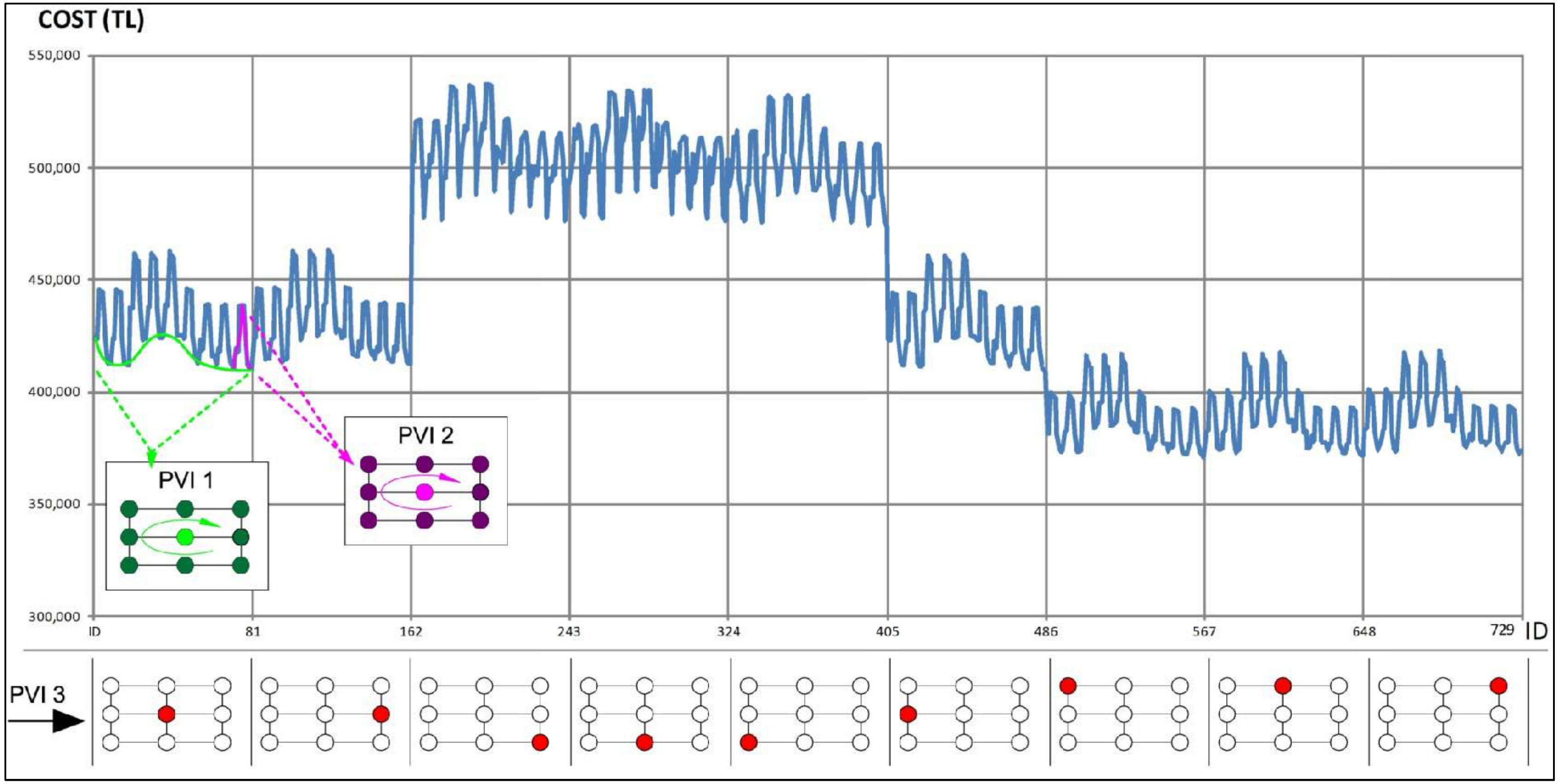

Figure 24: Cost variations for 729 cases

For the study road with the cost of 424,259.45 TL for the base case vertical alignment, the combinatorial and sequential processes were repetitively applied for all three steps of the optimizing process. The optimization was ended up after 8748 runs when all combinations are searched whereas only 405 runs were utilized for the sequential search. For both cases the run numbers in each step and the minimum costs obtained for each step are tabulated in Table 6. The difference between the minimum costs of the final solutions is less than 1%. This result indicates the success of the optimizing process. It should be kept in mind that the success level would be different for different problems. Also the final vertical alignments after continues 3 steps of optimizations for both combinatorial and sequential cases are shown in Figure 25.

Table 6: Comparison of the results of combinatorial and sequential cases

COMBINATORIAL CASE			
MESH	**RUNS**	**REV. COST(TL)**	**% of INITIAL**
SINGLE ONE STEP			
COARSE MESH	729	369,451.30	87.08
CONTINUOUS ONE STEP			
COARSE MESH	4 x 729	362,351.16	85.41
CONTINUOUS THREE STEPS			
COARSE MESH	4 x 729	362,351.16	85.41
FINE MESH	2 x 729	356,492.25	84.03
FINEST MESH	6 x 729	354,680.77	83.60
TOTAL	**8748 RUNS**	**354,680.77 TL**	**83.60 %**
SEQUENTIAL CASE			
MESH	**RUNS**	**REV. COST(TL)**	**% of INITIAL**
SINGLE ONE STEP			
COARSE MESH	27	370,945.87	87.43
CONTINUOUS ONE STEP			
COARSE MESH	7 x 27	368,949.24	86.96
CONTINUOUS THREE STEPS			
COARSE MESH	7 x 27	368,949.24	86.96
FINE MESH	3 x 27	359,968.30	84.85
FINEST MESH	5 x 27	357,297.43	84.22
TOTAL	**405 RUNS**	**357,297.43 TL**	**84.22 %**

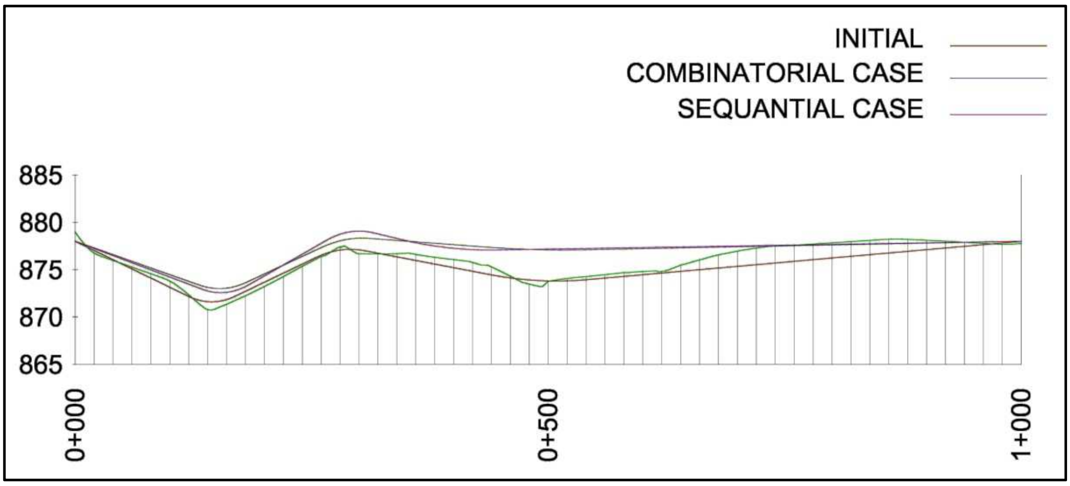

Figure 25: The vertical alignments obtained after continuous three steps of optimization, as a result of combinatorial and sequential processes.

3.6. THE EFFECT OF THE BASE CASE VERTICAL ALIGNMENT

In this study, the initial base case is assumed to be selected by the engineer in accordance with the design standards. The method adopted herein does not necessitate changing the curve lengths. Additionally, the module automatically eliminates the sample profiles with grades exceeding the specified maximum. Also the sample profiles with vertical curve conflicts are discarded by the system. Therefore the sample space for solutions will only include vertical alignments conforming to the adopted specifications.

On the other hand, the final solution will obviously be dependent on the base case vertical alignment constructed by the designer. Since the methodology adopted herein does not allow any change in the number of PVI's, all of the solutions will contain the same number of PVI's. In other words, the optimum vertical alignment reached will be the optimum one for the sample space bounded by the number of PVI's of the base case profile. Therefore the optimizing method used herein can be thought to be a fine tuning of the initial sample profile.

To evaluate the method's sensitivity on the base case profile, an investigation was conducted with 10 design engineers. These engineers were asked to design a vertical alignment with 3 PVI's for the given topography and the horizontal alignment of the study road by trying to minimize the earthwork cost.

Two different tendencies were observed in the initial design. 5 of the designers preferred to stick the surface as much as they can by steeper grades, whereas the other 5 drew smoother grade lines while trying to balance the cut and fill volumes. These designers and their initial alignments are represented by two groups; the initial vertical alignments closely fitting to the surface profile are called Group 1, and the initial vertical alignments with smoother grades are called Group 2.

In Group 1; two engineers have almost 1 year of experience in highway design, and other three members have experiences of 3,6 and 16 years. Also in Group 2; three engineers have 1 year of experience and other two members have 8 and 30 years of experience in highway design. The initial alignments of Group 1 and 2 are shown in Figure 26 and Figure 27 respectively.

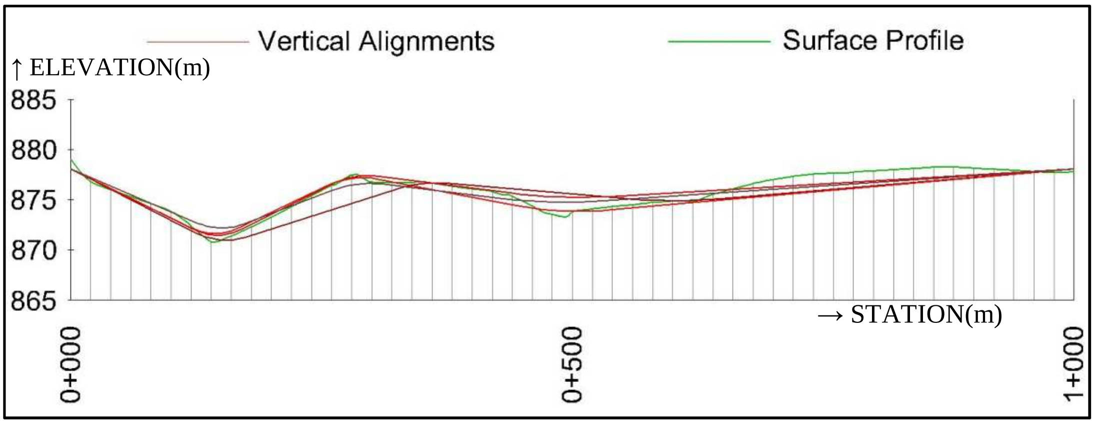

Figure 26: Initial alignments constructed by designers in Group 1

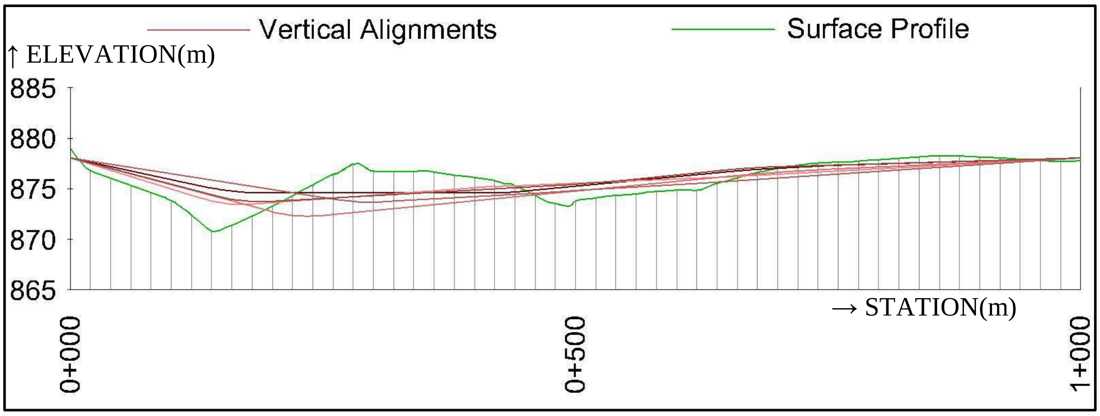

Figure 27: Initial alignments constructed by designers in Group 2

The sequential optimizing process is applied to all those 10 initial alignments. The final optimized alignments of Group 1 and 2 are shown in Figure 28 and Figure 29 respectively.

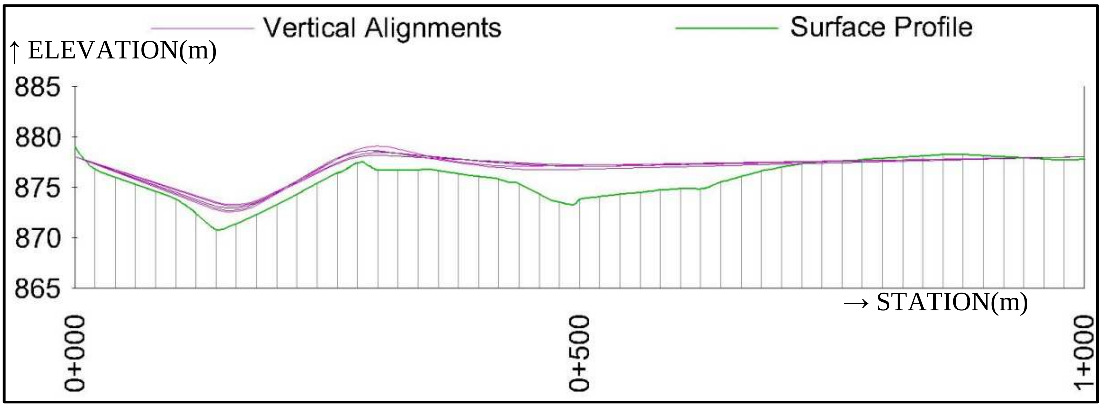

Figure 28: Optimized alignments of the designers in Group 1

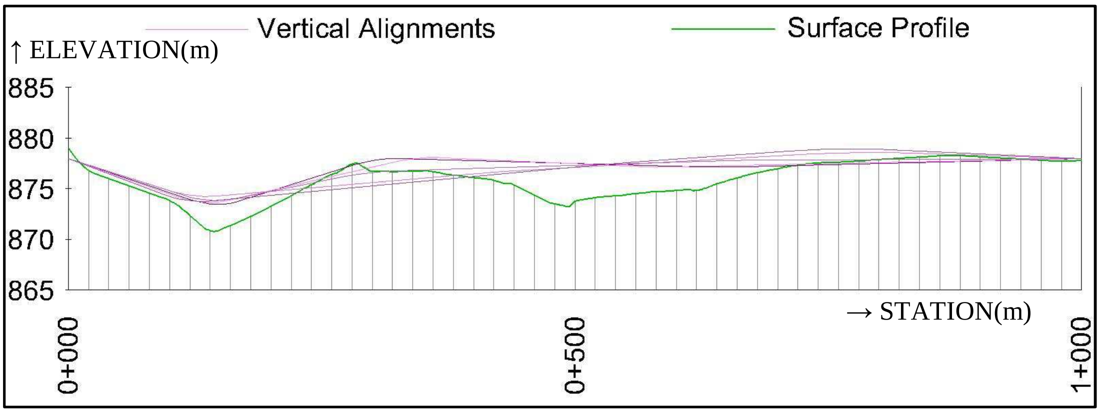

Figure 29: Optimized alignments of the designers in Group 2

Since the initial PVI locations were selected independently by the designers, it was not possible to reach exactly the same final alignment for all the alternatives by using the same mesh sizes. On the other hand, the costs of the optimized alignments are very close to each other in Group 1 and Group 2 separately. The overall sensitivity of convergence is directly related to the shift distances of finest mesh. The progresses in cost reductions through the optimization steps for each designer's alignment are shown in Figure 30 and Figure 31, for Groups 1 and 2 respectively.

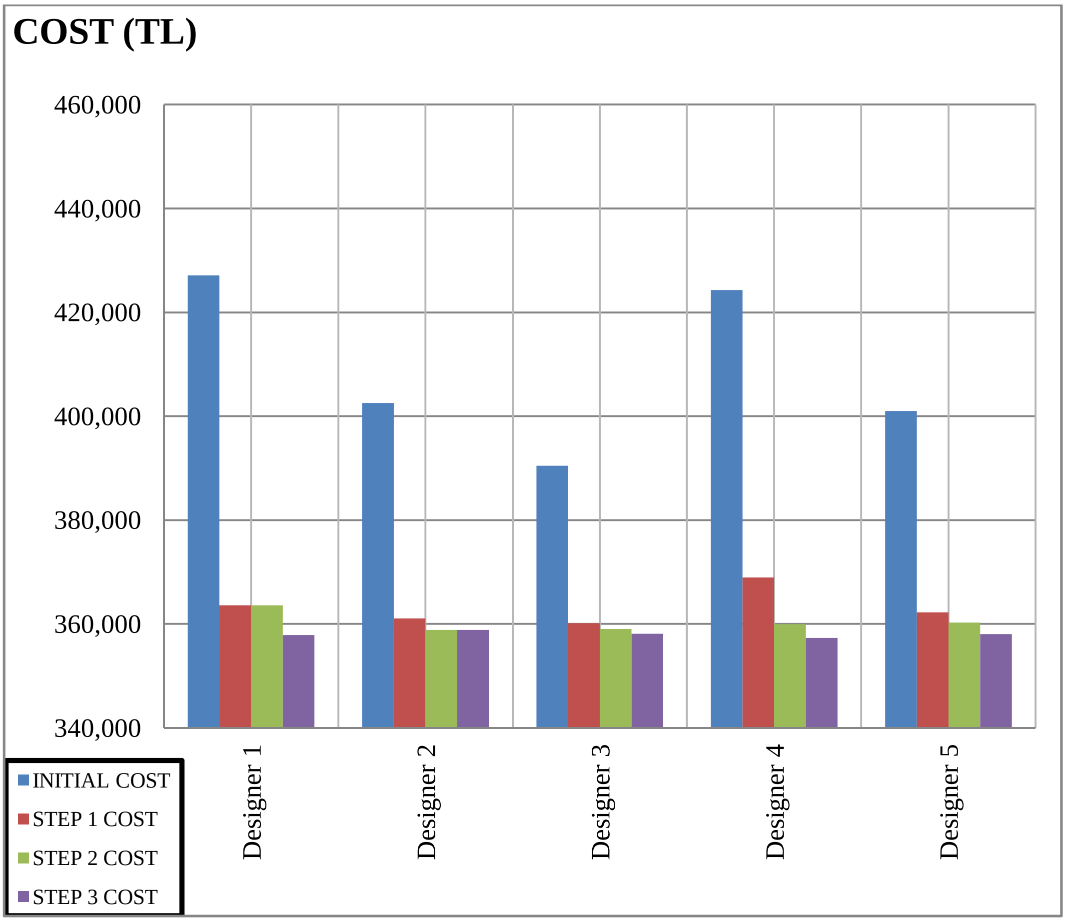

Figure 30: Cost reductions achieved by optimizing the alignments of designers in Group 1

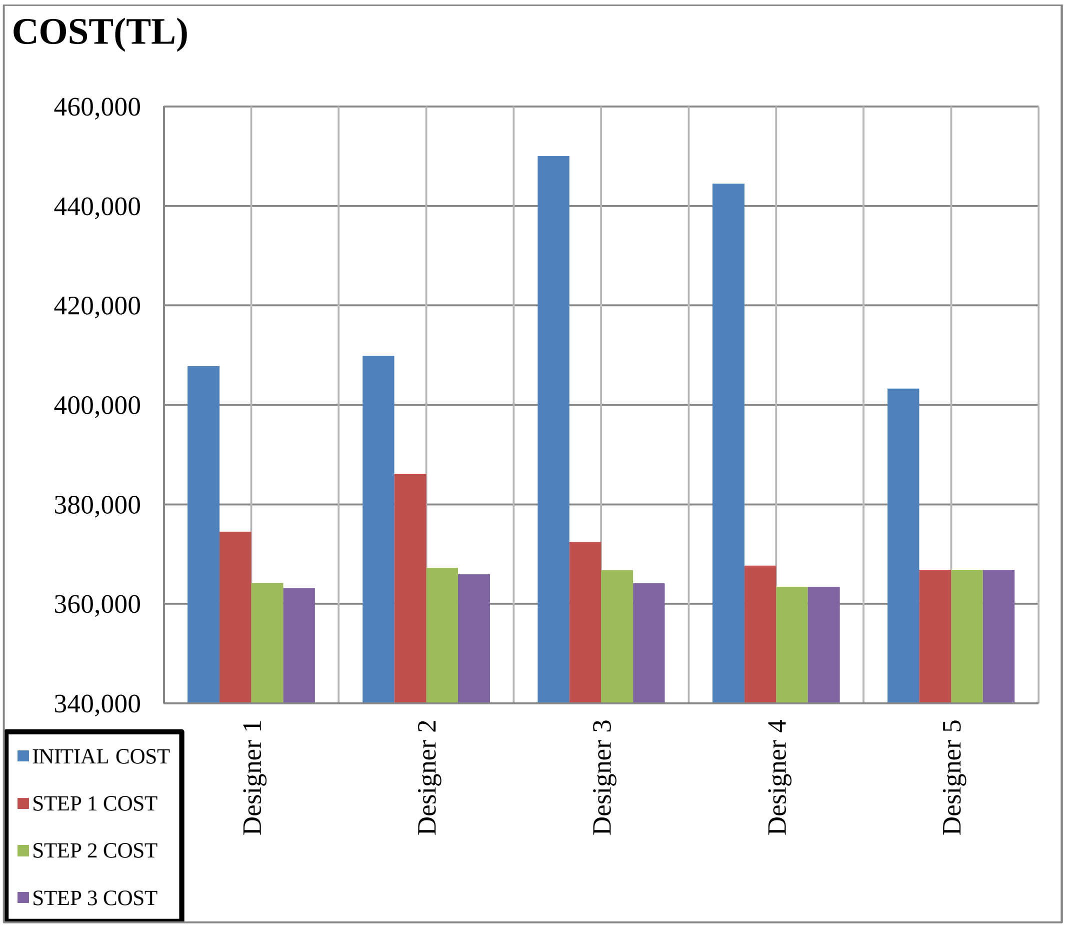

Figure 31: Cost reductions achieved by optimizing the alignments of designers in Group 2

For the initial alignments in Group 1, the average cost is 409,082.23 TL with a difference of 36,648.64 TL between the highest and the lowest. After three step of optimization, the costs of the final solutions lay between 357,297.43 TL and 358,857.79 TL.

On the other side, the costs of the initial alignments in Group 2 vary between 403,307.72 TL and 450,010.58 TL, with a difference of 46,702.86 TL between the highest and the lowest. At the end of three steps of optimization, the average cost of the optimized alignments becomes 364,711.22 TL with the maximum and minimum values of 366,836.15 TL and 363,153.05 TL respectively.

The optimization process provided cost reductions varying between 9.04 to 19.08 % for all of the initial designs. For different initial vertical alignments constructed by the designers involved in the study, it is observed that the cost and alignment differences become smaller and smaller after each step of the optimization process. For the study road, the designs from different designers in Group 1 are converged significantly. Besides, the optimized designs of Group 2 are considerably different from each other. Although only one horizontal alignment is used in this investigation, the results showed that the method is highly dependent on the initial base case alignment. This is expected since the method suggested herein is a fine tuning technique developed with an adopted heuristic algorithm.

The shift distances of finest mesh, which determines the sensitivity of the optimization process, are selected to get the minimum cost reduction value by around 1%. Certainly, the convergence level may be increased by adding more optimization steps with additional smaller shifts.

3.7. LONG CORRIDOR PERFORMANCE

In spite of the fact that, AutoCAD Civil 3D has no limit for the corridor length, the capacity of the current personal computers may not be adequate to complete the optimization process at once for very long highway segments. As the length of the highway segment increases, the modeling process of each run necessitates higher and higher computer memory and longer run time, which may result in computer errors. To select an efficient highway length for optimization, highway segments of 10, 50 and 100 km lengths were studied. The process started successfully for each design, but for 50 and 100 km highway segments it ended up with an error due to lack of free computer memory. Although the performance of the operations on highway models are also dependent on other factors, like the surface model detail, cross section type and the highway alignment characteristics, it is advised to divide the long highways to 10 km length segments in order to not to face with computer capacity problems.

Another critical point that can affect the highway length limit for optimization process is the record of temporary files. The software records one temporary file after every change in the highway model while working. While undo option of AutoCAD Civil 3D is active, the software records those temporary files to the temp folder in the hard disk of the computer. One system file created and recorded to the disk after every run of the optimization by a change in a single PVI. Due to the folder size limitations, the software stops with an error after 825 runs. This indicates that for an alignment with 10 PVI the possible number of optimization sets for one mesh is simply reduced to 9 which count for 10x9x9 = 810 runs. On the other hand, the possible run number can be significantly increased by turning the undo option to off. While the undo option is inactive, the software only works with the cache memory. By using a computer with 8GB of RAM, the maximum number of runs observed as 8189 which allows a total number of 45 optimization sets on an alignment with 20 PVI in one step. Such a performance can be considered sufficient for a 10 km length of highway design.

CHAPTER 4

THE MODULE "EARTHWORKER"

The module "EARTHWORKER" was created in Visual Basic programming language within the AutoCAD Civil 3D platform. The code of the module is given in APPENDIX A.

The module creates a sample space to apply the direct search method explained in Chapter 3. The module extracts the volume data for each sample solution from AutoCAD Civil 3D platform to calculate the earthwork cost. The stepwise direct search method was applied by running the module three times with three meshes to optimize the vertical alignment of a given highway project. The user interface shown in Figure 32 is prepared to enter data and control the module.

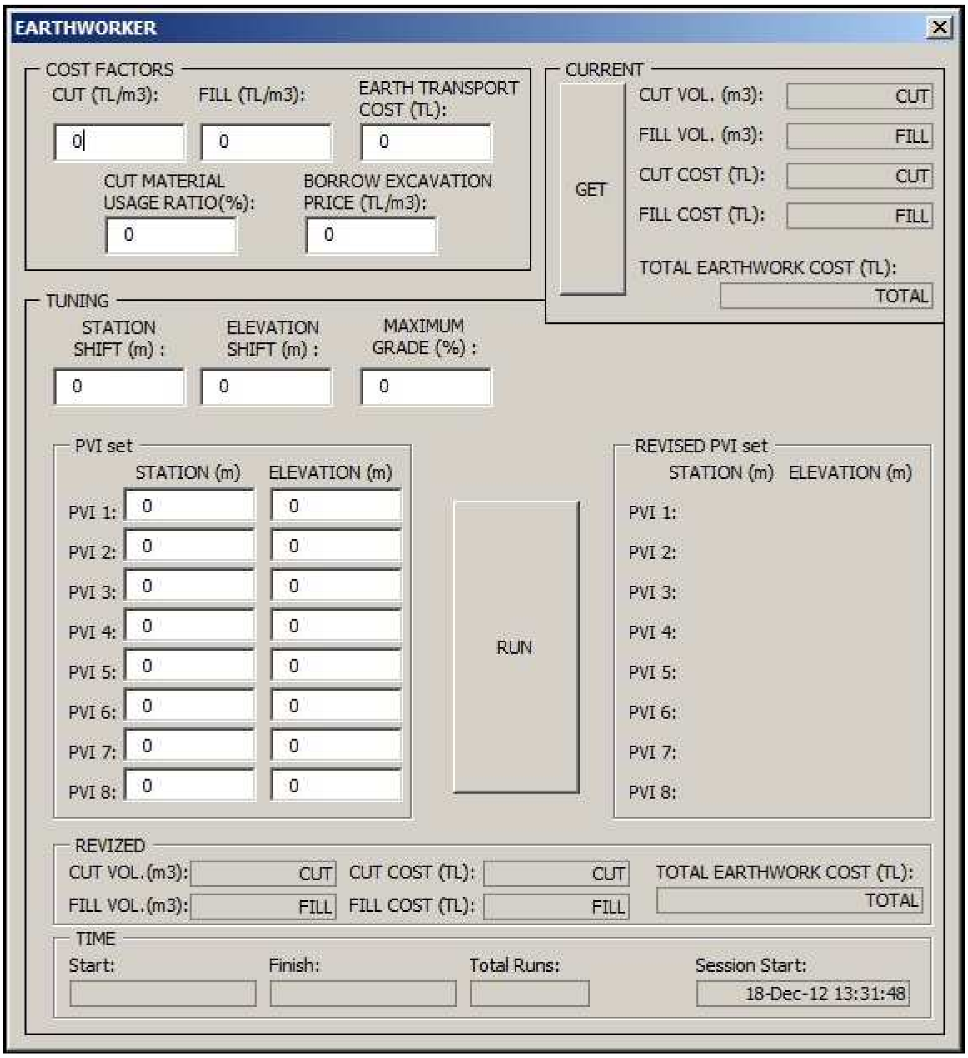

Figure 32: The user interface

The module first calculates the total earthwork cost of the initial vertical alignment. Then the optimization algorithm is applied by altering the locations of the selected PVI's with specified shift distances, Δx and Δy, of selected mesh.

The required inputs to the module are as follows:

1. Cut and fill unit prices,
2. Usable cut material ratio for fill,
3. Borrow pit excavation unit price,
4. Earthwork transportation cost calculated from mass-haul diagram,
5. Shift distances for elevation and station of PVI's, Δx and Δy,
6. Maximum allowable vertical grade,
7. Initial coordinates of PVI's, (x_i, y_i).

The outputs can be listed as follows:

1. Cut and fill volumes of the initial and revised vertical alignment,
2. Cut and fill costs of the initial and revised vertical alignment,
3. Total earthwork cost of the initial and revised vertical alignment,
4. Revised coordinates of PVI's (x_i^i, y_i^i),
5. Start and finish time,
6. Total number of runs.

There are two operations available in the module under "GET" and "RUN" buttons. Clicking the "GET" will provide the calculation of the earthwork cost by using the input unit prices and the initial earthwork volumes that are calculated and stored by the AutoCAD Civil 3D. The "RUN" operation on the other hand activates the module to perform the optimization by direct search method explained in Section 3. The flow charts of the processes activated by "GET" and "RUN" buttons are given in Figure 33 and Figure 34.

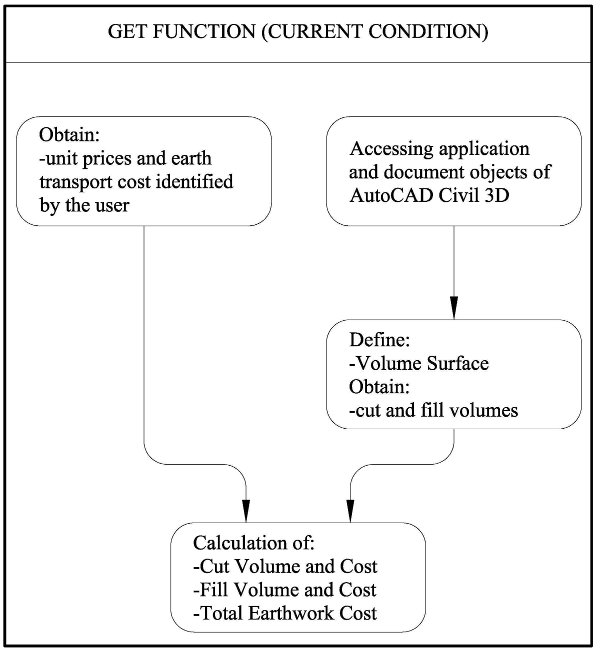

Figure 33: Flowchart of "GET"

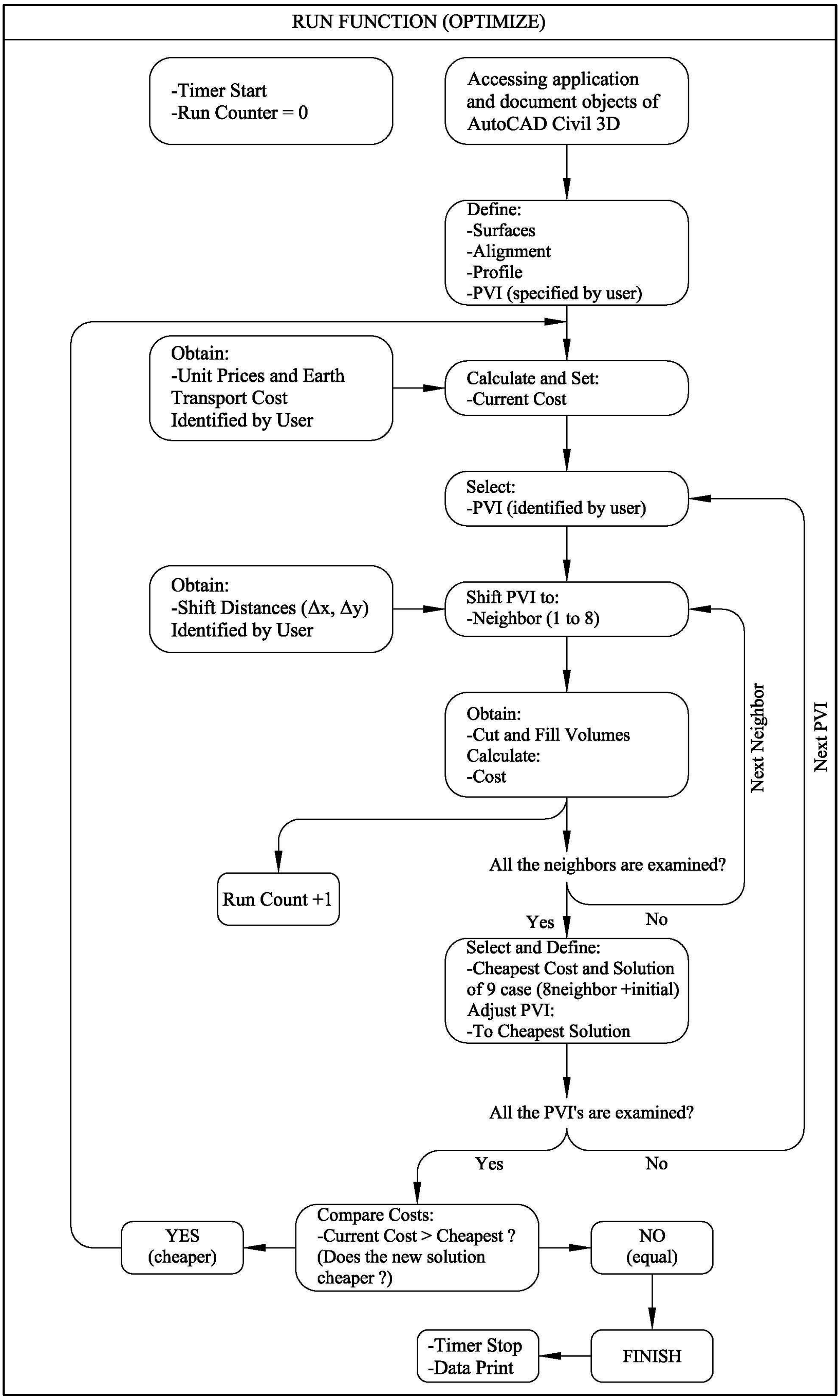

Figure 34: Flowchart of “RUN”

CHAPTER 5

PROCEDURE

In order to apply the optimization process explained in Chapter 3, the alternative horizontal alignment should be completed and the trial vertical alignment should also be formed in AutoCAD Civil 3D platform. The execution of "Earthworker" module calculates the excavation and embankment costs. The earthwork transportation cost for any solution should be calculated separately. The steps of the overall optimization process are explained in the following sections.

5.1. STEP ONE: HIGHWAY DESIGN ON AUTOCAD CIVIL 3D

To run the module and optimize the vertical alignment successfully, initial geometric design should be available in the AutoCAD Civil 3D. There are six steps to be completed for the preparation of a trial geometric design:

1. Digital terrain map of the surface is created,
2. Horizontal alignment is established,
3. Ground profile and vertical alignments are established,
4. Assembly (cross section) is created,
5. Corridor and corridor surface are created,
6. Volume surface is created.

In Appendix B; highway design steps on AutoCAD Civil 3D are explained in detail. Much detailed information can be found on AutoCAD Civil 3D User's Guide (User's Guide, AutoCAD Civil 3D 2011, 2010).

5.2. STEP TWO: EARTHWORK TRANSPORTATION COST

To calculate the earthwork transportation cost, it is necessary to draw the mass haul diagram and calculate the costs of waste, barrow and hauling based on optimum mass haul strategy manually.

Mass Haul Diagram is the plot of cumulative cut-fill volume versus distance and it is a tool to select the most economic scheme for the earthwork transportation. In cumulative volume calculation, cut volumes are taken as positive and fill volumes are taken as negative. To draw the mass haul diagram, the cut and fill areas of the cross sections at regular stations and then the cut and/or fill volumes between successive stations should be calculated. In this study, the mass haul diagrams created by the AutoCAD Civil 3D are used directly. The details for creating mass haul diagram in AutoCAD Civil 3D is explained in Appendix B.7.

5.2.1. SELECTION OF ECONOMIC BALANCE LINE

The economic hauling strategy and the corresponding earthwork transportation cost are based on by the economic balance line to be selected for the mass haul diagram. The balance lines are the horizontal lines drawn on the mass haul diagram. A balance line stars at a point on the mass curve and ends at another point on the mass curve. The cut and fill volumes between two successive points of the balance line on the mass curve are equal and they are balanced. The detailed information about mass haul diagrams can be found in many standard reference books. The Introduction to Transportation Engineering by Banks (Banks, 1998) is one such reference book.

The product of a volume of material times the average distance it is transported is referred to as haul and is expressed in stations times cubic meters The distance across a loop, say the distance labeled x in Figure 35, represents the distance that a particular unit volume of material (represented by the differential element dV) would be hauled. Integration of xdV between particular limits gives the total amount of haul between those limits. This means that total haul is represented on the diagram by the areas under the curve between given limits (Banks, 1998).

Hauling within 100m distance is taken as free hauling in Turkish practice, for distances longer than 100m; the unit price for hauling was calculated from Eq.1.

The unbalanced waste and borrow material volumes are obtained from the mass diagram as shown in Figure 35. The unit prices are calculated by using Eq.2.

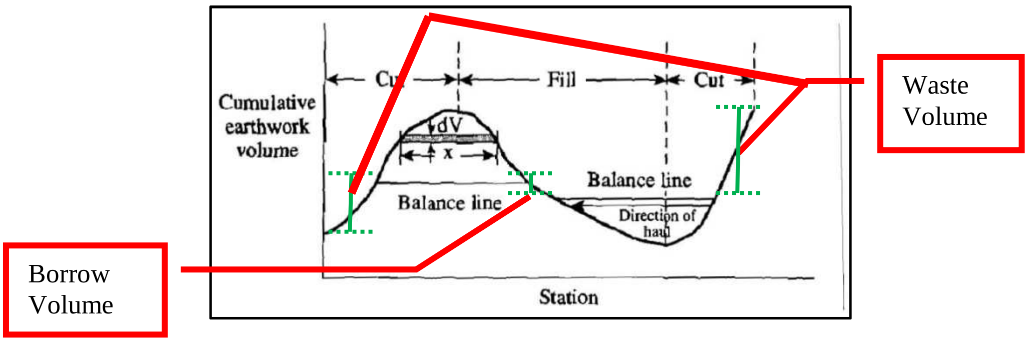

Figure 35: Properties from mass diagrams, from Banks

Hauling strategy is determined by the location of the balance line. For the most economical hauling it is necessary to select a balance line that would release the minimum earthwork transportation cost. The problem of selecting the most economical balance lines for a given mass haul diagram requires minimizing the total earthwork transportation cost function.

For this purpose, the limit of economic hauling distance should be determined. The limit of economical haul (LEH) was determined by finding the distance for which the cost of hauling a unit volume of material from cut to fill is equal to the sum of the costs of barrow and waste. The condition for the economic hauling is then:

$$F_{(Haul)} = F_{(Waste)} + F_{(Borrow)} \tag{10}$$

The LEH is the average haul distance (M) that satisfies the equality given by Eq.10. Inserting the unit price relations given by Eq.1 and Eq.2 into Eq.10, the parameter $\sqrt{M}$ can be solved and by taking the square of it the average haul distance M which is the limit of the average economical haul (LEH) can be determined.

By knowing the LEH, the economic balance line which defines the most economic hauling scheme can be drawn for any given mass haul diagram. The selection of the most economic balance line is done in a stepwise manner by studying the mass haul diagram loop by loop. For a single loop, the balance line that release an average haul distance equal to LEH is the most economic one provided that such a balance line is possible. For two loops in succession, the economic balance line is the line which has equal bases for crest and sag loops. An example of two loops in succession and its economic balance line is demonstrated in Figure 36.

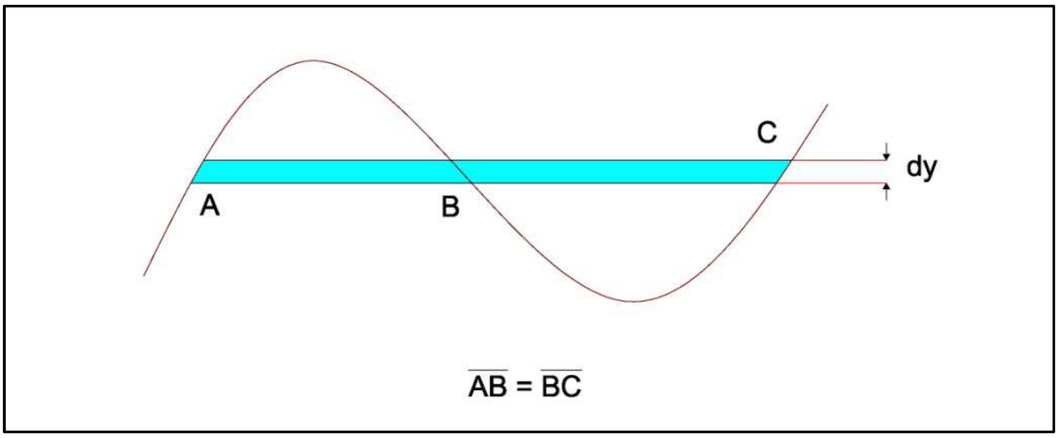

Figure 36: Balance line at even number of loops

The special treatment applied for two loop case as shown in Figure 36 can be generalized for successive even number of loops by drawing a balance line that satisfy the equality of summation of base of crest loops and summation of the bases of sag loops.

For odd number of multiple loops, balance lines were created optimally as shown in Figure 37.

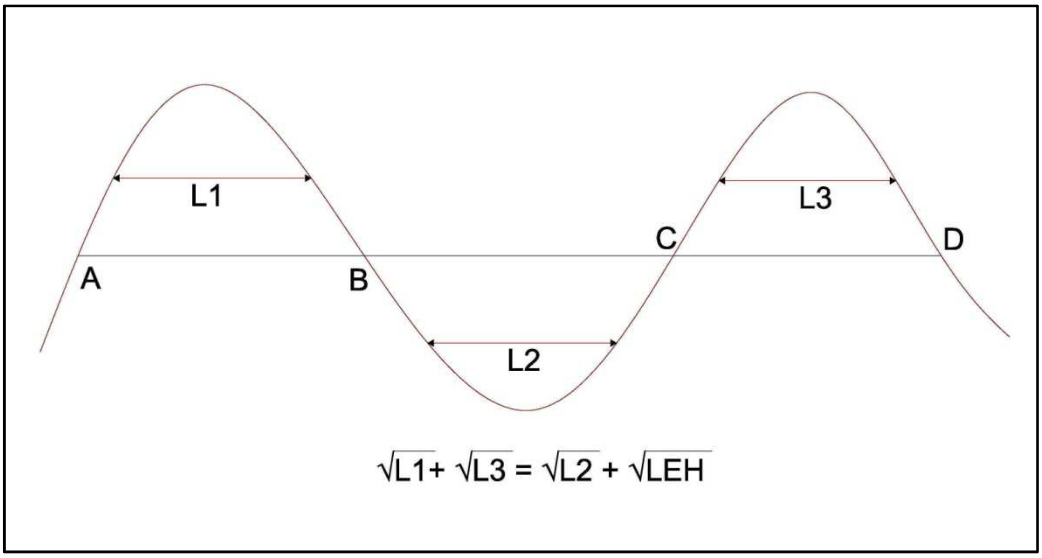

Figure 37: Balance line at odd number of loops

Once the economic balance line is selected, the volumes are obtained from the mass haul diagram and the costs are calculated by using Equations 6, 7, 8, and 9 mentioned in Chapter 3.1. In this study, an excel sheet was prepared for the calculations, and the volumes were calculated from the mass haul diagram manually by using the tabulated data.

5.3. STEP THREE: MODULE APPLICATION

The module "Earthworker" is used in this step. To use the module, installation of AutoCAD Civil 3D and Visual Basic enabler application are necessary. After setup, the necessary data explained in Chapter 4 should be inserted into the module for optimization. The details of the setup procedure and the usage of the module are explained in Appendix C.

By performing the "RUN" function of the module three times with different meshes, the stepwise direct search is applied to the vertical alignment. Before and after each step of application with different meshes, the earthwork transportation cost is calculated and added to the total earthwork cost.

In summary, first the highway geometry is designed in AutoCAD Civil 3D, then the earthwork transportation cost is calculated separately and the first step of optimization with coarse mesh is applied. After the first step, the mass haul diagram is revised and second step of optimization with fine mesh is applied. By the application of the third step of optimization with finest mesh, the procedure is completed and the final mass haul diagram is revised.

CHAPTER 6

CASE STUDIES

In this study, a number of optimization trials have been made on imaginary and real highway designs during the development of the process. In this chapter, optimizations on three virtual projects and a real highway project are presented

6.1. VIRTUAL ROADS

To demonstrate the progress, three virtual roads of 1km lengths are designed and optimized. The roads are designed to illustrate the study on three different terrain types; flat, rolling and mountainous. Three scenarios were made according to the terrain type; the maximum allowable gradient of the vertical alignment of the highway, the earthwork unit prices and the average distances to borrow pits and dumping areas have selected accordingly. In all the three design roads, the cross section is taken as the basic divided highway assembly of AutoCAD Civil 3D. This cross section is 34m wide and has two lanes of 3.6m, with 2.4m length shoulders and medians of 6.0m on both directions.

The process is done with a computer with i7 type quad core 3.40GHz of processor with 8GB of ram and 4GB graphic card. With this configuration, volume calculations for the virtual roads for one run take approximately 3.5sec. Since the process will continue until there is no more improvement, the total computation time varies depending on the run numbers to reach the lowest cost solution in each step.

For each road, first the plan views are illustrated in Figures 39, 41 and 43. The general properties are listed in Tables 7, 11 and 15 respectively for roads 1, 2 and 3. The optimization statistics are also tabulated in Tables 8 and 9 for road 1, in Tables 12 and 13 for road 2 and in Tables 16 and 17 for road 3.

Additionally the initial and final vertical alignments are demonstrated with blue and red colors in Figures 40, 42 and 44 and finally the summary tables are presented in Tables 10, 14 and 18, respectively for roads 1, 2 and 3.

VIRTUAL ROAD 1: FLAT TERRAIN

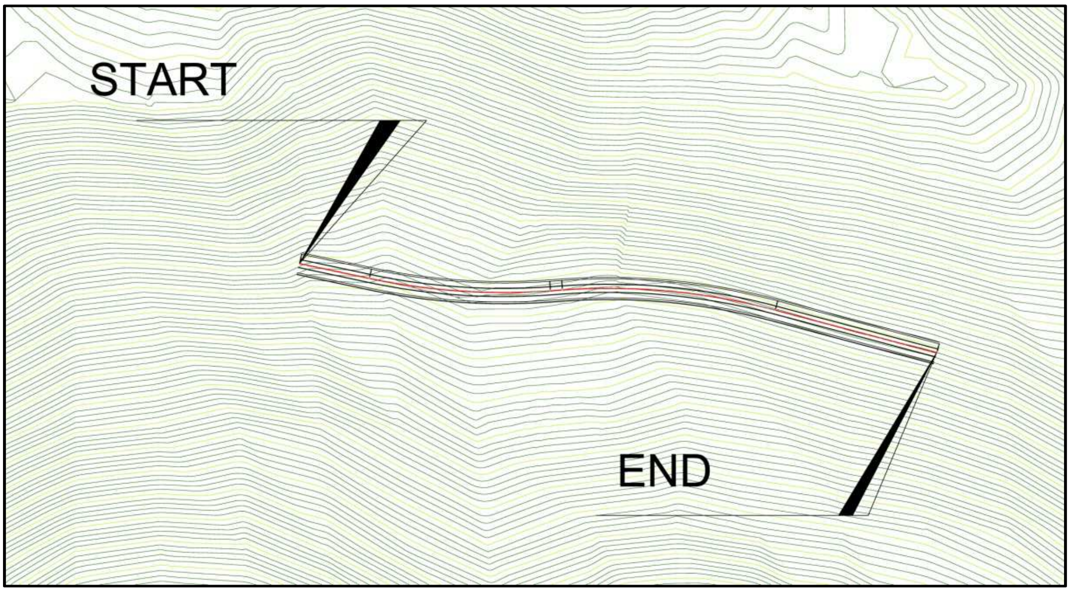

Figure 38: Road 1; plan view

Table 7: Road 1; general properties

PROPERTIES		
Total Surface Area (m2)	:	1619290
Total Number of Surface Data	:	19663
Length of the Road (m)	:	1000
Right of Way Width (m)	:	34
Total Number of PVI Examined	:	3
Max Vertical Gradient (%)	:	6
Soil Type	:	soft
Cut Price (TL/m3)	:	1.71
Fill Price (TL/m3)	:	1.49
Cut Material Usage Ratio (%)	:	80
Borrow Excavation Price (TL/m3)	:	1.45
Average Distance to Borrow Pit (m)	:	2000
Average Distance to Waste Area(m)	:	2000

Table 8: Road 1; step by step cost changes

MESH	START			END			DIFFERENCE
	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(earthwork) (TL)
COARSE	449,281.00	424,259.45	873,540.45	161,133.00	368,949.24	530,082.24	343,458.21
FINE	161,133.00	368,949.24	530,082.24	95,819.50	359,968.30	455,787.80	74,294.44
FINEST	95,819.50	359,968.30	455,787.80	80,685.00	357,297.43	437,982.43	17,805.36

Table 9: Road 1; step by step PVI locations

PVI No	INITIAL		AFTER COARSE MESH		AFTER FINE MESH		AFTER FINEST MESH	
	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)
0	0+000.00	878.00	0+000.00	878.00	0+000.00	878.00	0+000.00	878.00
1	0+144.00	871.00	0+164.00	873.00	0+164.00	873.00	0+159.00	872.00
2	0+280.00	877.50	0+300.00	879.50	0+300.00	879.50	0+290.00	879.50
3	0+490.00	873.50	0+430.00	875.50	0+414.00	876.50	0+394.00	877.00
4	1+000.00	878.00	1+000.00	878.00	1+000.00	878.00	1+000.00	878.00

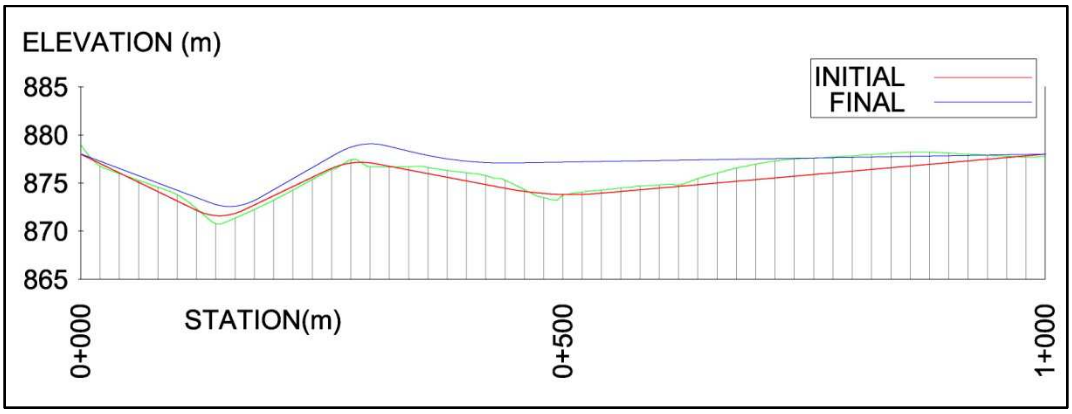

Figure 39: Road 1; initial and final alignments

Table 10: Road 1; optimization summary

TOTAL				
INITIAL	**FINAL**	**DIFFERENCE**	**COMPUTER**	
C(earthwork) (TL)	C(earthwork) (TL)	C(earthwork) (TL)	No. of runs	Time
873,540.45	437,982.43	435,558.02	405	27' 21"

VIRTUAL ROAD 2: ROLLING TERRAIN

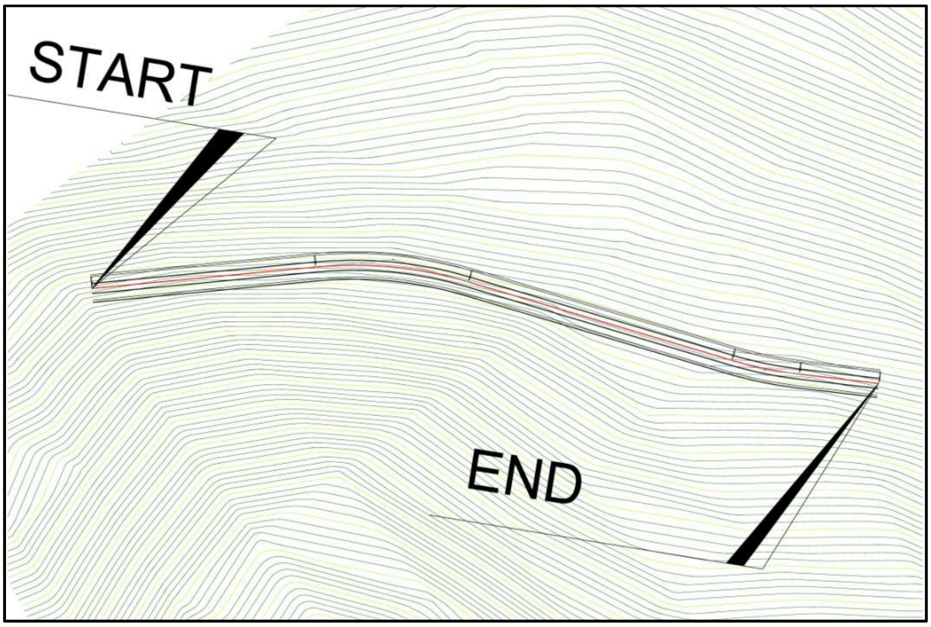

Figure 40: Road 2; plan view

Table 11: Road 2; general properties

PROPERTIES		
Total Surface Area (m2)	:	1619688
Total Number of Surface Data	:	9571
Length of the Road (m)	:	1000
Right of Way Width (m)	:	34
Total Number of PVI Examined	:	5
Max Vertical Gradient (%)	:	8
Soil Type	:	medium
Cut Price (TL/m3)	:	5.40
Fill Price (TL/m3)	:	0.80
Cut Material Usage Ratio (%)	:	90
Borrow Excavation Price (TL/m3)	:	5.14
Average Distance to Borrow Pit (m)	:	1000
Average Distance to Waste Area(m)	:	1000

Table 12: Road 2; step by step cost changes

MESH	START			END			DIFFERENCE
	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(earthwork) (TL)
COARSE	206,976.00	1,409,538.91	1,616,514.91	43,698.00	1,064,601.07	1,108,299.07	508,215.84
FINE	43,698.00	1,064,601.07	1,108,299.07	43,698.00	1,064,601.07	1,108,299.07	0.00
FINEST	43,698.00	1,064,601.07	1,108,299.07	42,478.00	1,063,229.06	1,105,707.06	2,592.01

Table 13: Road 2; step by step PVI locations

PVI No	INITIAL		AFTER COARSE MESH		AFTER FINE MESH		AFTER FINEST MESH	
	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)
0	0+000.00	715.00	0+000.00	715.00	0+000.00	715.00	0+000.00	715.00
1	0+115.00	712.60	0+115.00	714.60	0+115.00	714.60	0+115.00	714.60
2	0+390.00	718.10	0+390.00	720.10	0+390.00	720.10	0+390.00	720.10
3	0+575.00	715.40	0+565.00	717.40	0+565.00	717.40	0+560.00	717.40
4	0+790.00	717.00	0+780.00	717.00	0+780.00	717.00	0+785.00	717.00
5	0+900.00	712.00	0+900.00	712.00	0+900.00	712.00	0+890.00	712.00
6	1+000.00	715.00	1+000.00	715.00	1+000.00	715.00	1+000.00	715.00

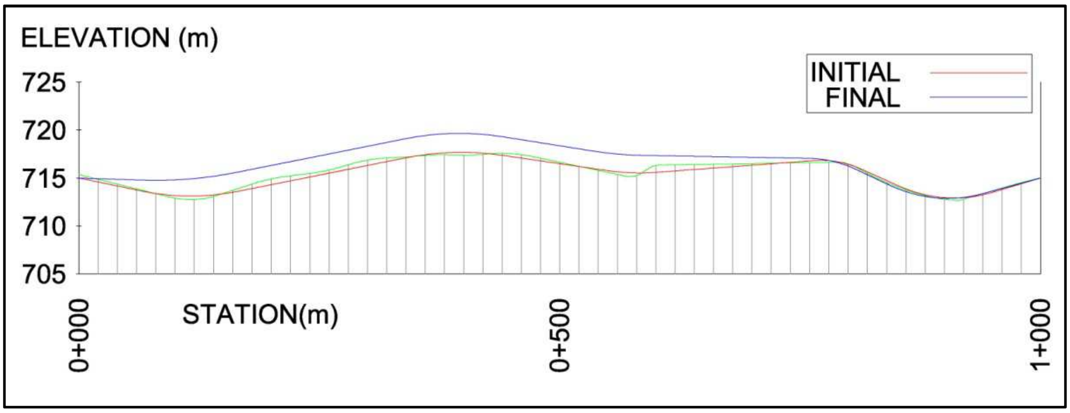

Figure 41: Road 2; initial and final alignments

Table 14: Road 2; optimization summary

TOTAL				
INITIAL	**FINAL**	**DIFFERENCE**	**COMPUTER**	
C(earthwork) (TL)	C(earthwork) (TL)	C(earthwork) (TL)	No. of runs	Time
1,616,514.91	1,105,707.06	510,807.85	315	17' 29"

VIRTUAL ROAD 3: MOUNTAINOUS TERRAIN

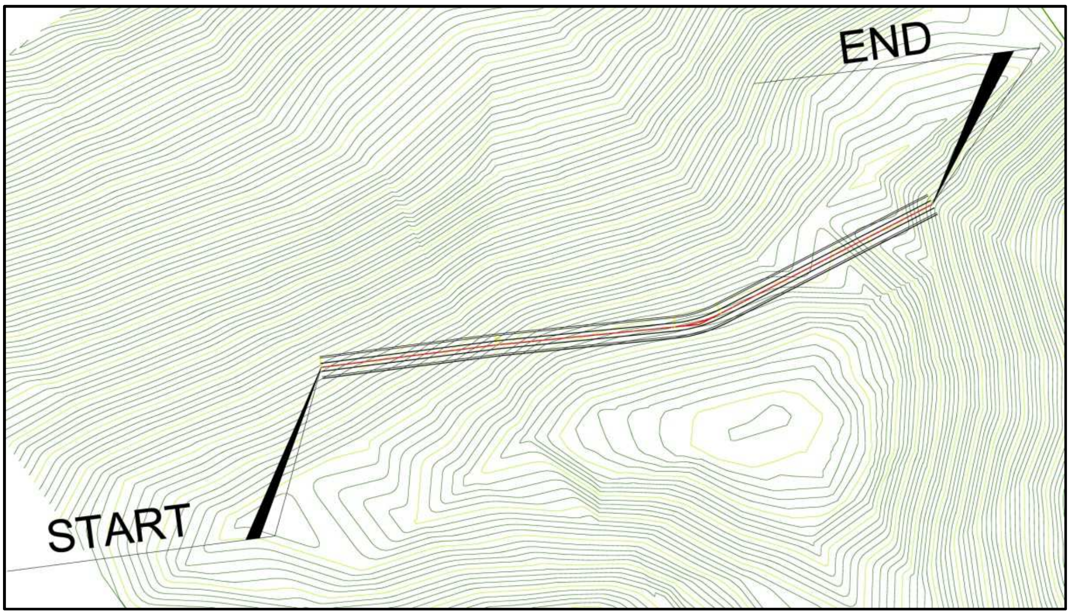

Figure 42: Road 3; plan view

Table 15: Road 3; general properties

PROPERTIES		
Total Surface Area (m2)	:	1597363
Total Number of Surface Data	:	9226
Length of the Road (m)	:	1000
Right of Way Width (m)	:	34
Total Number of PVI Examined	:	4
Max Vertical Gradient (%)	:	12
Soil Type	:	hard
Cut Price (TL/m3)	:	6.45
Fill Price (TL/m3)	:	0.25
Cut Material Usage Ratio (%)	:	95
Borrow Excavation Price (TL/m3)	:	6.19
Average Distance to Borrow Pit (m)	:	500
Average Distance to Waste Area(m)	:	1000

Table 16: Road 3; step by step cost changes

MESH	START			END			DIFFERENCE
	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(earthwork) (TL)
COARSE	188,280.50	1,163,969.51	1,352,250.01	98,077.00	851,632.17	949,709.17	402,540.84
FINE	98,077.00	851,632.17	949,709.17	109,652.50	844,716.65	954,369.15	-4,659.99
FINEST	109,652.50	844,716.65	954,369.15	107,157.00	838,536.00	945,693.00	8,676.16

Table 17: Road 3; step by step PVI locations

PVI No	INITIAL		AFTER COARSE MESH		AFTER FINE MESH		AFTER FINEST MESH	
	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)
0	0+000.00	932.73	0+000.00	932.73	0+000.00	932.73	0+000.00	932.73
1	0+353.75	966.23	0+343.75	968.23	0+351.75	969.23	0+346.75	968.73
2	0+556.01	976.10	0+606.01	978.10	0+582.01	978.10	0+592.01	978.10
3	0+821.42	966.32	0+821.42	966.32	0+821.42	966.32	0+816.42	966.82
4	0+909.2	956.03	0+909.2	956.03	0+909.2	956.03	0+904.2	956.53
5	1+000.00	945.53	1+000.00	945.53	1+000.00	945.53	1+000.00	945.53

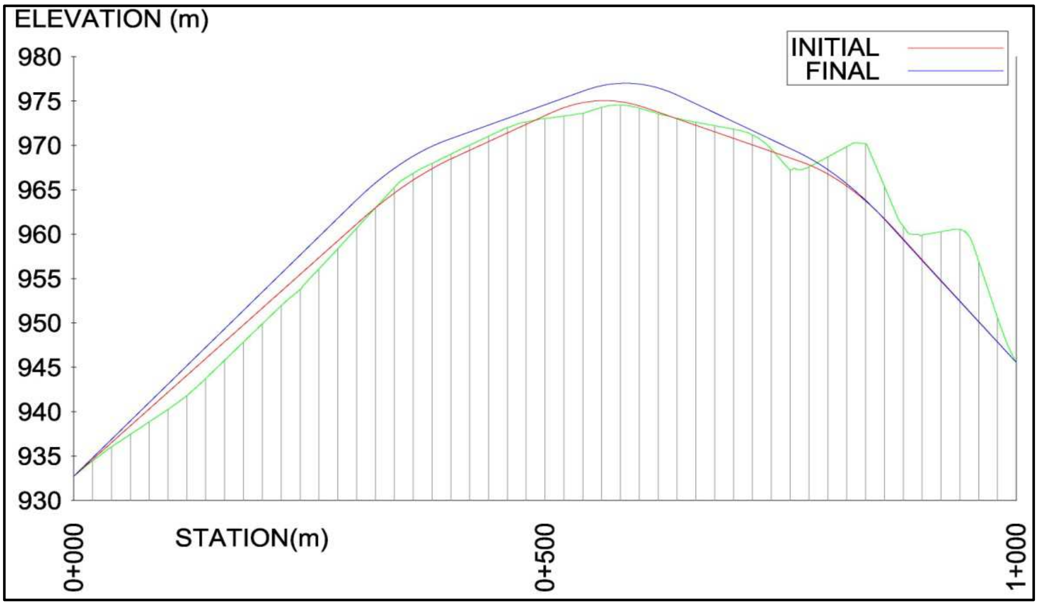

Figure 43: Road 3; initial and final alignments

Table 18: Road 3; optimization summary

TOTAL				
INITIAL	**FINAL**	**DIFFERENCE**	**COMPUTER**	
C(earthwork) (TL)	C(earthwork) (TL)	C(earthwork) (TL)	No. of runs	Time
1,352,250.01	945,693.00	406,557.01	468	24' 3"

For all three roads, considerable amounts of cost reductions are achieved by the application of the optimization process. The cost reductions are tabulated for all three roads separately for cut and fill costs and earthwork transportation costs and overall earthwork costs in Table 19.

Table 19: Cost changes for three roads

	COST CHANGES		
	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)
ROAD 1:	368,596.00	66,962.02	435,558.02
ROAD 2:	164,498.00	346,309.85	510,807.85
ROAD 3:	81,123.50	325,433.51	406,557.01

Additionally, the percent ratios of cost reductions per initial earthwork costs are also tabulated in Table 20. As expected, the cut and fill cost reduction percentages observed for highways on flat terrain are less than the percentages observed for the highways on mountainous terrain. Another interesting point to mention is that the earthwork transportation cost reductions on flat terrain are greater than the reductions on mountainous terrain.

Table 20: Cost change ratios for three roads

	COST CHANGES/INITIAL EARTHWORK COST		
	C(transport) (%)	C(cut&fill) (%)	C(earthwork) (%)
ROAD 1:	42.20	7.67	49.87
ROAD 2:	10.18	21.42	31.60
ROAD 3:	6.00	24.07	30.07

6.2. A SEGMENT OF KASTAMONU–TAŞKÖPRÜ ROAD

In this section, a real life highway design was optimized by the method suggested in this study. The design road is a relocation road between Hanönü and Taşköprü in the province of Kastamonu. The road is called Kastamonu - Taşköprü road. The start and end points of the project are at km: 54+552.81 and km: 64+248.82 respectively, as can be seen on Figure 44 also with the location of the road. The reason for relocation is a planned hydroelectricity power plant which will submerge the old road under water. The total length of the road is approximately 10 kilometers. For the optimization process, a piece of approximately 2.5 kilometers was chosen.

Figure 44: Location of the Kastamonu - Taşköprü road

The start km of the road was changed to 0+000.00 as the necessity to work the module, as explained in Appendix B. The plan view of the road segment is demonstrated in Figure 45.

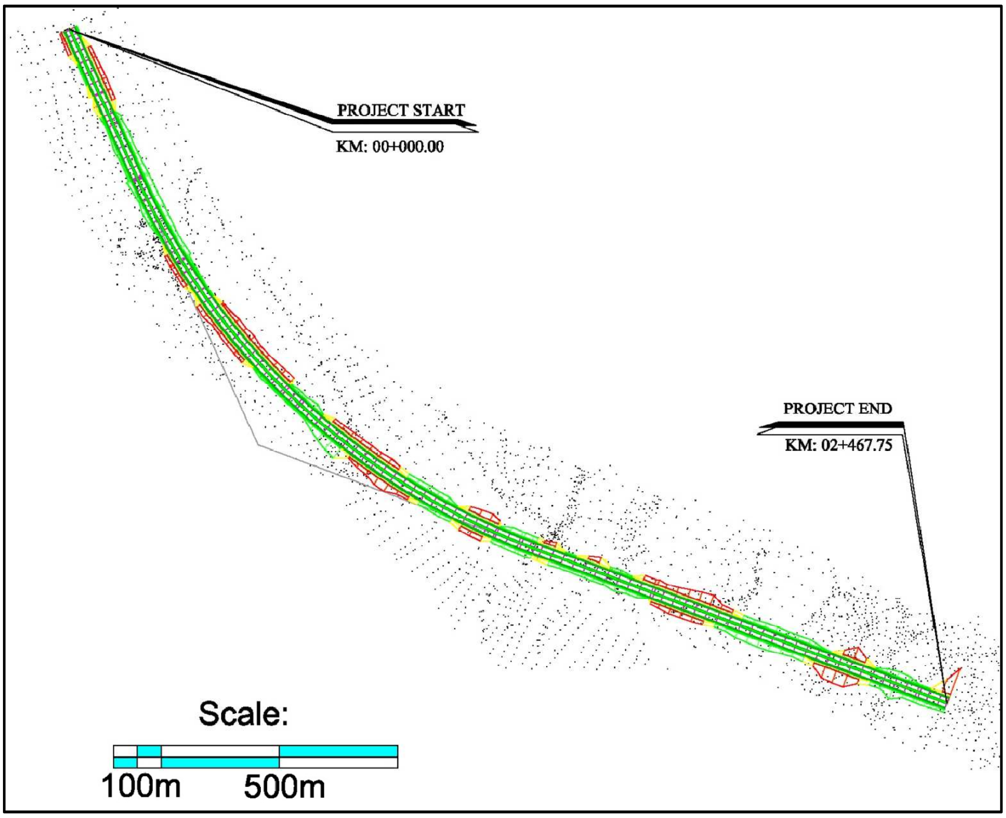

Figure 45: Plan of Kastamonu – Taşköprü road

The data tables for the Kastamonu - Taşköprü road are prepared in general properties, cost changes, PVI locations and optimization summary separately in Tables 21 through 24. Also initial and final vertical alignments are demonstrated on the same profile view given in Figure 46. Much detailed information about the study can be found in Appendix D.

Table 21: General properties of Kastamonu Taşköprü road

PROPERTIES		
Total Surface Area (m2)	:	960200
Total Number of Surface Data	:	3473
Length of the Road (m)	:	2467.751
Right of Way Width (m)	:	26
Total Number of PVI Examined	:	4
Max Vertical Gradient (%)	:	8
Soil Type (mixed) :		
-soil		40%
-loose rock		30%
-soft rock		25%
-hard rock		5%
Cut Price (TL/m3)	:	3.1395
Fill Price (TL/m3)	:	0.9110
Cut Material Usage Ratio (%)	:	87.5
Borrow Excavation Price (TL/m3)	:	2.9870
Average Distance to Borrow Pit (m)	:	1200
Average Distance to Waste Area(m)	:	600

Table 22: Kastamonu-Taşköprü road; step by step cost changes

MESH	START			END			DIFFERENCE
	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(transport) (TL)	C(cut&fill) (TL)	C(earthwork) (TL)	C(earthwork) (TL)
COARSE	312,834.50	1,097,576.49	1,410,410.99	215,188.00	828,706.83	1,043,894.83	366,516.16
FINE	215,188.00	828,706.83	1,043,894.83	215,188.00	828,706.83	1,043,894.83	0.00
FINEST	215,188.00	828,706.83	1,043,894.83	214,475.00	828,464.15	1,042,939.15	955.68

Table 23: Kastamonu-Taşköprü road; step by step PVI locations

PVI No	INITIAL		AFTER COARSE MESH		AFTER FINE MESH		AFTER FINEST MESH	
	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)	Station (m)	Elevation (m)
0	0+000.00	546.31	0+000.00	546.31	0+000.00	546.31	0+000.00	546.31
1	0+127.55	549.00	0+127.55	551.00	0+127.55	551.00	0+122.55	551.00
2	0+447.55	545.00	0+427.55	543.00	0+427.55	543.00	0+427.55	543.00
3	1+207.55	513.80	1+187.55	511.80	1+187.55	511.80	1+187.55	511.80
4	2+102.55	520.70	2+132.55	520.70	2+132.55	520.70	2+132.55	520.70
5	2+467.75	538.05	2+467.75	538.05	2+467.75	538.05	2+467.75	538.05

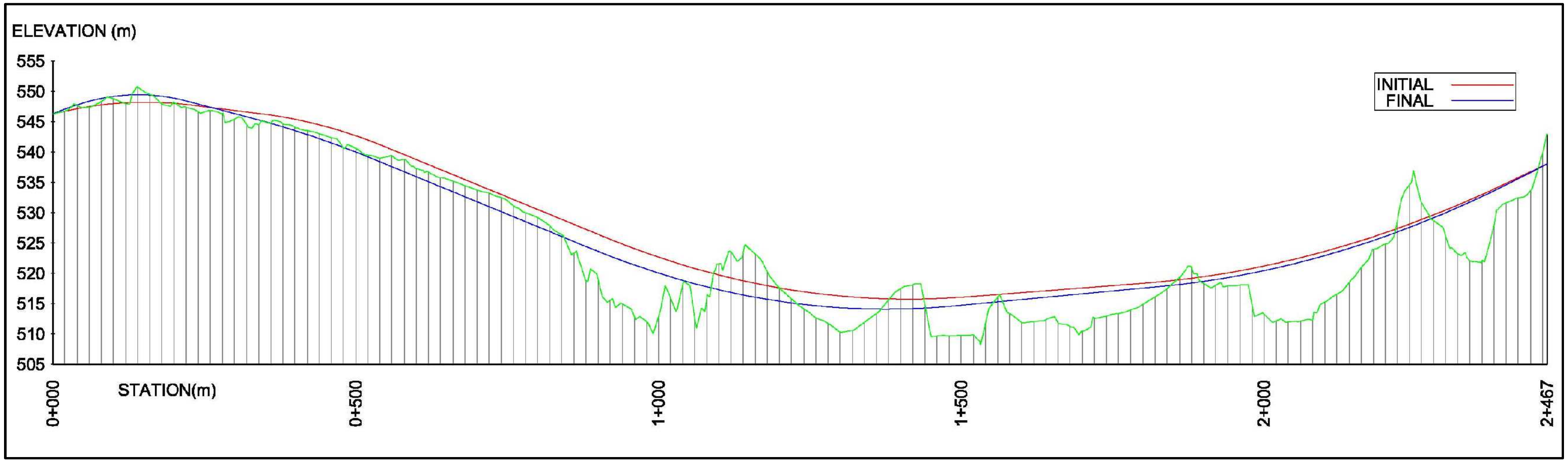

Figure 46: Kastamonu-Taşköprü road; initial and final alignments

Table 24: Kastamonu-Taşköprü road; optimization summary

TOTAL				
INITIAL	**FINAL**	**DIFFERENCE**	**COMPUTER**	
C(earthwork) (TL)	C(earthwork) (TL)	C(earthwork) (TL)	No. of runs	Time
1,410,410.99	1,042,939.15	367,471.84	288	23' 23"

CHAPTER 7

SUMMARY AND CONCLUSIONS

Because of the continuous growth in transportation needs of our contemporary societies, the need for expansion and improvement of existing highway networks are inevitable. Construction of new facilities and improvement of existing ones necessitate enormous investments and improper designs may result in serious economic costs. For this reason, there are several studies in literature that aim to optimize the highway alignments while minimizing the costs. The optimizing process for a highway alignment with its three dimensional geometry and the random nature of the topography is a multivariable, complex and non-differentiable problem. As a result, no optimizing strategy has been developed yet to find the best or minimum cost solution for a given highway problem. The methods developed and suggested in literature are simplified and generally aim to reach very rough solutions.

In this thesis work, it is aimed to optimize any vertical alignment alternative constructed by the designer for an existing or an already fixed horizontal alignment of a highway on a given topography. The direct search technique was selected as the method for optimizing. The base case condition is taken as the initial vertical alignment constructed by the designer. The optimizing process is applied in a stepwise manner and the solution space at every step is bounded by moving the initial PVI's only to some neighbor points around the initial ones. For optimizing process a program module was prepared using Visual Basic programming language and integrated to AutoCAD Civil 3D software. The idea behind using CAD software as the working platform is to create a practical and efficient optimization tool to be used in vertical alignments of real highway projects.

The cut and fill volumes are obtained directly from the CAD software and the unit prices of General Directorate of Highways, Directorate of Construction and Consultancy Tenders Section (Karayolları Genel Müdürlüğü, 2012) are used in the calculation of the earthwork costs. At the end of each step of optimization the mass haul diagram was obtained from CAD program and the earthwork transportation costs are calculated based on economic hauling consideration. Although the calculation of the earthwork transportation cost from the mass haul diagram is a very complicated task, earthwork costs will only be precise when cost of hauling is also included. The total earthwork cost is found by the summation of excavation, embankment and earthwork transportation costs at the end of each step.

Although the earthwork transportation costs generally decrease with the decrease of the cut and fill volumes, the reverse may also be encountered from time to time depending on the cut and fill locations through the highway. As an example, in the virtual road 3 studied herein, although the cut and fill costs were decreased, the earthwork transportation cost calculated after the second step is obtained higher than the previous one, resulting a higher earthwork cost in total.

The optimization method was tested on several virtual projects and a real highway project. Considerable earthwork cost reductions were achieved for all of them.

In virtual road project 1, the earthwork cost is reduced from 873.540,45 TL to 437.982,43 TL by the application of optimizing process. This reduction corresponds to 49.87%. It is interesting that the reduction in the earthwork transportation cost is the biggest part of the overall reduction. The earthwork transportation cost reduction is from 449.281,00 TL to 80.685,00 TL.

In virtual road project 2, the percent reduction achieved is 31.60%. The overall cost is reduced from 1.616.514,91 TL to 1.105.707,06 TL with a reduction of 510,807.85 TL. The share of transportation cost reduction is 164,498.00 TL.

In virtual road project 3, the earthwork cost is reduced by 30.07%. The initial cost of 1.352.250,01 TL is reduced to 945.693,00 TL. The transportation cost reduction is only 81,123.50 TL out of 406,557.01 TL total.

In Kastamonu-Taşköprü road project, 26.05% reduction is achieved in total earthwork cost. The initial and the final costs are 1.410.410,99 TL and 1.042.939,15 TL respectively. For this highway the decrease in the earthwork transportation cost is only 98,359.50 TL out of 367,471.84 TL total.

The results are seemed quite satisfying; the earthwork costs on the studied alignments were decreased significantly by the application of the optimization process.

Considering the wide usage of the AutoCAD Civil 3D software in highway designs, the optimization method developed can be considered as a practical and efficient method for the designers. By using AutoCAD Civil 3D in earthwork volume calculations, the volumes are calculated precisely in this study.

The method can be improved by including the earthwork transportation costs calculation from mass haul diagram directly in the program module in further studies.

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APPENDIX A

CODE OF THE MODULE "EARTHWORKER"

```
Private Sub UserForm_Activate()

'grand timer
acilis = Now
Label47.Caption = acilis

MsgBox ("Please make sure that; there is only 1 alignment and 1
profile(wide space), assembly, corridor, corridorsurface and volumesurface
created on that alignment at the drawing.")
End Sub


Private Sub CommandButton1_Click()

'kick off meeting
Dim oDocument As AeccDocument
Dim oAcadApp As AcadApplication
Set oAcadApp = ThisDrawing.Application
Const sCivilAppName = "AeccXUiLand.AeccApplication.9.0"
Dim oCivilApp As AeccApplication
Set oCivilApp = oAcadApp.GetInterfaceObject(sCivilAppName)
Set oDocument = oCivilApp.ActiveDocument

'application of changes
Dim oApp As AcadApplication
Set oApp = ThisDrawing.Application
Dim sAppName As String
sAppName = "AeccXUiRoadway.AeccRoadwayApplication.9.0"
Dim oRoadwayApplication As AeccRoadwayApplication
Set oRoadwayApplication = oApp.GetInterfaceObject(sAppName)
Dim oRoadwayDocument As AeccRoadwayDocument
Set oRoadwayDocument = oRoadwayApplication.ActiveDocument
Dim oCorridors As AeccCorridors
Set oCorridors = oRoadwayDocument.Corridors
Dim oCorridor As AeccCorridor
For Each oCorridor In oCorridors
'Debug.Print "Corridor: " & oCorridor.Name
oCorridor.Rebuild
Next
oCivilApp.ZoomExtents
oCivilApp.ActiveDocument.SendCommand ("regenall ")

'Define surfaces
Dim i As Integer
For i = 0 To oDocument.Surfaces.Count - 1
Set osurface = oDocument.Surfaces.Item(i)
```

```
Select Case (osurface.Type)
Case aecckTinSurface:
Dim oTinSurface As AeccTinSurface
Set oTinSurface = osurface
Set oTinSurface = oDocument.Surfaces.Item(i)
osurface.Rebuild
'Debug.Print oTinSurface.Name & ": TIN"
Case aecckGridVolumeSurface:
Dim oGridVolume As AeccGridVolumeSurface
Set oGridVolume = osurface
'Debug.Print oGridVolume.Name & ": Grid Volume"
Case aecckTinVolumeSurface:
Dim oTinVolumeSurface As AeccTinVolumeSurface
Set oTinVolumeSurface = osurface
osurface.Rebuild
'Debug.Print oTinVolumeSurface.Name & ": TIN Volume"
End Select
Next i

Dim dCutVol As Double
Dim dFillVol As Double

dCutVol = oTinVolumeSurface.Statistics.CutVolume
dFillVol = oTinVolumeSurface.Statistics.FillVolume

Label43.Caption = Round(dCutVol, 3)
Label44.Caption = Round(dFillVol, 3)

Dim cutup As Double
cutup = TextBox16.Text

Dim fillup As Double
fillup = TextBox17.Text

Dim ewtrc As Double
ewtrc = TextBox18.Text

Dim cmur As Double
cmur = (TextBox23.Text / 100)

Dim beup As Double
beup = TextBox24.Text

Dim becost As Double
If (dFillVol - dCutVol * cmur) > 0 Then
becost = (dFillVol - dCutVol * cmur) * beup
Else
becost = 0
End If

Dim cost As Double
Dim ccost As Double
Dim fcost As Double

ccost = Abs(dCutVol * cutup)
fcost = Abs(dFillVol * fillup) + becost
```

```
cost = Abs(dCutVol) * cutup + Abs(dFillVol) * fillup + ewtrc + becost
Label84.Caption = Round(ccost, 3)
Label83.Caption = Round(fcost, 3)
Label45.Caption = Round(cost, 2)

End Sub

Private Sub CommandButton2_Click()

'timer start
baslangic = Now
Label29.Caption = baslangic

'counter start
Dim runnumber As Integer
runnumber = 0

'kick off meeting
Dim oDocument As AeccDocument
Dim oAcadApp As AcadApplication
Set oAcadApp = ThisDrawing.Application
Const sCivilAppName = "AeccXUiLand.AeccApplication.9.0"
Dim oCivilApp As AeccApplication
Set oCivilApp = oAcadApp.GetInterfaceObject(sCivilAppName)
Set oDocument = oCivilApp.ActiveDocument

'Define surfaces
Dim i As Integer
For i = 0 To oDocument.Surfaces.Count - 1
Set osurface = oDocument.Surfaces.Item(i)
Select Case (osurface.Type)
Case aecckTinSurface:
Dim oTinSurface As AeccTinSurface
Set oTinSurface = osurface
Set oTinSurface = oDocument.Surfaces.Item(i)
osurface.Rebuild
'Debug.Print oTinSurface.Name & ": TIN"
Case aecckGridVolumeSurface:
Dim oGridVolume As AeccGridVolumeSurface
Set oGridVolume = osurface
'Debug.Print oGridVolume.Name & ": Grid Volume"
Case aecckTinVolumeSurface:
Dim oTinVolumeSurface As AeccTinVolumeSurface
Set oTinVolumeSurface = osurface
osurface.Rebuild
'Debug.Print oTinVolumeSurface.Name & ": TIN Volume"
End Select
Next i

'Define alignment
Dim oAlignments As AeccAlignments
Set oAlignment = oDocument.AlignmentsSiteless.Item(0)
'Debug.Print "Name of the alignment: "; oAlignment.Name

'Define profile
Dim oProfiles As AeccProfiles
```

```
Set oProfiles = oAlignment.Profiles
Dim oProfile As AeccProfile
Set oProfile = oProfiles.Item(1)

'-------------------------------------------------------
'Define PVI
'getting user's PVI data

Dim PVI(1 To 8) As AeccProfilePVI

Dim stat(1 To 8), elev(1 To 8) As Integer

'------------------------------------------------------------

stat(1) = TextBox3.Text

elev(1) = TextBox4.Text

If stat(1) + elev(1) = 0 Then
GoTo send1
End If

Set PVI(1) = Nothing
Set PVI(1) = oProfile.PVIs.ItemAt(stat(1), elev(1))
'Debug.Print "PVI closest to station S1 is at station: ";
'Debug.Print PVI(1).Station
'Debug.Print "Elevation";
'Debug.Print PVI(1).Elevation

GoTo devam1
send1:
devam1:

'--------------------------------------------------------------

stat(2) = TextBox5.Text

elev(2) = TextBox6.Text

If stat(2) + elev(2) = 0 Then
GoTo send2
End If

Set PVI(2) = Nothing
Set PVI(2) = oProfile.PVIs.ItemAt(stat(2), elev(2))
'Debug.Print "PVI closest to station S2 is at station: ";
'Debug.Print PVI(2).Station
'Debug.Print "Elevation";
'Debug.Print PVI(2).Elevation

GoTo devam2
send2:
devam2:

'--------------------------------------------------------------
```

```
stat(3) = TextBox7.Text

elev(3) = TextBox8.Text

If stat(3) + elev(3) = 0 Then
GoTo send3
End If

Set PVI(3) = Nothing
Set PVI(3) = oProfile.PVIs.ItemAt(stat(3), elev(3))
'Debug.Print "PVI closest to station S3 is at station: ";
'Debug.Print PVI(3).Station
'Debug.Print "Elevation";
'Debug.Print PVI(3).Elevation

GoTo devam3
send3:
devam3:

'-------------------------------------------------------------

stat(4) = TextBox9.Text

elev(4) = TextBox10.Text

If stat(4) + elev(4) = 0 Then
GoTo send4
End If

Set PVI(4) = Nothing
Set PVI(4) = oProfile.PVIs.ItemAt(stat(4), elev(4))
'Debug.Print "PVI closest to station S4 is at station: ";
'Debug.Print PVI(4).Station
'Debug.Print "Elevation";
'Debug.Print PVI(4).Elevation

GoTo devam4
send4:
devam4:

'-------------------------------------------------------------

stat(5) = TextBox11.Text

elev(5) = TextBox12.Text

If stat(5) + elev(5) = 0 Then
GoTo send5
End If

Set PVI(5) = Nothing
Set PVI(5) = oProfile.PVIs.ItemAt(stat(5), elev(5))
'Debug.Print "PVI closest to station S5 is at station: ";
'Debug.Print PVI(5).Station
'Debug.Print "Elevation";
'Debug.Print PVI(5).Elevation
```

```
GoTo devam5
send5:
devam5:

'--------------------------------------------------------------

stat(6) = TextBox13.Text

elev(6) = TextBox14.Text

If stat(6) + elev(6) = 0 Then
GoTo send6
End If

Set PVI(6) = Nothing
Set PVI(6) = oProfile.PVIs.ItemAt(stat(6), elev(6))
'Debug.Print "PVI closest to station S6 is at station: ";
'Debug.Print PVI(6).Station
'Debug.Print "Elevation";
'Debug.Print PVI(6).Elevation

GoTo devam6
send6:
devam6:

'--------------------------------------------------------------

stat(7) = TextBox19.Text

elev(7) = TextBox20.Text

If stat(7) + elev(7) = 0 Then
GoTo send7
End If

Set PVI(7) = Nothing
Set PVI(7) = oProfile.PVIs.ItemAt(stat(7), elev(7))
'Debug.Print "PVI closest to station S7 is at station: ";
'Debug.Print PVI(7).Station
'Debug.Print "Elevation";
'Debug.Print PVI(7).Elevation

GoTo devam7
send7:
devam7:

'---------------------------------------------------------------

stat(8) = TextBox21.Text

elev(8) = TextBox22.Text

If stat(8) + elev(8) = 0 Then
GoTo send8
End If
```

```
Set PVI(8) = Nothing
Set PVI(8) = oProfile.PVIs.ItemAt(stat(8), elev(8))
'Debug.Print "PVI closest to station S8 is at station: ";
'Debug.Print PVI(8).Station
'Debug.Print "Elevation";
'Debug.Print PVI(8).Elevation

GoTo devam8
send8:
devam8:

'----------------------------------------------------------------

'getting user's stepsizes
Dim x As Double
Dim y As Double

x = TextBox1.Text

y = TextBox2.Text

'--------------------------------------------------------------

bigbang:

'getting current price
Dim dcut As Double
Dim dFill As Double

dcut = oTinVolumeSurface.Statistics.CutVolume
dFill = oTinVolumeSurface.Statistics.FillVolume

Dim cutup As Double
cutup = TextBox16.Text

Dim fillup As Double
fillup = TextBox17.Text

Dim ewtrc As Double
ewtrc = TextBox18.Text

Dim cmur As Double
cmur = (TextBox23.Text / 100)

Dim beup As Double
beup = TextBox24.Text

Dim becost00 As Double
If (dFill - dcut * cmur) > 0 Then
becost00 = (dFill - dcut * cmur) * beup
Else
becost00 = 0
End If

Dim startcost As Double
```

```
startcost = Abs(dcut) * cutup + Abs(dFill) * fillup + ewtrc + becost00

'----------------------------------------------------------

'define loop for PVI change
Dim n As Integer
For n = 1 To 8

Select Case n

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

End Select

'------------------------------------------------------------------

'zero station+elevation trap
If stat(n) + elev(n) = 0 Then
GoTo trap
End If

'------------------------------------------------------------------
'horizontal curve interaction handler
On Error GoTo Hata

'preparation for loop
Dim e As Integer
'Dim dNetVol(0 To 8) As Double
Dim dCutVol(0 To 8) As Double
Dim dFillVol(0 To 8) As Double

'getting current volumes
'dNetVol(0) = oTinVolumeSurface.Statistics.NetVolume
dCutVol(0) = oTinVolumeSurface.Statistics.CutVolume
dFillVol(0) = oTinVolumeSurface.Statistics.FillVolume

'define loop
For e = 1 To 8

Select Case e

Case 1
yatay = x
dusey = 0

Case 2
yatay = 0
dusey = -y
```

```
Case 3
yatay = -x
dusey = 0

Case 4
yatay = -x
dusey = 0

Case 5
yatay = 0
dusey = y

Case 6
yatay = 0
dusey = y

Case 7
yatay = x
dusey = 0

Case 8
yatay = x
dusey = 0

End Select

'adjustment
PVI(n).Station = PVI(n).Station + yatay
PVI(n).Elevation = PVI(n).Elevation + dusey
'Debug.Print "station";
'Debug.Print PVI(n).Station
'Debug.Print "Elevation";
'Debug.Print PVI(n).Elevation

'application of changes
Dim oApp As AcadApplication
Set oApp = ThisDrawing.Application
Dim sAppName As String
sAppName = "AeccXUiRoadway.AeccRoadwayApplication.9.0"
Dim oRoadwayApplication As AeccRoadwayApplication
Set oRoadwayApplication = oApp.GetInterfaceObject(sAppName)
Dim oRoadwayDocument As AeccRoadwayDocument
Set oRoadwayDocument = oRoadwayApplication.ActiveDocument
Dim oCorridors As AeccCorridors
Set oCorridors = oRoadwayDocument.Corridors
Dim oCorridor As AeccCorridor
For Each oCorridor In oCorridors
'Debug.Print "Corridor: " & oCorridor.Name
oCorridor.Rebuild
Next
oCivilApp.ZoomExtents
oCivilApp.ActiveDocument.SendCommand ("regenall ")

'check grade
'Debug.Print PVI(n).GradeIn
```

```
'Debug.Print PVI(n).GradeOut
Dim egim As Integer

'--------------------------------------------------
egim = TextBox15.Text

If Abs(PVI(n).GradeIn) > (egim / 100) Or Abs(PVI(n).GradeOut) > (egim /
100) Then GoTo Devam

'rebuild surface
oTinVolumeSurface.Rebuild

'get the volumes
'dNetVol(e) = oTinVolumeSurface.Statistics.NetVolume
dCutVol(e) = oTinVolumeSurface.Statistics.CutVolume
dFillVol(e) = oTinVolumeSurface.Statistics.FillVolume

Dim becost(0 To 8) As Double
If (dFillVol(e) - dCutVol(e) * cmur) > 0 Then
becost(e) = (dFillVol(e) - dCutVol(e) * cmur) * beup
Else
becost(e) = 0
End If

'Debug.Print dCutVol(e) & ": cut"
'Debug.Print dFillVol(e) & ": fill"
'Debug.Print dNetVol(e) & ": net"

'grade check handler release
Devam:

'horizontal curve interaction handler release
Hata:

Next e

'adjustment from 8 to 0
PVI(n).Station = PVI(n).Station - x
PVI(n).Elevation = PVI(n).Elevation - y
'Debug.Print "Elevation";
'Debug.Print PVI(n).Elevation
'Debug.Print "station";
'Debug.Print PVI(n).Station

'application of changes
Set oApp = ThisDrawing.Application
Set oRoadwayApplication = oApp.GetInterfaceObject(sAppName)
Set oRoadwayDocument = oRoadwayApplication.ActiveDocument
Set oCorridors = oRoadwayDocument.Corridors
For Each oCorridor In oCorridors
'Debug.Print "Corridor: " & oCorridor.Name
oCorridor.Rebuild
Next
oCivilApp.ZoomExtents
oCivilApp.ActiveDocument.SendCommand ("regenall ")
```

```
'rebuild surface
oTinVolumeSurface.Rebuild

'egg test
Dim azpara, adaypara As Double
Dim azparaNO As Byte

Dim becost0 As Double
If (dFillVol(0) - dCutVol(0) * cmur) > 0 Then
becost0 = (dFillVol(0) - dCutVol(0) * cmur) * beup
Else
becost0 = 0
End If

azpara = Abs(dCutVol(0)) * cutup + Abs(dFillVol(0)) * fillup + ewtrc +
becost0
azparaNO = 0

Dim f As Byte
For f = 1 To 8

    adaypara = Abs(dCutVol(f)) * cutup + Abs(dFillVol(f)) * fillup + ewtrc
+ becost(f)
    If (adaypara - ewtrc) <> 0 Then
    If azpara > adaypara Then
        azpara = adaypara
        azparaNO = f
    End If
    End If

Next f

'adjust PVI for the srongest egg; define location
Select Case azparaNO

Case 0
yatay = 0
dusey = 0

Case 1
yatay = x
dusey = 0

Case 2
yatay = x
dusey = -y

Case 3
yatay = 0
dusey = -y

Case 4
yatay = -x
dusey = -y

Case 5
```

```
yatay = -x
dusey = 0

Case 6
yatay = -x
dusey = y

Case 7
yatay = 0
dusey = y

Case 8
yatay = x
dusey = y

End Select

'adjustment
PVI(n).Station = PVI(n).Station + yatay
PVI(n).Elevation = PVI(n).Elevation + dusey
'Debug.Print "Elevation";
'Debug.Print PVI(n).Elevation
'Debug.Print "station";
'Debug.Print PVI(n).Station

'application of changes
Set oApp = ThisDrawing.Application
Set oRoadwayApplication = oApp.GetInterfaceObject(sAppName)
Set oRoadwayDocument = oRoadwayApplication.ActiveDocument
Set oCorridors = oRoadwayDocument.Corridors
For Each oCorridor In oCorridors
'Debug.Print "Corridor: " & oCorridor.Name
oCorridor.Rebuild
Next
oCivilApp.ZoomExtents
oCivilApp.ActiveDocument.SendCommand ("regenall ")

'rebuild surface
oTinVolumeSurface.Rebuild

'count the run
runnumber = runnumber + 9

'zero station+elevation trap release
trap:

Next n

'---------------------------------------------------------

'zero run trap
If azpara = 0 Then
GoTo zero:
End If

'the tireless optimizer itself
```

```
If startcost > azpara Then
GoTo bigbang
End If

'zero trap
zero:

'printout
Label9.Caption = Round(azpara, 2)
Label39.Caption = Round(oTinVolumeSurface.Statistics.FillVolume, 3)
Label40.Caption = Round(oTinVolumeSurface.Statistics.CutVolume, 3)

Dim becostson As Double
If (oTinVolumeSurface.Statistics.FillVolume -
oTinVolumeSurface.Statistics.CutVolume * cmur) > 0 Then
becostson = (oTinVolumeSurface.Statistics.FillVolume -
oTinVolumeSurface.Statistics.CutVolume * cmur) * beup
Else
becostson = 0
End If

Label80.Caption = Round(oTinVolumeSurface.Statistics.FillVolume * fillup +
becostson, 3)
Label79.Caption = Round(oTinVolumeSurface.Statistics.CutVolume * cutup, 3)

'finalize

'---------------------------------------------------------

If stat(1) + elev(1) = 0 Then
GoTo sendet1
End If

Label61.Caption = Round(PVI(1).Station, 3)
Label62.Caption = Round(PVI(1).Elevation, 3)

GoTo devamet1
sendet1:
devamet1:

'---------------------------------------------------------

If stat(2) + elev(2) = 0 Then
GoTo sendet2
End If

Label63.Caption = Round(PVI(2).Station, 3)
Label64.Caption = Round(PVI(2).Elevation, 3)

GoTo devamet2
sendet2:
devamet2:

'---------------------------------------------------------
If stat(3) + elev(3) = 0 Then
GoTo sendet3
```

```
End If

Label65.Caption = Round(PVI(3).Station, 3)
Label66.Caption = Round(PVI(3).Elevation, 3)

GoTo devamet3
sendet3:
devamet3:

'----------------------------------------------------------

If stat(4) + elev(4) = 0 Then
GoTo sendet4
End If

Label67.Caption = Round(PVI(4).Station, 3)
Label68.Caption = Round(PVI(4).Elevation, 3)

GoTo devamet4
sendet4:
devamet4:

'----------------------------------------------------------

If stat(5) + elev(5) = 0 Then
GoTo sendet5
End If

Label69.Caption = Round(PVI(5).Station, 3)
Label70.Caption = Round(PVI(5).Elevation, 3)

GoTo devamet5
sendet5:
devamet5:

'----------------------------------------------------------

If stat(6) + elev(6) = 0 Then
GoTo sendet6
End If

Label71.Caption = Round(PVI(6).Station, 3)
Label72.Caption = Round(PVI(6).Elevation, 3)

GoTo devamet6
sendet6:
devamet6:

'----------------------------------------------------------

If stat(7) + elev(7) = 0 Then
GoTo sendet7
End If

Label100.Caption = Round(PVI(7).Station, 3)
Label101.Caption = Round(PVI(7).Elevation, 3)
```

```
GoTo devamet7
sendet7:
devamet7:

'----------------------------------------------------------

If stat(8) + elev(8) = 0 Then
GoTo sendet8
End If

Label102.Caption = Round(PVI(8).Station, 3)
Label103.Caption = Round(PVI(8).Elevation, 3)

GoTo devamet8
sendet8:
devamet8:

'----------------------------------------------------------

'show the runs
Label74.Caption = runnumber

'timer stop
bitis = Now
Label30.Caption = bitis

MsgBox ("FINISH")

End Sub
```

APPENDIX B

HIGHWAY DESIGN ON AUTOCAD CIVIL 3D

Items necessary in geometric design of the highway section should be defined in the drawing file step by step. There are numerous ways to create these items using the software, but only a typical procedure for each step is explained here. Much detailed information can be found on AutoCAD Civil 3D User’s Guide (User’s Guide, AutoCAD Civil 3D 2011, 2010).

The AutoCAD Civil 3D interface with an empty drawing is demonstrated in Figure 47.

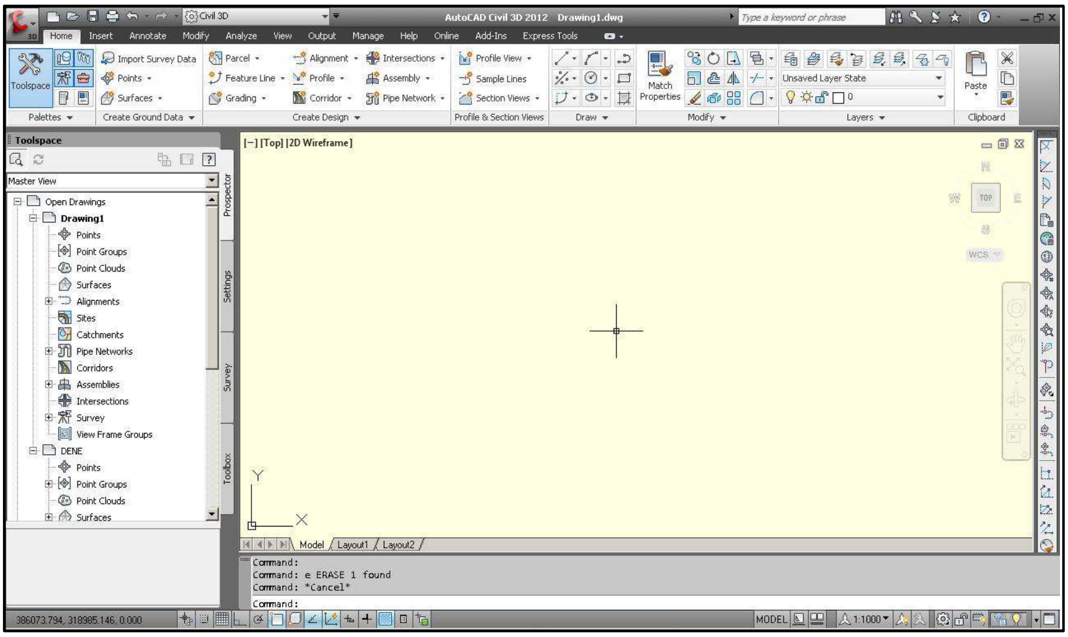


Figure 47: AutoCAD Civil 3D interface

B.1. GROUND SURFACE

A surface is the digital representation of the project area. To start the highway design, the project area should first be identified on the drawing. There are various types of surface and surface import methods available in the software. In highway design, a TIN (triangulated irregular network) surface was created from contour or random point data, which represents the project area. To prepare the surface, first an empty surface is created.

To create an empty surface; Click Home tab ➢ Create Ground Data panel ➢ Surfaces drop-down ➢ Create Surface. The command is demonstrated in Figure 48.

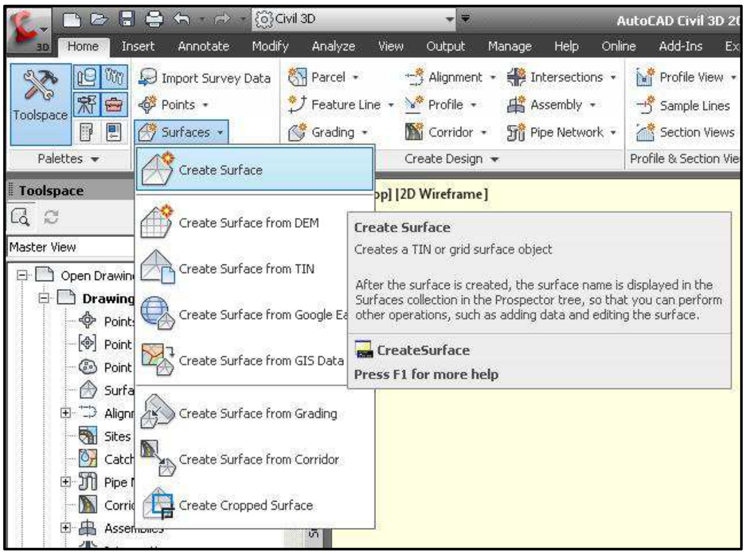


Figure 48: Creating an empty surface

In the Create Surface dialog box, in the Type list, TIN Surface is selected. The default settings can be used for simplicity; or the user can change the name, description and other parameters for detailed studies, see Figure 49.

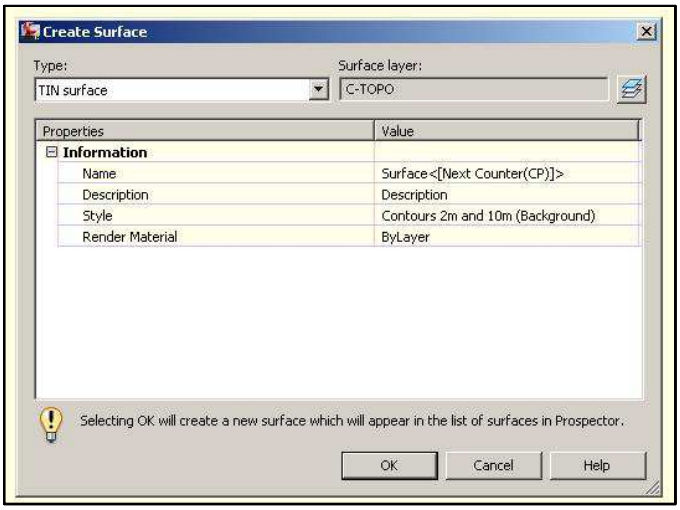


Figure 49: Create Surface dialog box

After creating an empty surface, the next step is to insert the map data to the surface. Usually, contour or random elevation points were available as map data. The contours or points were first copied to the drawing, and then inserted.

To insert the data; Prospector tab: Surfaces ➤ <surface-name> ➤ Definition ➤ right-click ➤ <data-type> ➤ Add. The command is demonstrated in Figure 50.

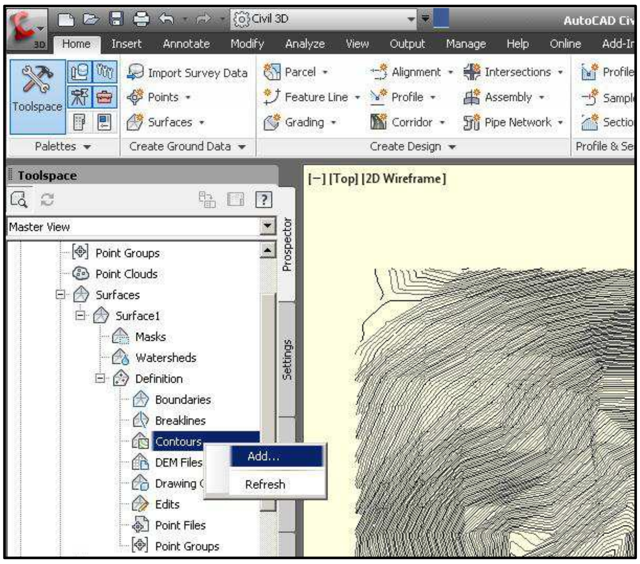


Figure 50: Adding contours to the design surface

The next dialog box can be accepted directly with default settings, see Figure 51. The detailed changes of these settings can be applied in further studies. Finally the items are selected from the drawing and inserted to the surface. At random point data, the data type can be selected as drawing objects and the same procedure can be applied.

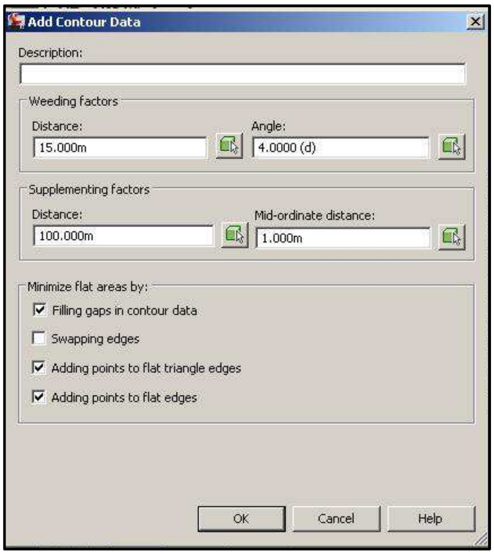


Figure 51: Add contour data dialog box

B.2. ALIGNMENT

The next step in AutoCAD Civil 3D design is to create the alignment. The alignment here refers to the horizontal alignment of highway, and vertical alignment will be created later in profiles section.

Alignments can be stand-alone objects or the parent object of profiles, sections, and corridors. If you edit an alignment, the changes are automatically reflected in any related objects (User's Guide, AutoCAD Civil 3D 2011, 2010).

As with the creation of the surface, there are various ways to create the alignment. Here, creating an Alignment with the Alignment Creation Tools is explained.

To create an alignment; Click Home tab ➤ Create Design panel ➤ Alignment drop-down ➤ Alignment Creation Tools. The command is demonstrated in Figure 52.

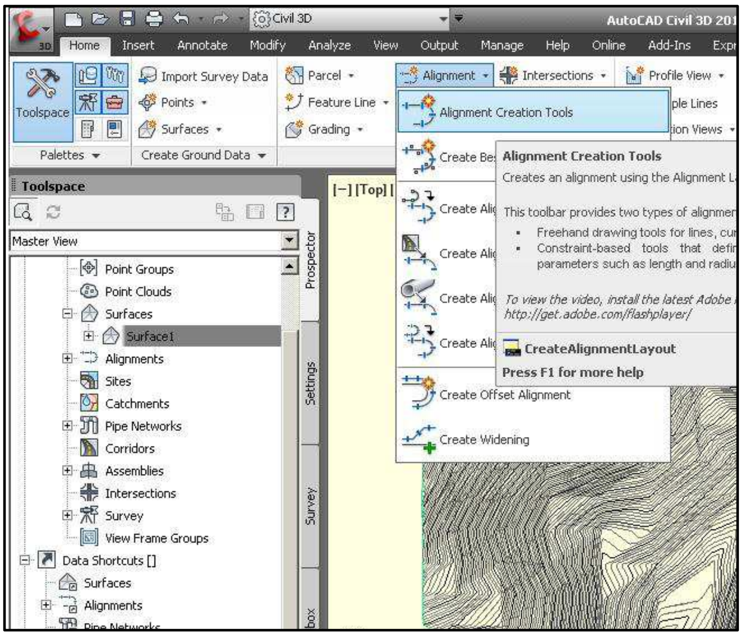


Figure 52: Alignment creation

Like the previous steps, the general settings can be changed from the dialog box opened, or can be left as default settings, as will be done here. All the settings can be changed, except the starting station data. Although the starting station can be changed in highway projects in real life, the study alignment should be started at 0+000.00 km, to run the optimization module "Earthworker" successfully. See the dialog box in Figure 53.

Figure 53: Create alignment dialog box

By accepting the settings, the Alignment Layout Tools toolbar (see Figure 54) pops up to create the alignment. By using this toolbar, the alignment can be created in various ways.

Figure 54: Alignment Layout Tools toolbar

The basic technique is first to draw the straight lines as per the standard application, then curve application. First, draw tangent-tangent command is selected and the intersection points are established on the surface.

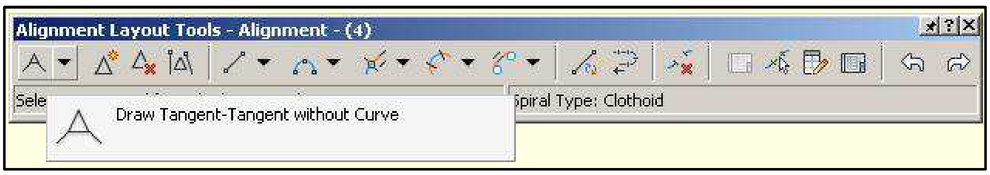


Figure 55: Draw Tangent-Tangent command

Figure 56: Drawing Tangent-Tangent lines without curve

Then, the curves are fitted between the lines finishing the alignment creation. To establish a curve between two lines, there are various ways also listed below the curve fit button in Alignment Layout Tools toolbar. Free Curve Fillet (Between two entities, radius) is used and demonstrated in Figure 57 and Figure 58.

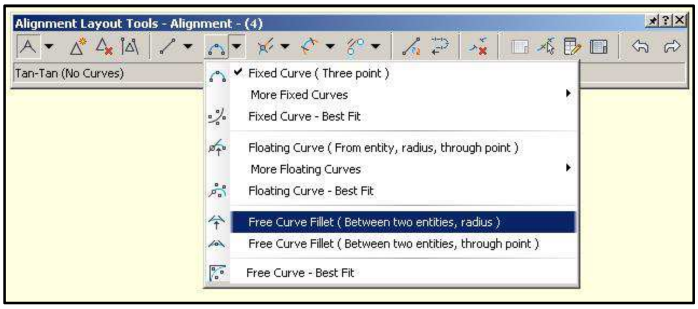


Figure 57: Free Curve Fillet (Between two entities, radius) command

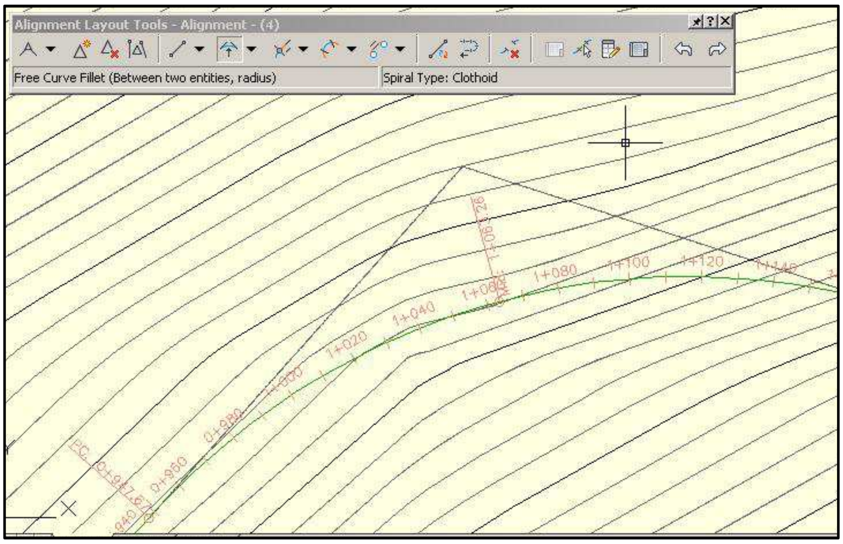


Figure 58: Curve fit operation

If a correction needs to be done on the alignment after the creation is finished, it can be applied also by Alignment Layout Tools toolbar or manually. The related commands will appear on the menu bar, when the alignment is selected.

B.3. PROFILES

Once the horizontal alignment is fixed, the vertical alignment can then be created. To do this, first the surface profile of the horizontal alignment is created, and then the vertical alignment is created on the profile view. After finishing the profiles section there will be created one surface profile and one layout profile -referring vertical alignment of highway- on the drawing. In the software, there are again various ways of working on profiles; the common way is demonstrated here.

To create a surface profile along the alignment; Click Home tab ➤ Create Design panel ➤ Profile drop-down ➤ Create Surface Profile. The command was demonstrated in Figure 59.

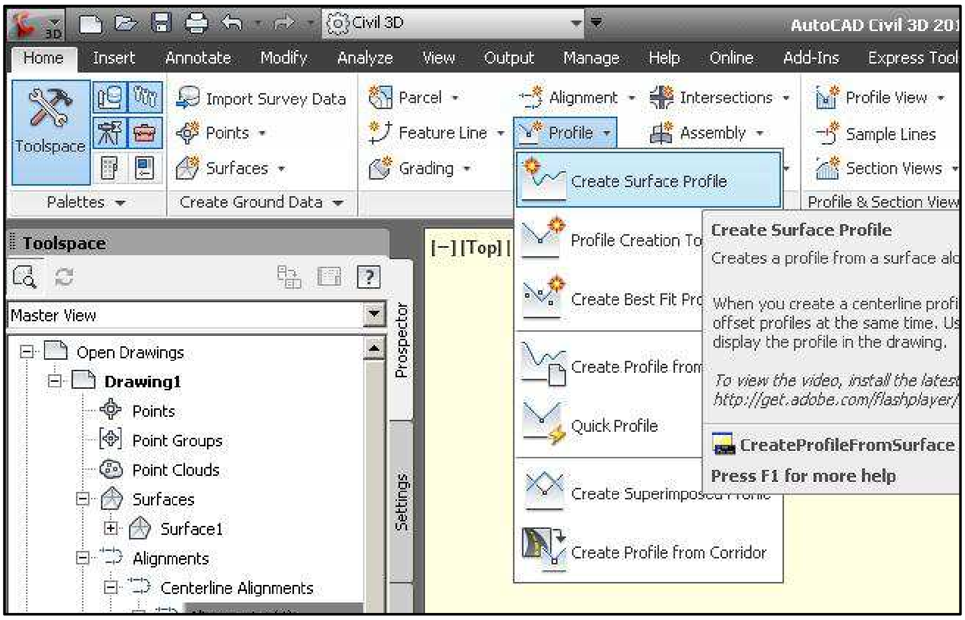


Figure 59: Create Surface Profile command

After executing the above command, another dialog box appears, see Figure 60. In this dialog box, the user should identify the related alignment and the surface, and the start and end stations of the profile set. Here, there should be only one alignment and one surface in the drawing, to successful operation of the module, so these items should appear in the dialog box as defaults.

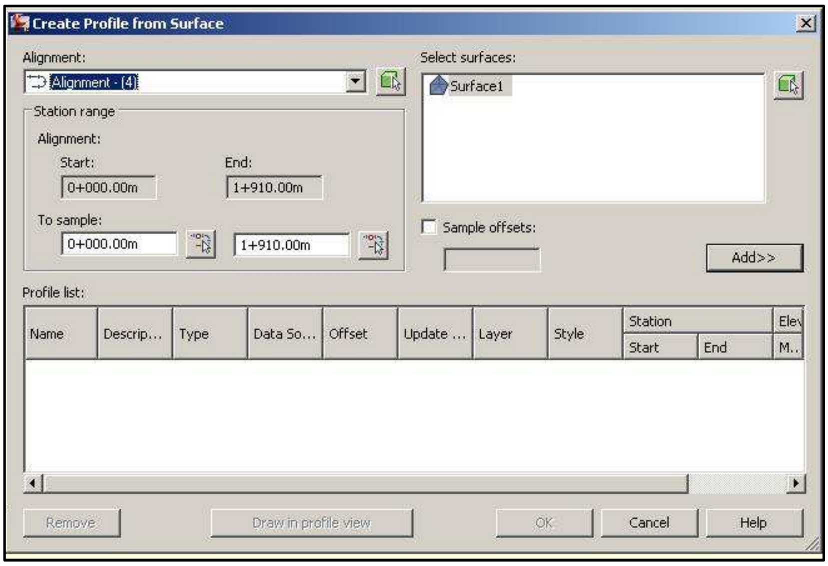


Figure 60: Create Profile from Surface dialog box

By clicking the Add button in the dialog box, the profile is created and listed in profile list, see Figure 61. Then the Draw in profile view command is selected and the profile set style option set appears in create profile view-general dialog box as demonstrated in Figure 62.

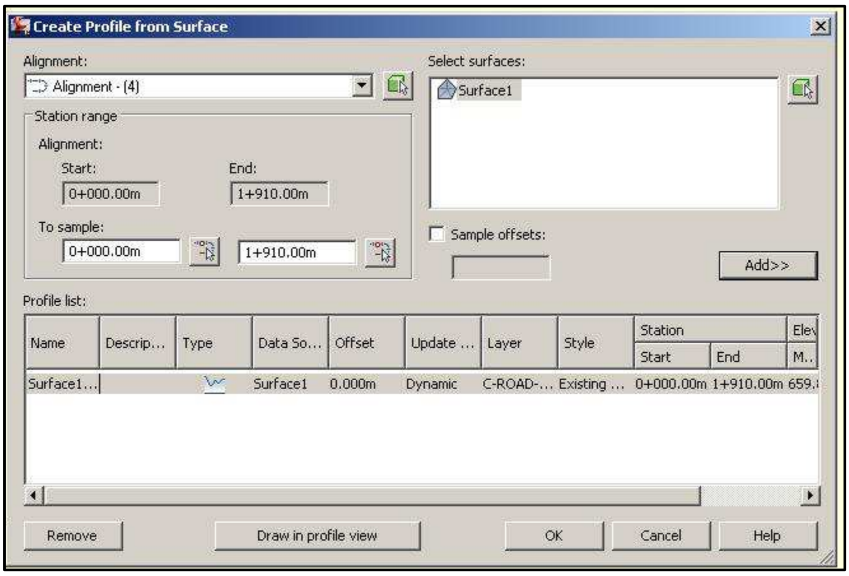


Figure 61: Create Profile from Surface dialog box, profile created

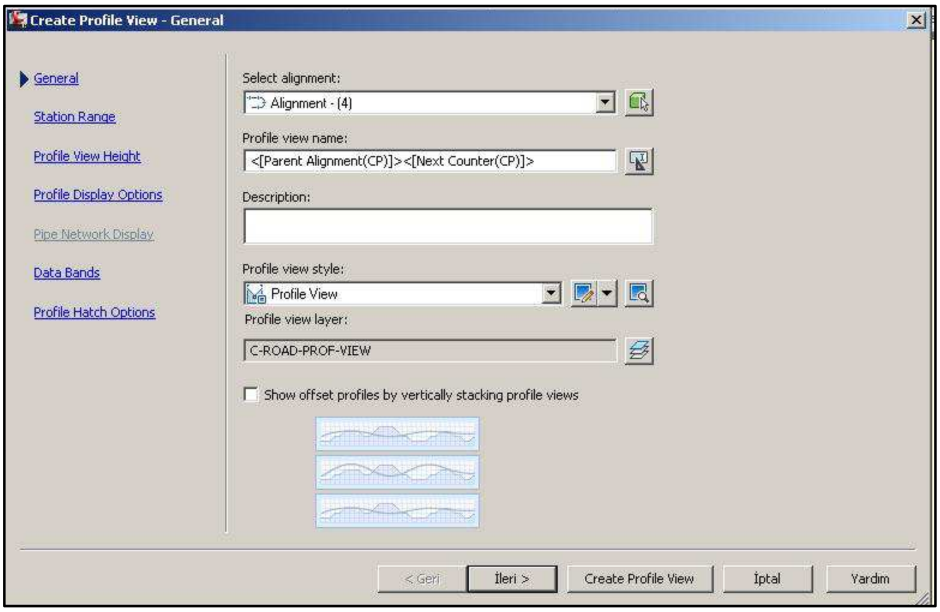


Figure 62: Create Profile View dialog box

In Create Profile View dialog box, all the options could be left as their default settings, but two changes make the rest of the process simpler. The first one is to change the name of the profile. The reason behind this idea is that; there are two profiles created in the design process, surface and design (surface and vertical alignment of highway respectively), and the designer may find it difficult to identify the required profile set, if their names are profile 1 and profile 2. The name of the profile set can be changed at this point, from the dialog box, by editing the profile view name, as demonstrated in Figure 63.

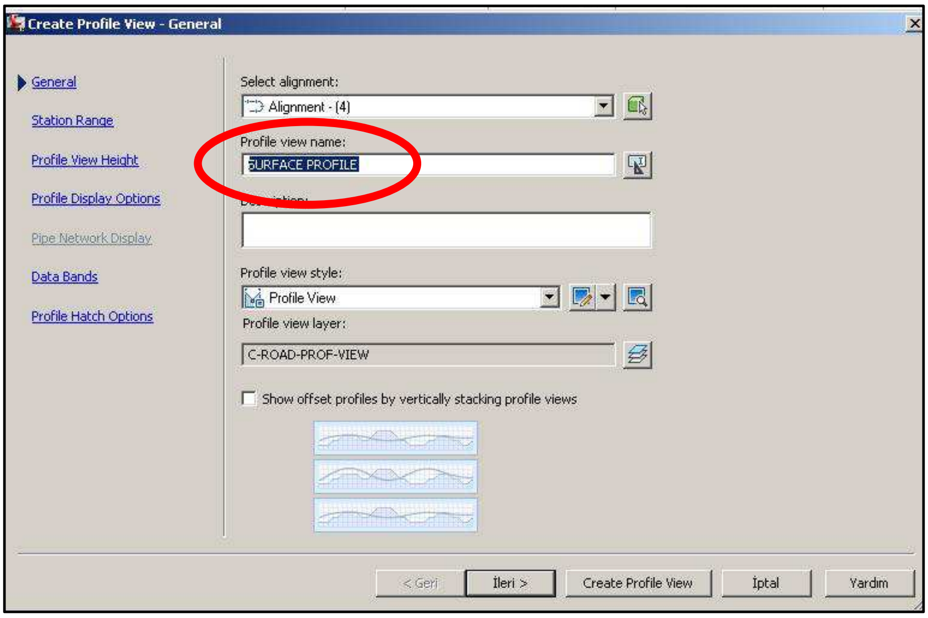


Figure 63: Changing the profile name

The other point is the profile view height settings. Before creating the profile, the elevation range should be expanded to cover all the elevation changes in optimization stage. Since the software is running based on visual data entrance, the solution range is limited in the view range of the profile. In other words, the solution space is limited by the borders of the profile view. Depending on the surface conditions, generally widening of the minimum and maximum default values by approximately 50 meters is observed as necessary. While changing the profile view height, split profile view may turned on automatically, this option should be turned off. Expanding the profile height is demonstrated in Figure 64.

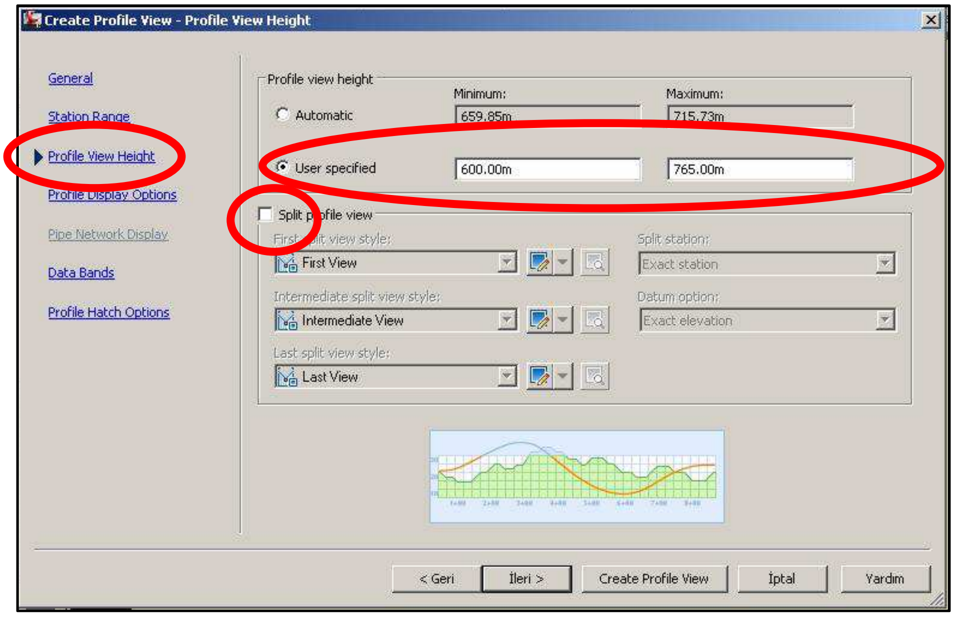


Figure 64: Expanding the profile height

The other profile view settings can be left as their default options. After all settings are finished, create profile view command enables the user to set the location of the profile view on the drawing. It could be placed anywhere, but a clear location close enough to the surface data is preferred, to not to expand the drawing limits and not use unnecessary CPU. A typical profile view is demonstrated in Figure 65.

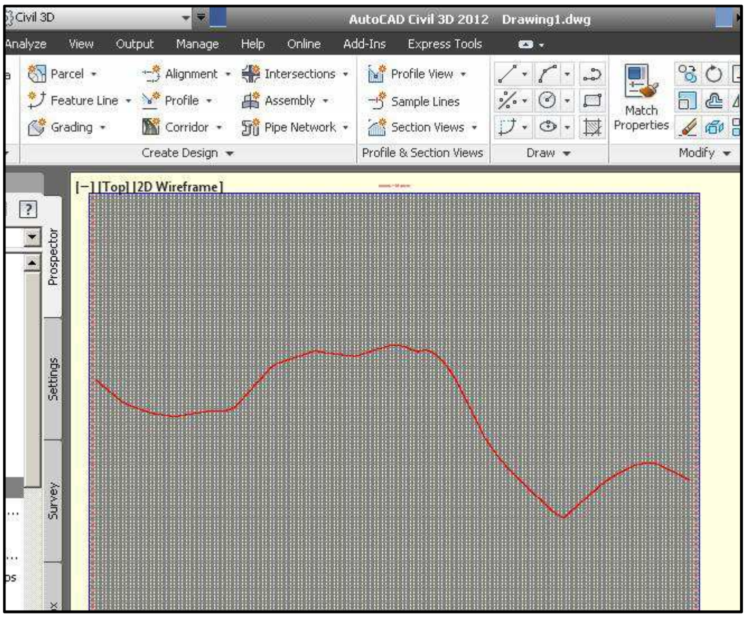


Figure 65: Surface profile view on drawing

Once the surface profile along the alignment is established, the layout profile (vertical alignment) can then be created. Among all the profile creation ways, using the profile creation tools is explained here, by which the typical design procedure can be followed. To use the profile creation tools; Click Home tab ➤ Create Design panel ➤ Profile drop-down ➤ Profile Creation Tools. The command is demonstrated in Figure 66.

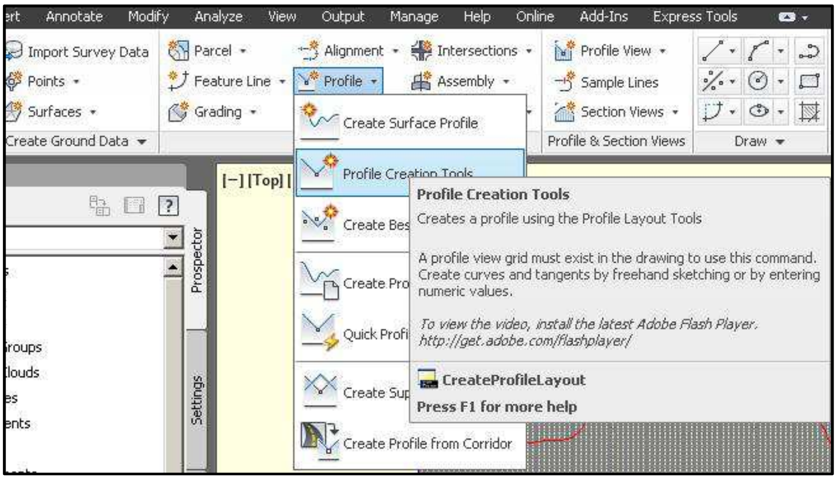


Figure 66: Profile Creation Tools command

Then the software asks the user to choose the profile view, on which the layout profile will be created. When the profile view is selected, the create profile-draw new dialog box opens. In the dialog box, it is recommended to give a name for the profile set, different from the surface profile set, for the reasons mentioned above. There is also another option under the design criteria tab, which allows user to check the vertical alignment with design criteria, but the method is out of scope of this study. The other settings can be left on their default options. The dialog box is demonstrated in Figure 67.

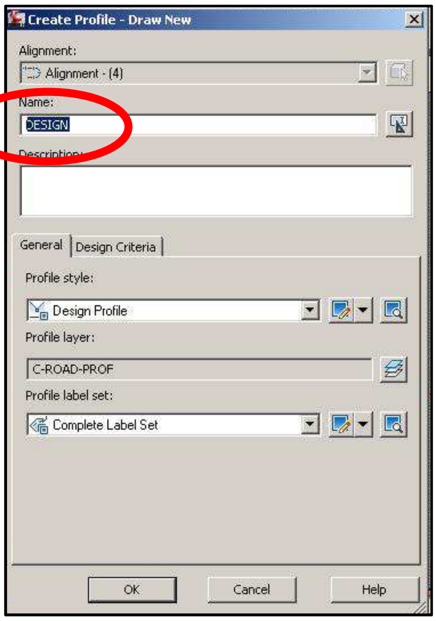


Figure 67: Create Profile dialog box and the name option

Immediately after accepting the settings, Profile Layout Tools opens up. The toolbar is demonstrated in Figure 68. Like in the other steps of design, there are many different ways to create the layout profile (vertical alignment of highway) by using the commands on Profile Layout Tools toolbar. In this point, creating the tangents and then applying the vertical parabolic curves is the technique explained, which best represents the standard procedure.

Figure 68: Profile Layout Tools toolbar

To create the tangents of layout profile (vertical alignment of highway), the command draw tangents can be used. The command is identified in Figure 69. Just after clicking the button, the user can locate the Point of Vertical Intersections (PVI) on the profile view, by clicking the PVI locations on the profile set view.

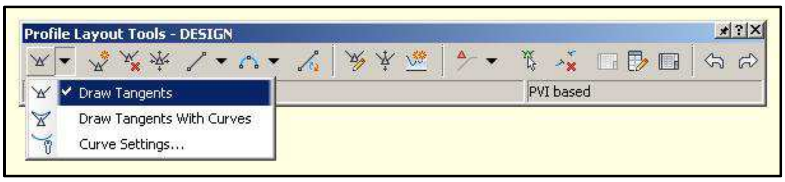


Figure 69: Draw Tangents command

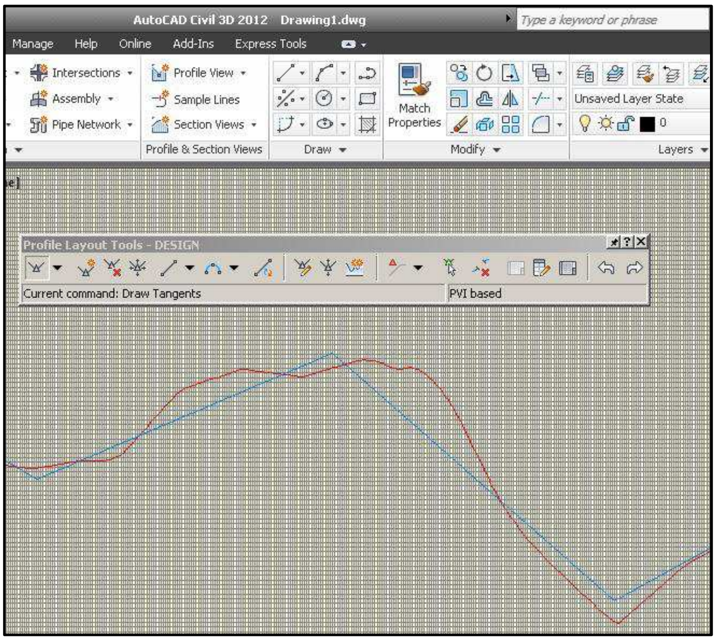


Figure 70: Drawing Tangents Profile Layout

After the PVI locations are specified, the parabolic vertical curves are added with the draw vertical curves command on the Profile Layout Tools toolbar. The method preferred is to draw Free Vertical Curve (Parameter), by which the curves are created by selecting the intersection and defining the curve length. The command is demonstrated in Figure 71. After the command button is clicked, AutoCAD Civil 3D asks the user to identify the first entity (entrance tangent line), second entity (exit tangent line) and curve length one by one. It may be useful if the command line is followed by the user in this operation. The application example is illustrated in Figure 72.

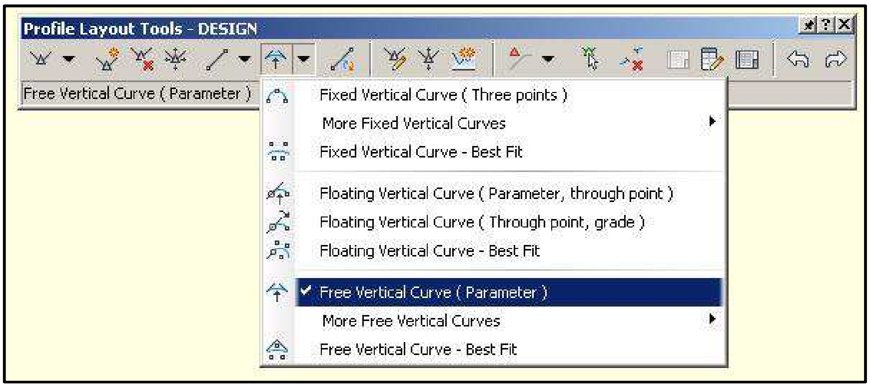


Figure 71: Free Vertical Curve command

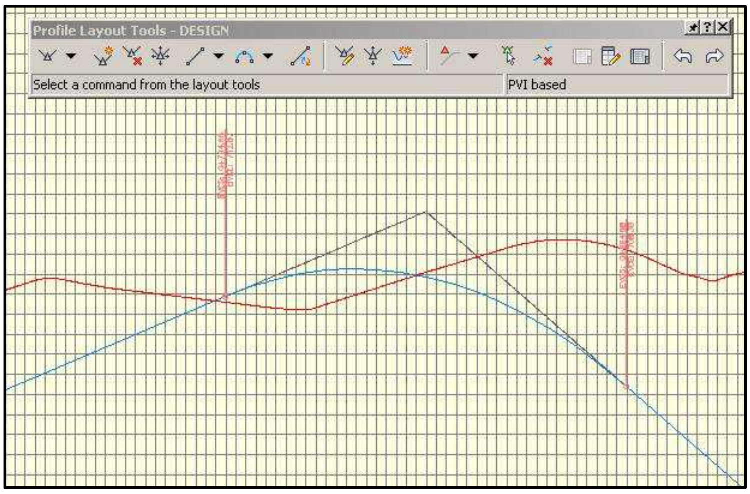


Figure 72: Vertical curve application

The user can make changes to the layout profile (vertical alignment of the highway) also after the creation is finished. By selecting the layout profile, the profile tab is displayed on the main ribbon. On profile tab, when the geometry editor is selected, Profile Layout Tools toolbar will become available again to make the design changes. To adjust the profile, the profile Grid View command is a very practical tool, which opens up profile entities table, in which the profile statistics are shown and can be changed directly. The steps of the operation are demonstrated in Figure 73, Figure 74 and Figure 75.

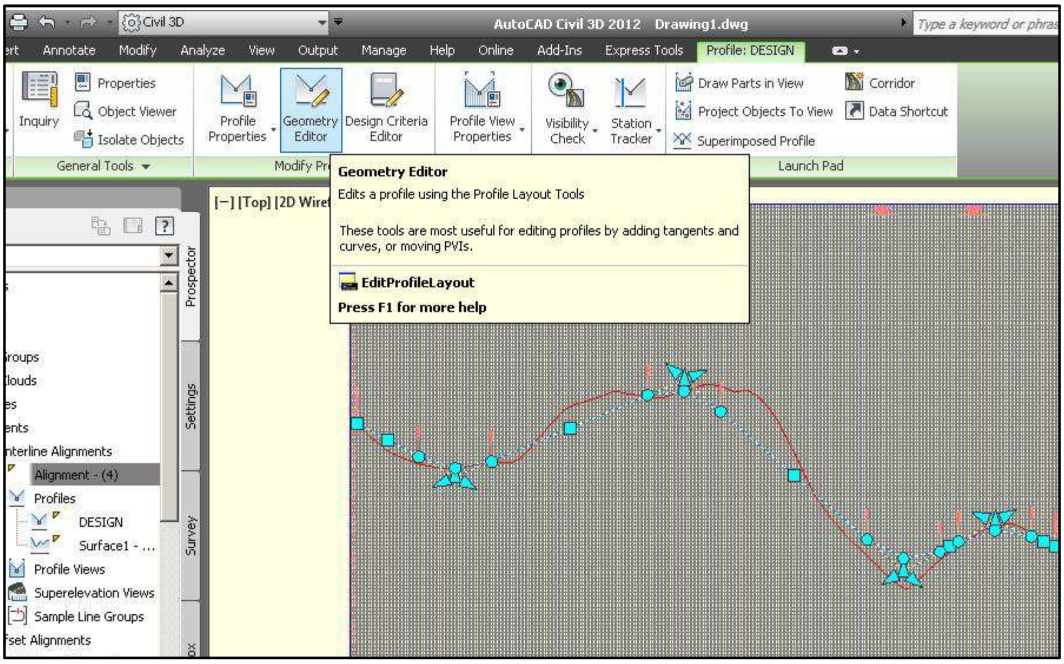


Figure 73: Geometry Editor command

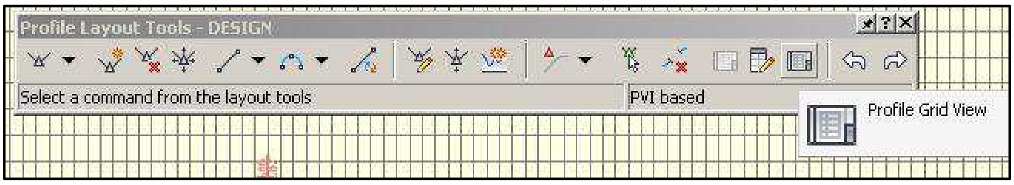
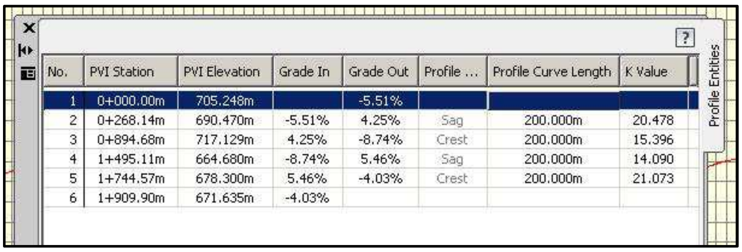


Figure 74: Profile Grid View command



No.	PVI Station	PVI Elevation	Grade In	Grade Out	Profile ...	Profile Curve Length	K Value
1	0+000.00m	705.248m		-5.51%			
2	0+268.14m	690.470m	-5.51%	4.25%	Sag	200.000m	20.478
3	0+894.68m	717.129m	4.25%	-8.74%	Crest	200.000m	15.396
4	1+495.11m	664.680m	-8.74%	5.46%	Sag	200.000m	14.090
5	1+744.57m	678.300m	5.46%	-4.03%	Crest	200.000m	21.073
6	1+909.90m	671.635m	-4.03%				

Figure 75: Profile Entities table

B.4. ASSEMBLY (CROSS SECTION)

Assembly refers to the cross section of the highway model, which is applied trough the 3D highway alignment at incremental locations to create the highway model. At AutoCAD Civil 3D, there is an assembly and subassembly object library, by which the user can select the cross section structures. For this study, a basic divided highway assembly is used in creation of the highway corridor. The simplest way to create an assembly is by adding an assembly object to the drawing from the tool palette. To display the Tool Palettes window: Click Home tab ➤ Palettes panel ➤ Tool palettes. The command is demonstrated in Figure 76.

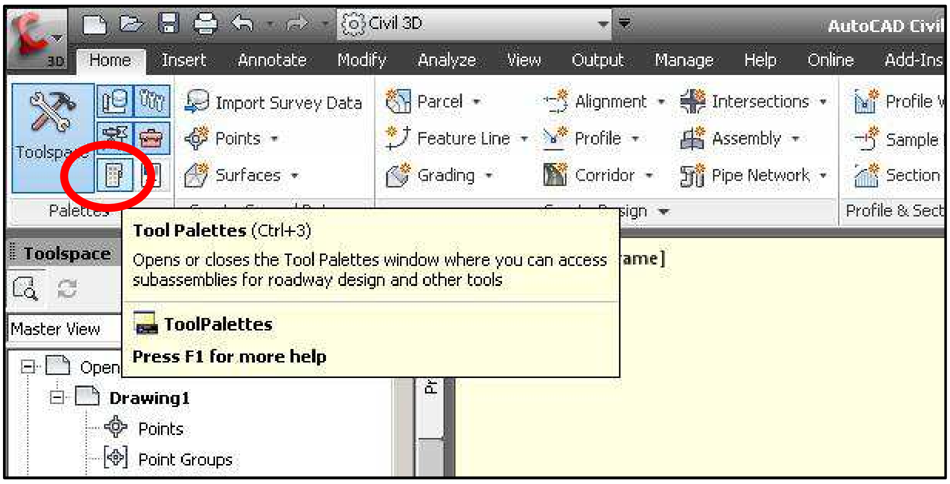


Figure 76: Access to Tool Palettes

In the tool palettes, click the desired assembly, and then the software asks for a location in the drawing, by simply clicking an empty location, the assembly will be added to the drawing and can be used for Corridor, that is, highway model. The tool palette is demonstrated in Figure 77.

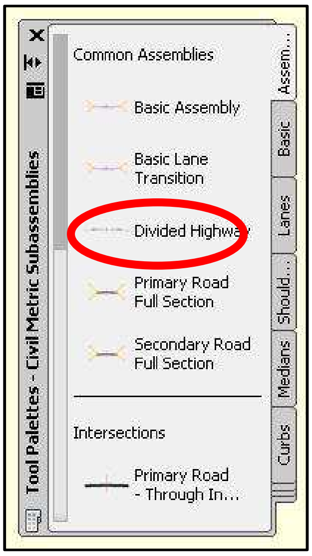


Figure 77: Tool Palettes

The assembly properties can be changed after the assembly is added to the drawing. To change the assembly properties; by clicking on the assembly, the ribbon changes to the assembly tab, and then the assembly properties command is selected. The command is demonstrated in Figure 78. By selecting the properties, the software asks the user to identify the assembly, which can be done by clicking on the center of the assembly object. The changes then can be made on the construction tab of the assembly properties dialog box that opens up. The dialog box is demonstrated in Figure 79.

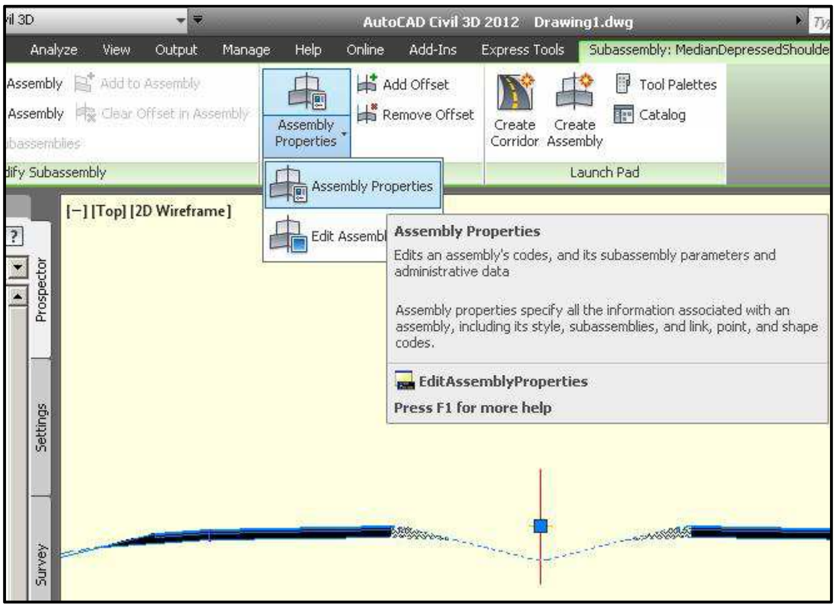


Figure 78: Access to Assembly Properties command

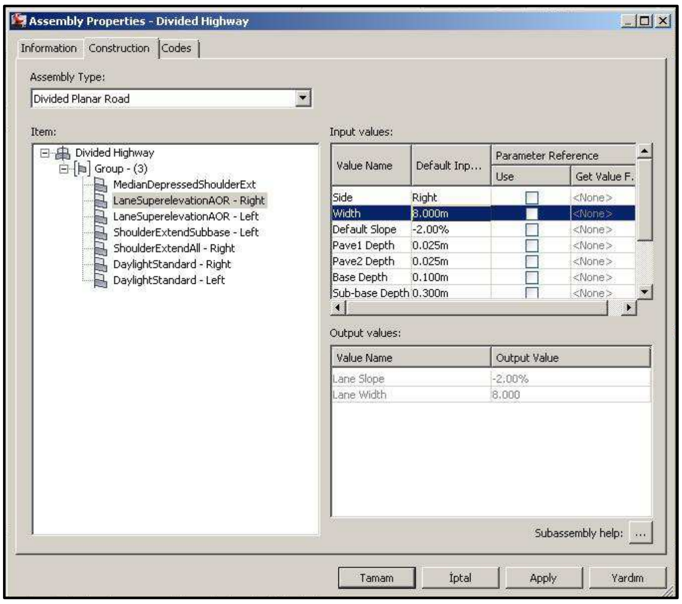


Figure 79: Assembly Properties Dialog Box

B.5. CORRIDOR (HIGHWAY MODEL)

A corridor model builds on and uses various AutoCAD Civil 3D objects and data, including assemblies, alignments, surfaces, and profiles. A corridor object is created from a baseline (alignment) by placing 2D sections (assemblies) at incremental locations, and by creating matching slopes that reach a surface model at each incremental location (User’s Guide, AutoCAD Civil 3D 2011, 2010).

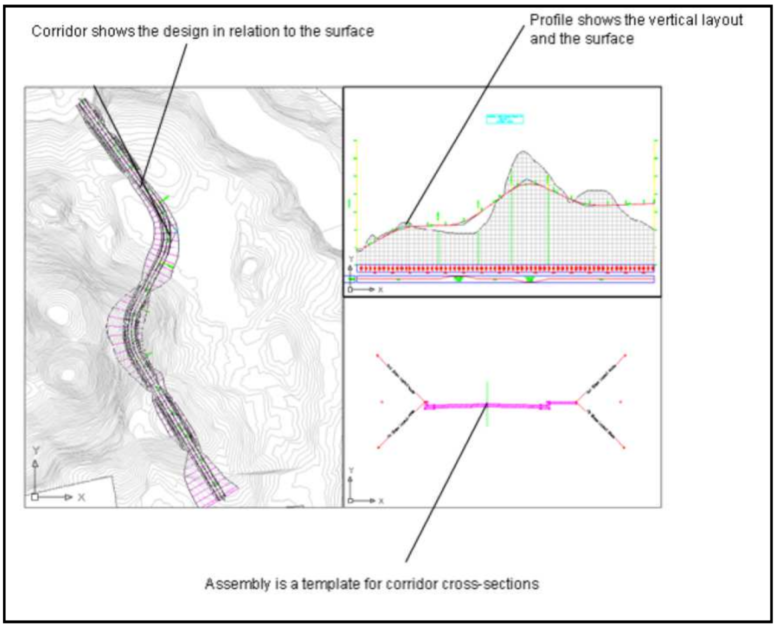


Figure 80: Elements of a corridor design, figure from User’s Guide (User’s Guide, AutoCAD Civil 3D 2011, 2010)

In this study, creating a simple corridor is sufficient. To create a simple corridor; Click Home tab ➤ Create Design panel ➤ Corridor drop-down ➤ Create Simple Corridor. The command is demonstrated in Figure 81.

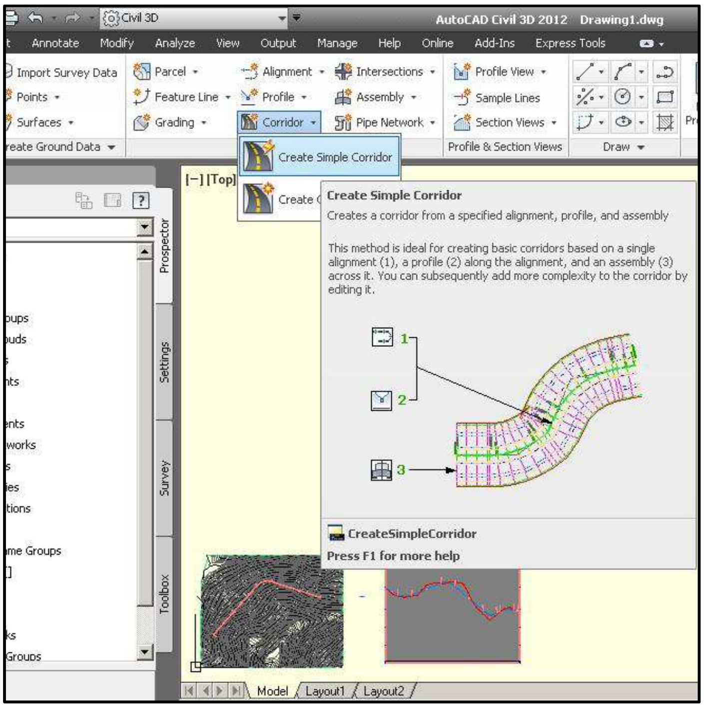


Figure 81: Create Simple Corridor command

In the Create Simple Corridor dialog box that opens up, as per Figure 82, the name of the corridor and the display style can be changed, but it is not necessary in this study, the default settings can be accepted. After accepting the settings, the software asks the user to identify the alignment, profile and assembly, one after another. The items can be selected from drawing, also the command line can be followed at this point, where stated; by pressing Enter from keyboard; the list of the objects will appear and the items can easily be selected. Since one of each item is created, there would be only one item on each list, except the profile. Care should be taken when identifying the layout profile. As mentioned in previous sections, the different name chosen for the layout profile will help the user to refer to the desired profile easily. The lists are demonstrated in Figure 83, Figure 84 and Figure 85 .

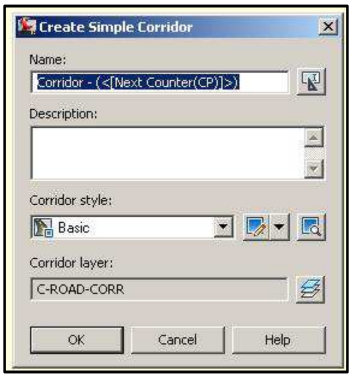


Figure 82: Create Simple Corridor dialog box

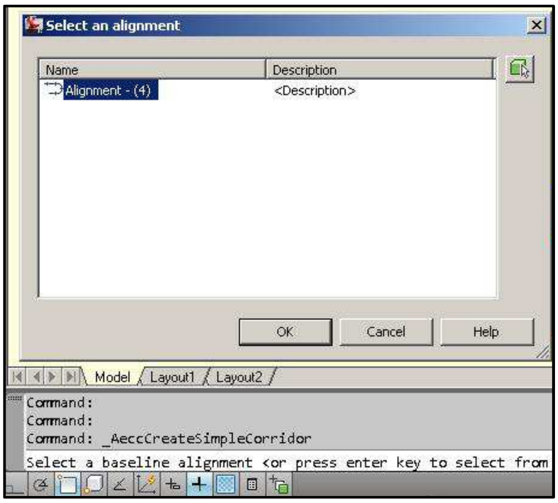


Figure 83: Alignment list

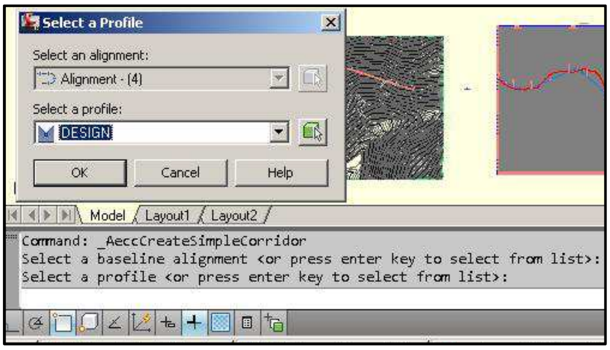


Figure 84: Profile list

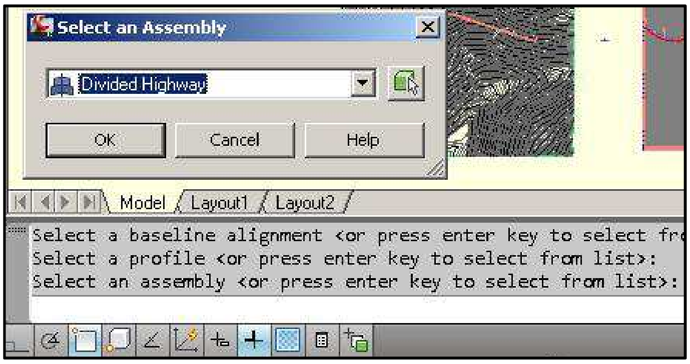


Figure 85: Assembly list

After the identification of the corridor elements, Target Mapping dialog box opens up, where the existing surface is selected for the construction of the corridor. There are also other options for the corridor model for further analysis. The Target Mapping dialog box and the surface set option are demonstrated in Figure 86.

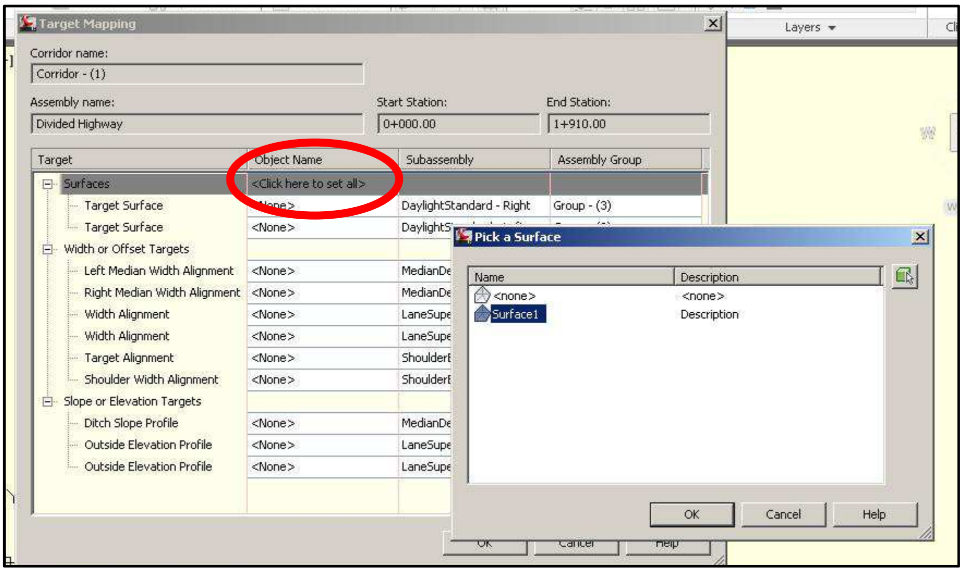


Figure 86: Setting the surface for corridor

As per the selection of the surface and accepting the settings, AutoCAD Civil 3D generates the corridor. If there arise any conflict at the intersection points design and existing surface, the software reports the conflicts, after generating the corridor. Most of the time, the user may face conflicts at starting and end kilometers of the corridor. The errors may occur because of the graphical insertion of PVI data at vertical alignment. To solve this, the PVI kilometers should be controlled and corrected by Geometry Editor, as explained in Section B.3 of this study.

At this point, a corridor surface should have been created. To start the creation of the corridor surface, the user should right click on the corridor item from Toolspace menu (at the left hand side of the screen as default) under the Corridors group, and select properties first (see Figure 87).

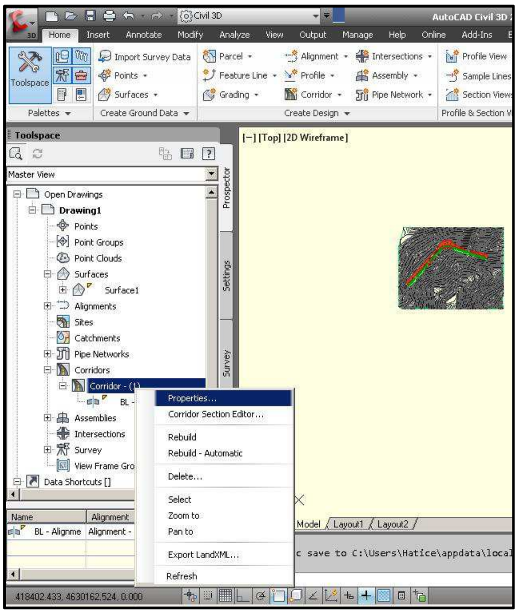


Figure 87: Access to corridor properties

Then in the Corridor Properties dialog box, from the surface tab, the corridor surface is created by Create a Corridor Surface and Add Data commands, as demonstrated in Figure 88 .

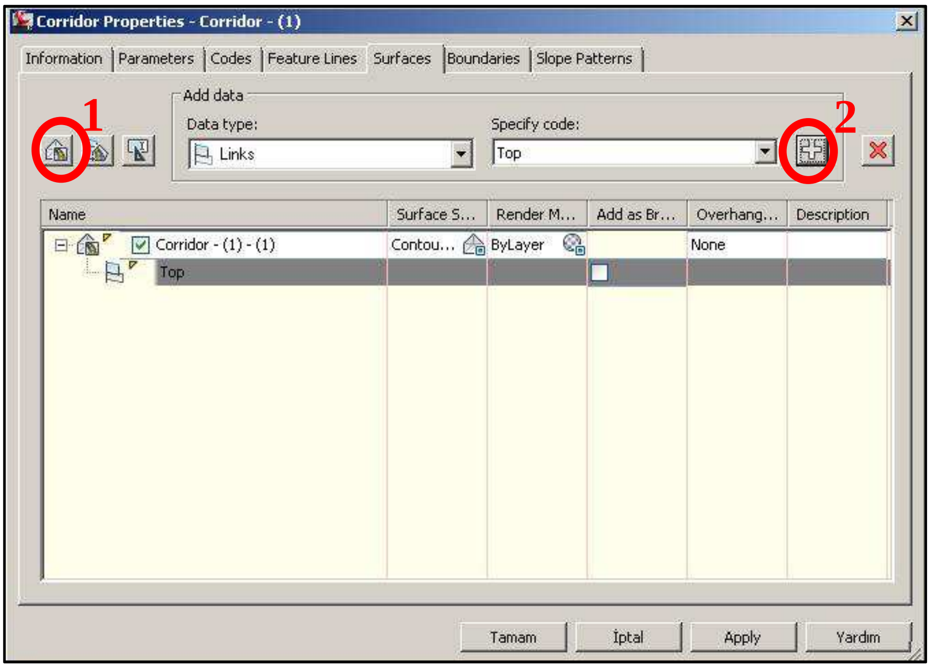


Figure 88: Creating corridor surface

By clicking Apply and OK buttons, the corridor surface is created and added to the items listed in Toolspace menu under the Surface group. From the Toolspace menu, it is necessary to set the software to rebuild the corridor and corridor surface automatically, to revise highway surface automatically when any changes on alignment or profile occurs. This is possible from the Toolspace menu, by right clicking on corridor and corridor surface and choosing Rebuild - Automatic option. The method for corridor and the corridor surface is demonstrated in Figure 89 and Figure 90.

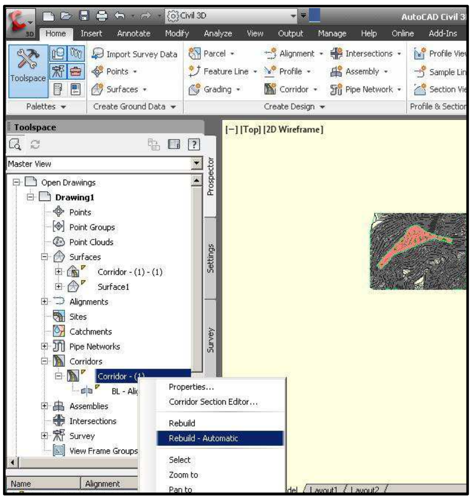


Figure 89: Rebuild - Automatic command on Corridor item

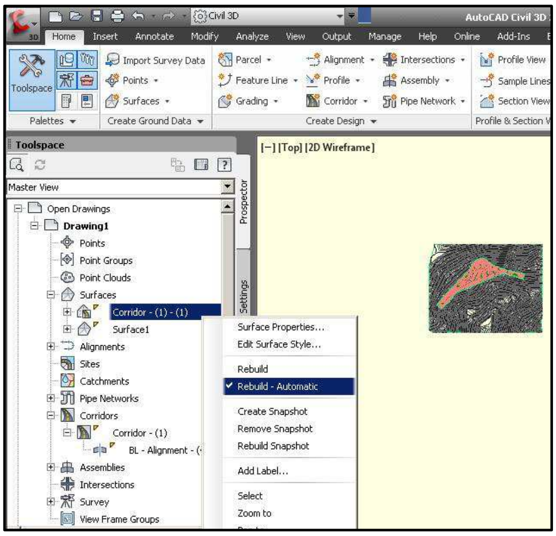


Figure 90: Rebuild - Automatic command on Corridor Surface item

B.6. VOLUME SURFACE

A volume surface provides an exact difference between the base and comparison surfaces at AutoCAD Civil 3D. In this study, following the steps mentioned in previous chapters, a TIN (triangulated irregular network) volume surface is created for calculation of cut and fill volumes.

A TIN volume surface is a composite of points in a base surface and comparison surface. A TIN volume surface provides an exact difference between the base and comparison surfaces. Therefore, the Z-value of any point in the volume surface is precisely the difference between the Z of the comparison surface at that point and the base surface at that point. This is true whether the comparison and base surfaces are both grid surface, both TIN surfaces, or one of each (User's Guide, AutoCAD Civil 3D 2011, 2010).

To create a TIN volume surface; Click Home tab ➤ Create Ground Data panel ➤ Surfaces drop-down ➤ Create Surface, and in the Type list, select TIN Volume Surface. The command is demonstrated in Figure 91 and Figure 92.

Figure 91: Create Surface Command

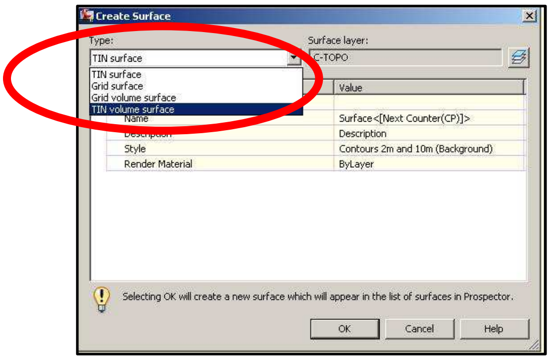


Figure 92: Selection of TIN Volume Surface

In the Create Surface dialog box, the base and comparison surfaces are selected as existing surface and the corridor surface respectively. The selection is demonstrated in Figure 93 .

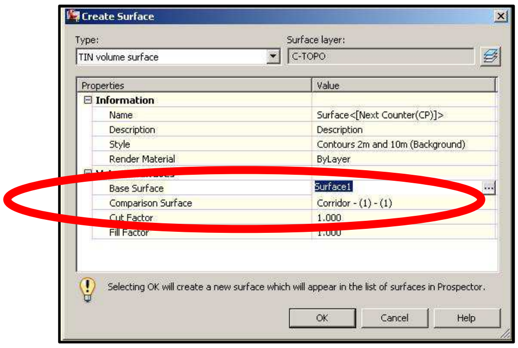


Figure 93: Selection of Base and Comparison Surfaces

By accepting the settings by clicking OK, the volume surface is created and listed in Toolspace menu under the Surfaces group. At this point, it is also useful to set the volume surface to automatic rebuild to revise after any design change. This is done from Toolspace menu, like explained for corridor and corridor surface in previous section. The command is demonstrated in Figure 94.

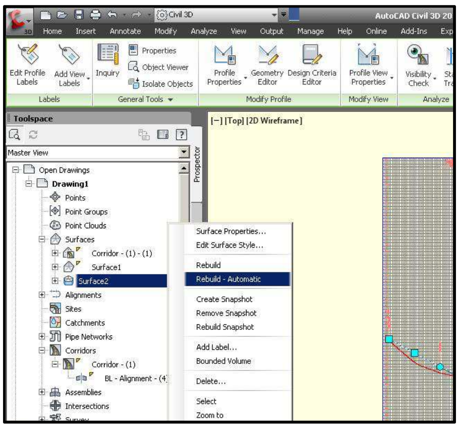


Figure 94: Rebuild- Automatic setting of Volume Surface

After completing the highway design by the procedure explained in this section, the drawing file became ready to operate the module "EARTHWORKER".

B.7. MASS HAUL DIAGRAM

Before starting the creation of the Mass Haul Diagram, it is strictly recommended to create a copy of the drawing file to work on, to keep one copy of the design drawing without cross section and mass haul diagram data. Since the software simultaneously applies the changes on design items, it is efficient to run the module on the drawing file, which does not contain cross sections and mass haul diagram. The PVI location changes can be applied later manually by Geometry Editor as explained in Section B.3., after each run to the drawing that contains cross sections and mass haul diagram.

To create the cross sections and mass haul diagram, the software needs sample lines from the corridor. Sample lines are linear AutoCAD Civil 3D objects that are used to imaginary cut sections across the corridor. To create a perpendicular sample line of a specified lateral width, through the corridor; Click Home tab ➤ Profile & Section Views panel ➤ Sample Lines (see Figure 95).

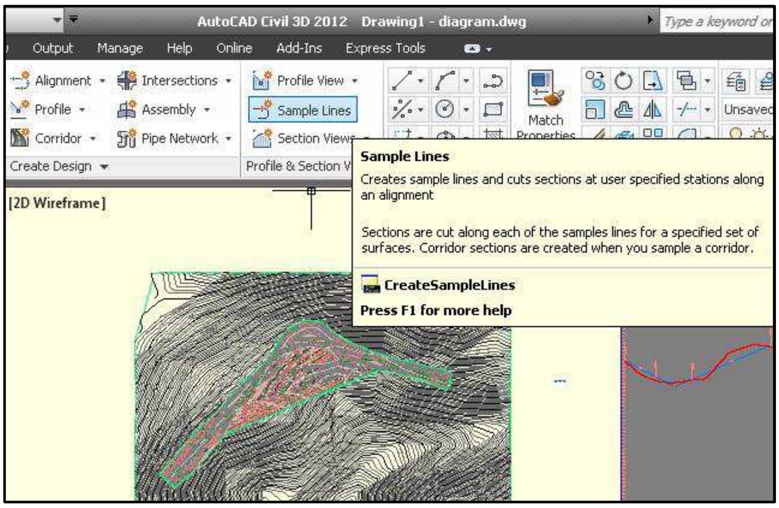


Figure 95: Sample Lines command

After the command is executed, the cursor changes to pick mode and the user will be prompted to select an alignment. The alignment can be selected from the drawing or from alignment list which appears by pressing Enter on the keyboard (see Figure 96).

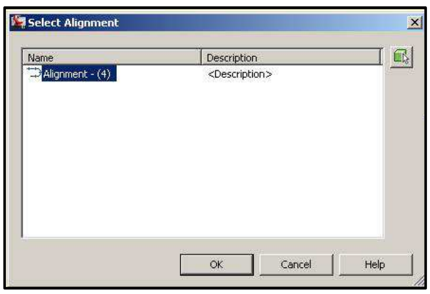


Figure 96: Alignment selection from alignment list

After the selection of the alignment, Create Sample Line Group dialog box opens. There is no need to change any default setting, so the settings are accepted by clicking OK. The dialog box is demonstrated in Figure 97.

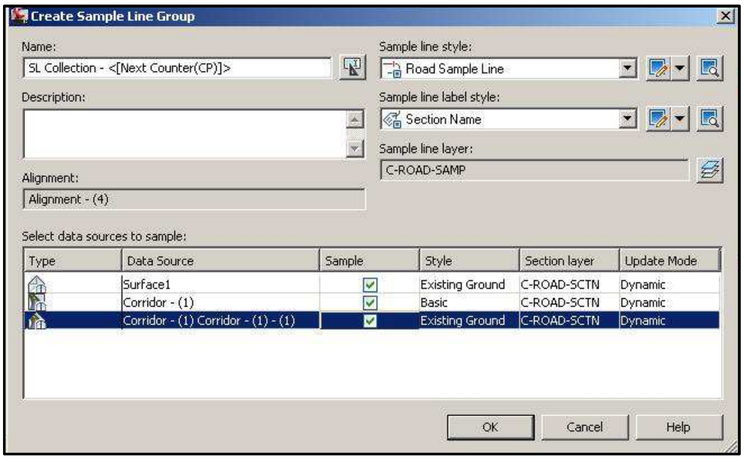


Figure 97: Create Sample Line Group dialog box

By accepting the settings, the view changes and the software asks the user to specify the station along the alignment as per Figure 98. At this point, Sample Line Creation Method should have changed to By Range of Stations, from the Sample Line Tool toolpalette, to create series of sample lines through alignment. The command is demonstrated in Figure 99.

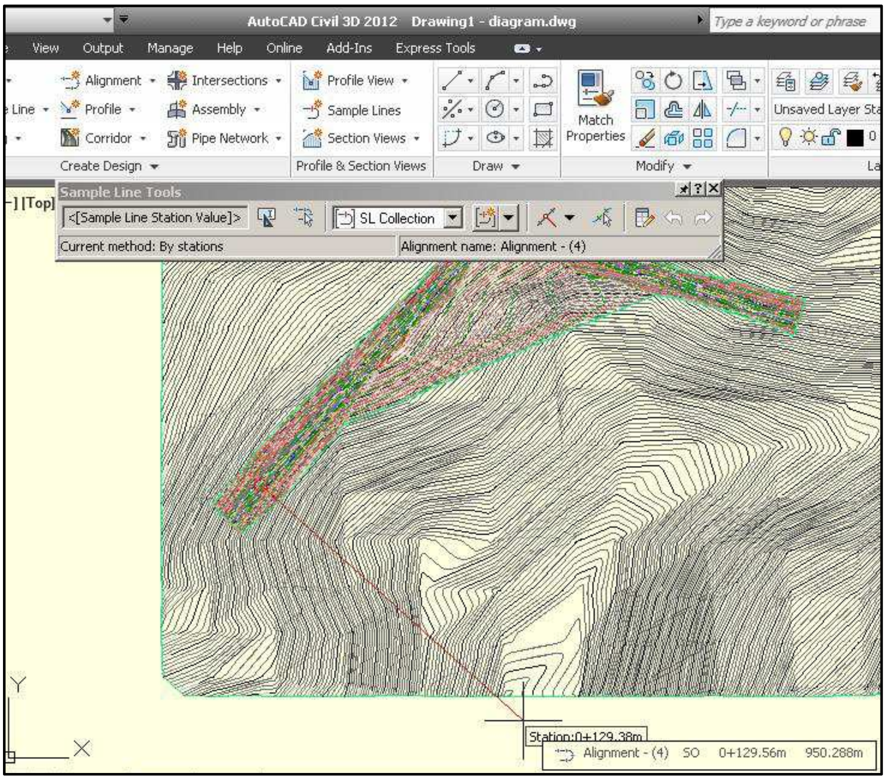


Figure 98: Station specification screen

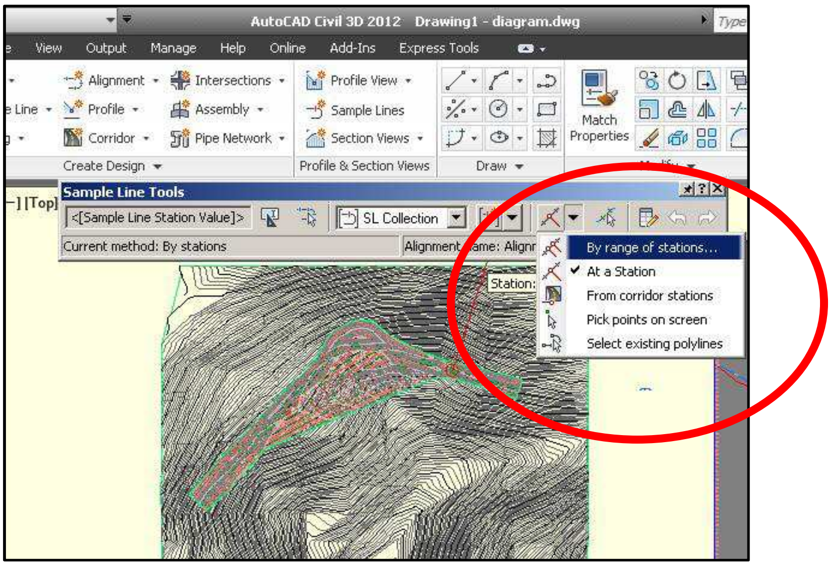


Figure 99: Selecting Sample Line Creation Method

Create Sample Lines dialog box opens at this point. Left and right swath widths and sampling increments can be changed for more accurate calculations. For a demonstration of the dialog box and changing the parameters; see Figure 100.

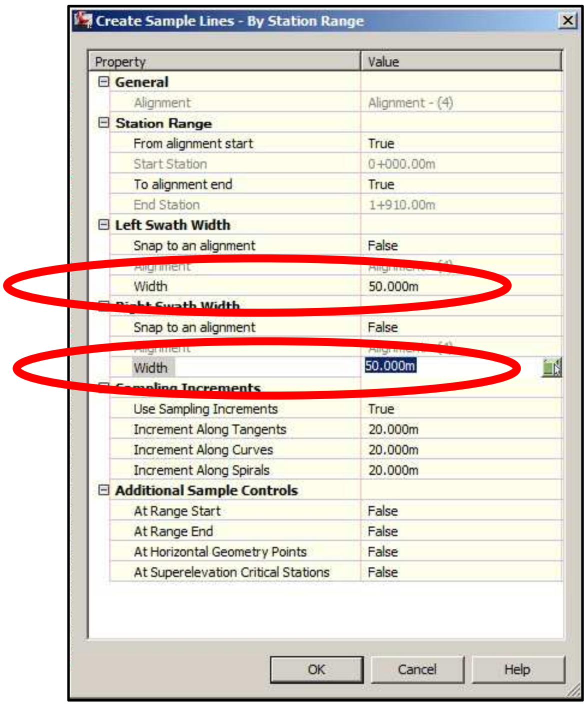


Figure 100: Create Sample Lines dialog box

By accepting the settings, and by pressing an extra Spacebar or Enter, the sample lines are created. The sample lines can be observed also from the plan view at this point (see Figure 101).

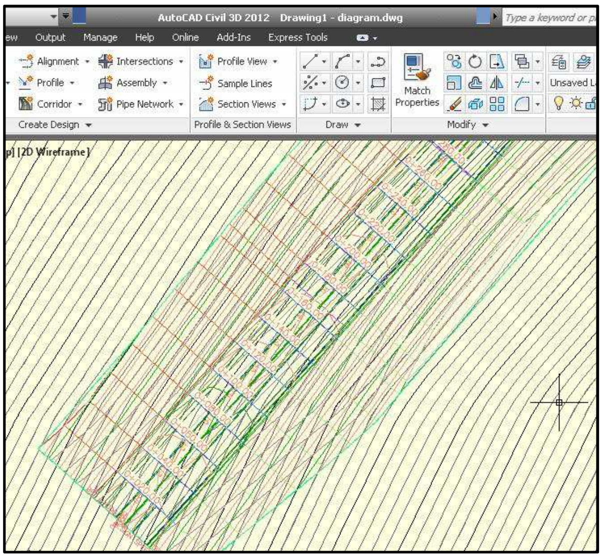


Figure 101: Sample lines from plan

The cross section set is created from the sample lines at this point. In AutoCAD Civil 3D, the cross section set is called as Section Views. To create Section Views; Click Home tab ➤ Profile & Section Views panel ➤ Section Views drop-down ➤ Create Multiple Views. The command is demonstrated in Figure 102 .

Figure 102: Create Multiple Views Command

The Create Multiple Views command leads to the Create Multiple Section Views dialog box. The default settings are accepted here also by clicking Create Section Views command. The Create Multiple Section Views dialog box is demonstrated in Figure 103 .

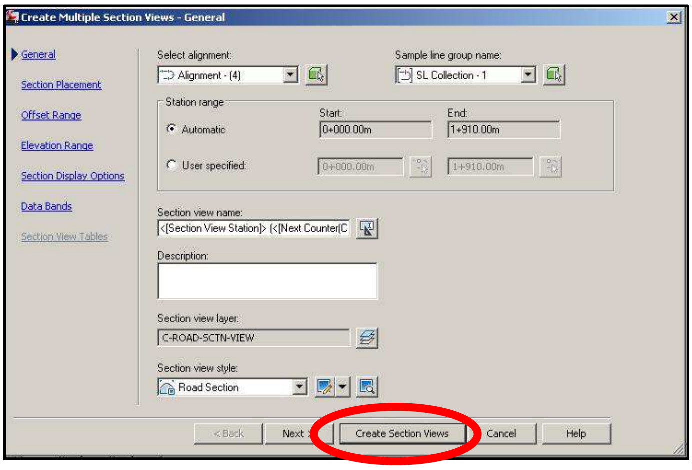


Figure 103: Create Multiple Section Views dialog box

The software then asks for the place, any empty place can be selected by clicking the location. The cross section views are then created at the selected location. The Section Views are selected to call the section tab for further operations (see Figure 104).

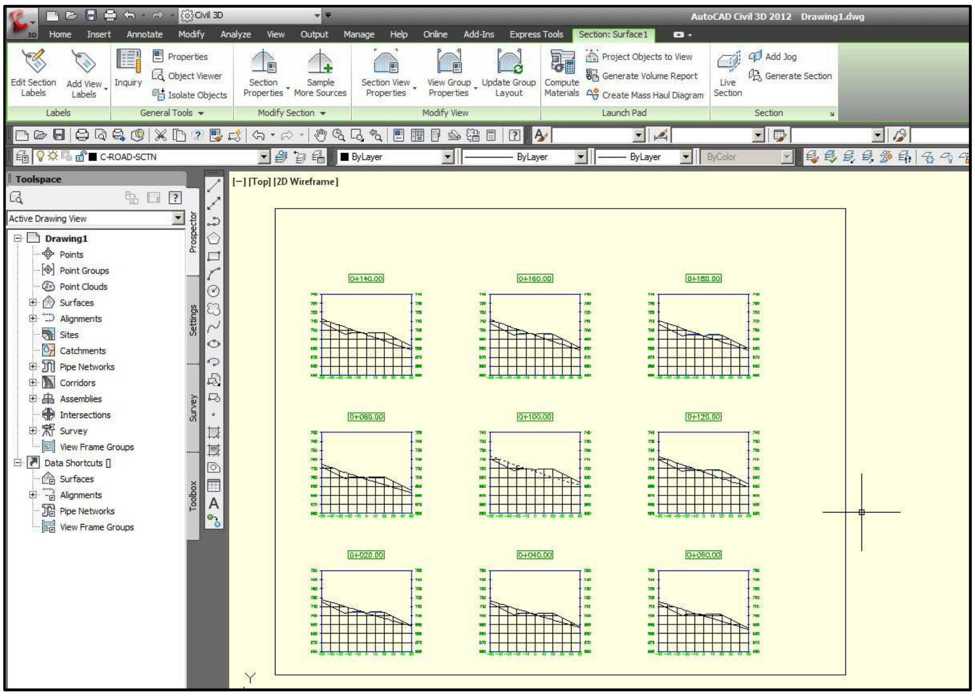


Figure 104: Cross sections and Section tab

At this point, it is necessary to define the materials. From the section tab, Compute Materials command is selected, and alignment and sample line groups are identified and then the ground surface and the corridor surface are specified. The procedure is demonstrated in Figure 105 through Figure 107.

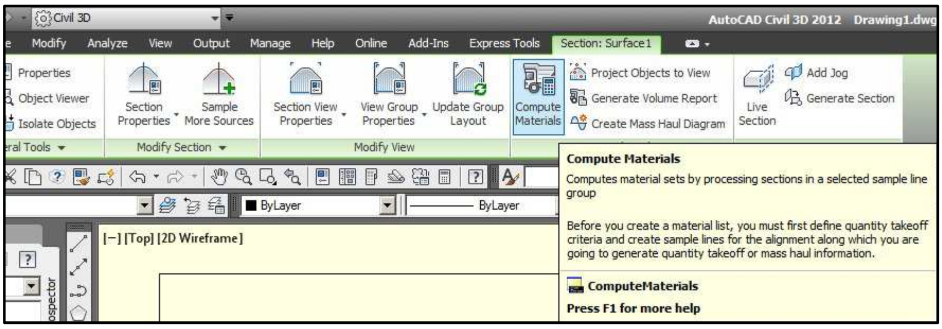


Figure 105: Compute Materials command

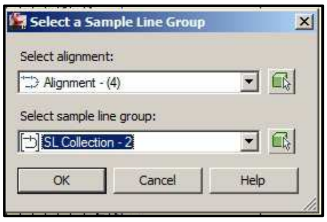


Figure 106: Selection of Alignment and Sample Line Group

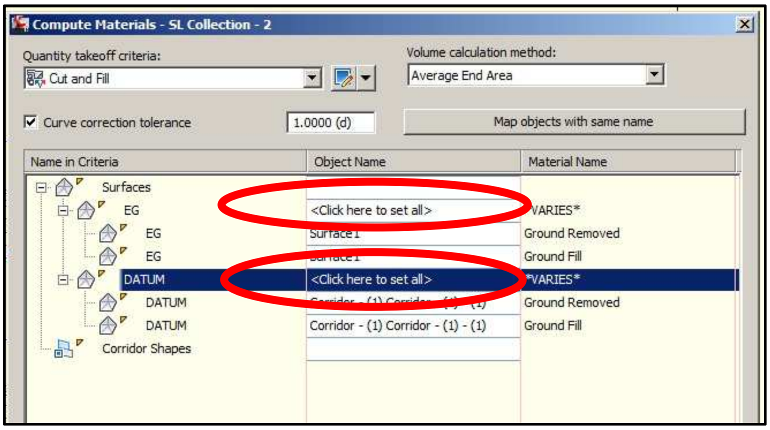


Figure 107: Identification of Surface and Corridor in Compute Materials dialog box

Mass haul diagram is created from the section tab, which becomes available after the selection of the sections. The command is demonstrated in Figure 108 .

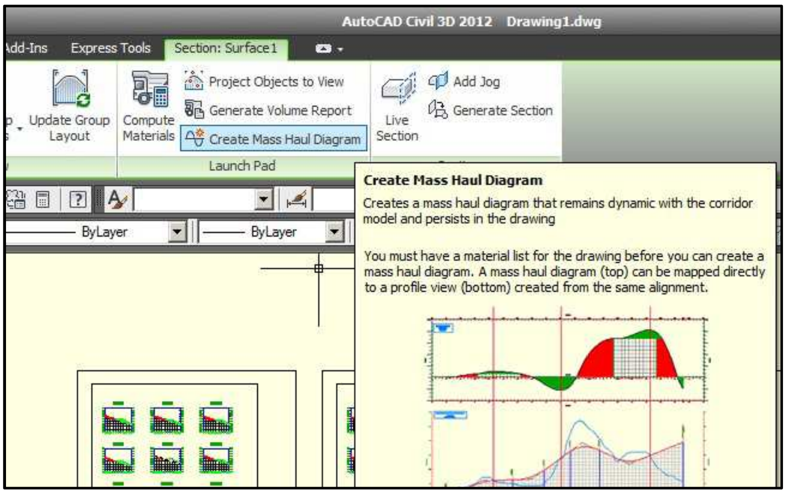


Figure 108: Create Mass Haul Diagram command

In the study, free hauling distance is taken as 100m as explained in Section 5.2.1. To define the free hauling distance in the mass haul diagram created, free haul distance is specified as 100m in the Balancing Options tab of Create Mass Haul Diagram dialog box as demonstrated Figure 109.

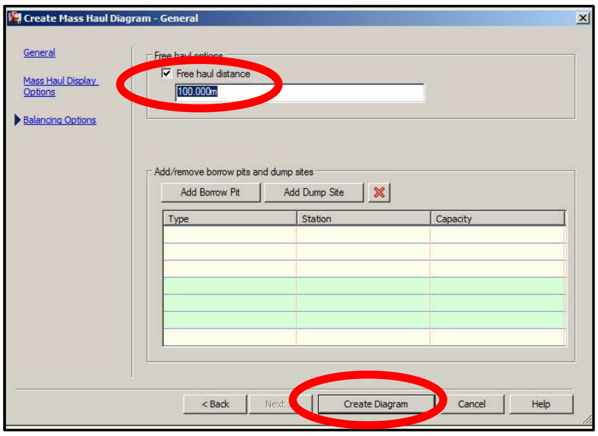


Figure 109: Selection of free haul distance

By clicking on Create Diagram button, the mass haul diagram is ready to be created following the location identification by the user. The final view of the mass haul diagram with default style settings is demonstrated in Figure 110.

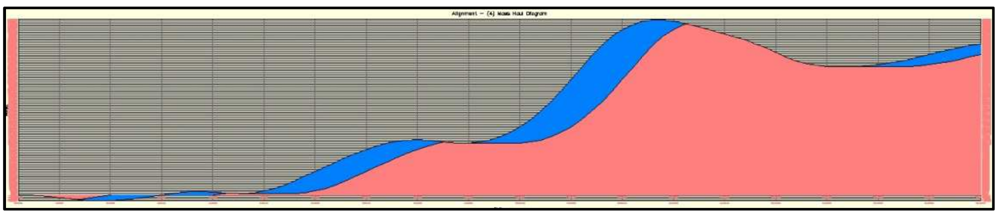


Figure 110: Mass haul diagram created

The style settings can be changed from the mass haul tab, which appears after the selection of the mass haul diagram, under the mass haul view properties command. The user can customize the view settings as they like, so details of such changes are not mentioned here. The command and the one of the most useful views of the mass haul diagram for this study are demonstrated in Figure 111 and Figure 112 respectively.

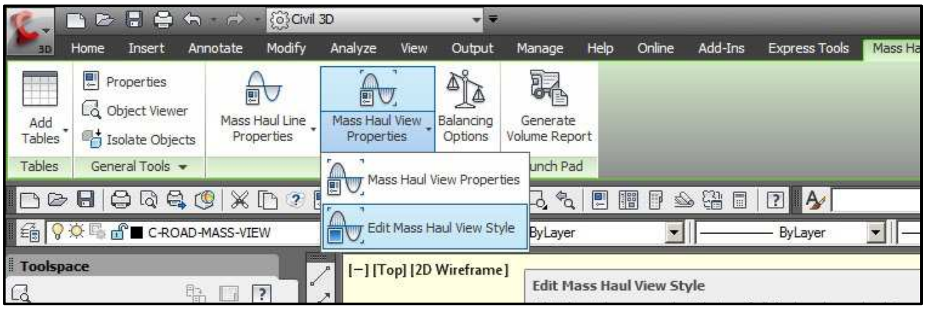


Figure 111: Mass Haul View Properties

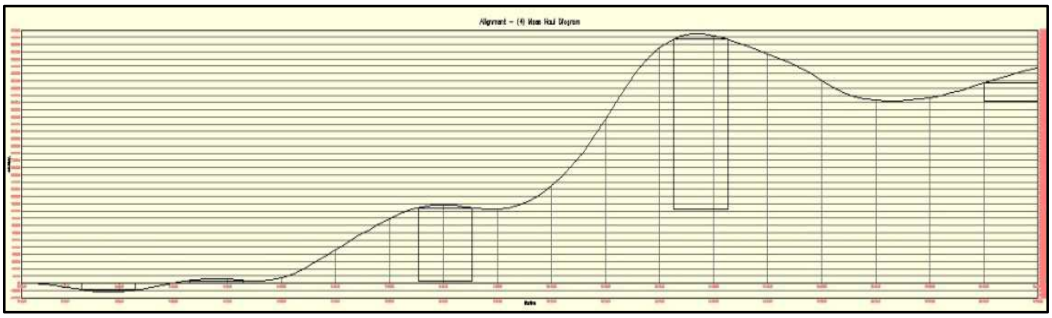


Figure 112: Mass haul diagram in a useful view

Although a drawing sheet of AutoCAD Civil 3D can save a number of solutions, there should be only one design item for the module to work on. In other words; only one project with its definite horizontal alignment and the tentative initial vertical alignment can be optimized at once.

APPENDIX C

INSTALLATION AND USAGE OF THE MODULE “EARTHWORKER”

First, the AutoCAD Civil 3D software should be installed to the computer and for the versions later than 2009; AutoCAD Civil 3D VBA Enabler should also be downloaded free from the official web page of AutoCAD, and installed to access visual basic applications.

After a trial to access the VBA commands from manage tab, a massage box is appeared with a free download link for VBA enabler from the software. So the VBA enabler is downloaded and set up to the computer, making VBA applications enable. Then the module should be loaded. To load the module; Click Manage tab ➤Applications panel ➤Applications drop-down ➤ Load project. The command is demonstrated in Figure 113. Or typing VBALOAD to command line is another way.

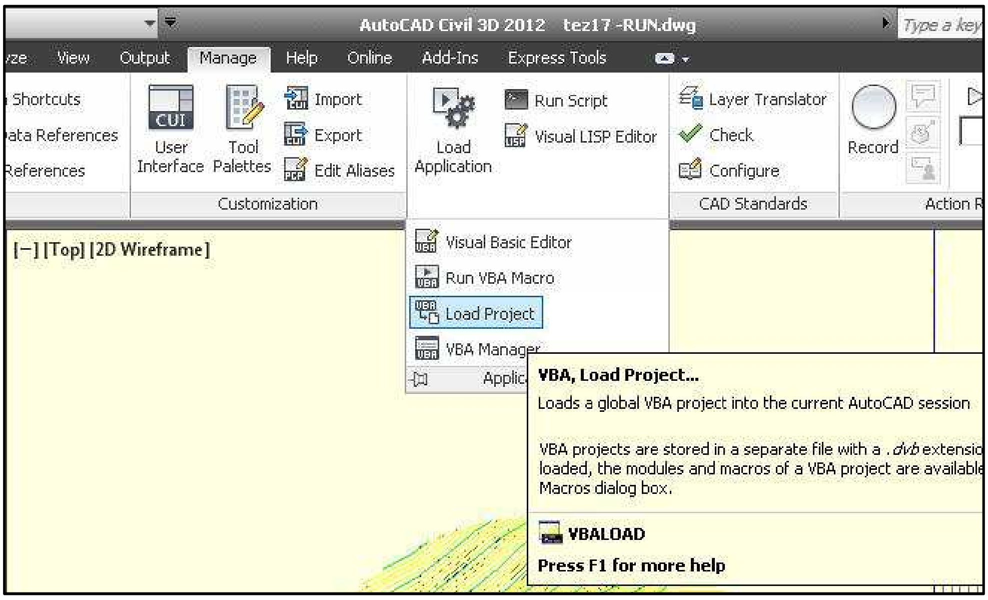


Figure 113: Loading project

After opening of the project, the project editor should be opened from the applications drop down menu or by typing VBAIDE to command line and the macro should be operate by clicking run. The commands are demonstrated in Figure 114 and Figure 115.

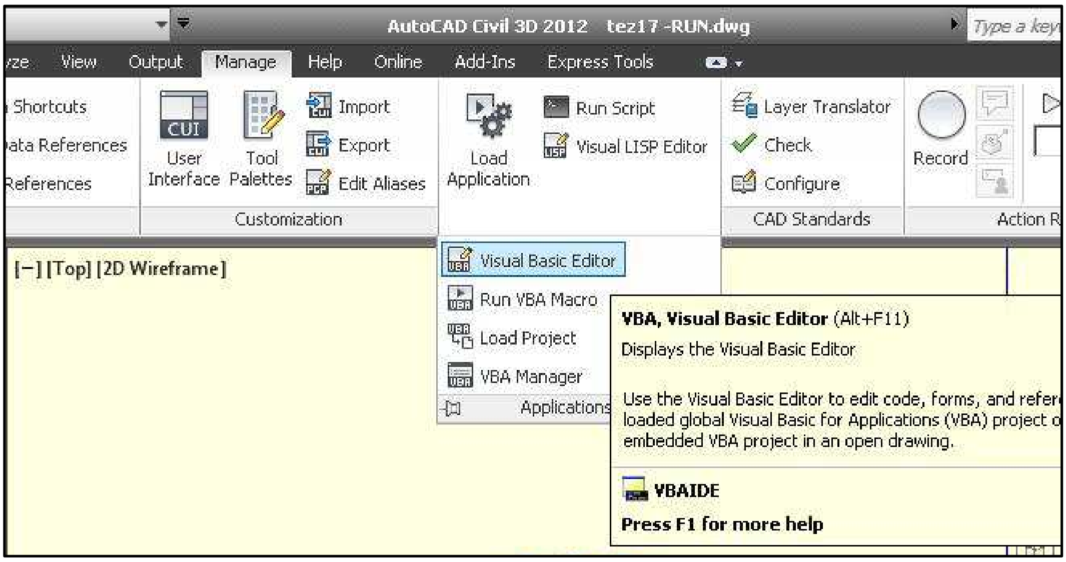


Figure 114: Visual Basic Editor

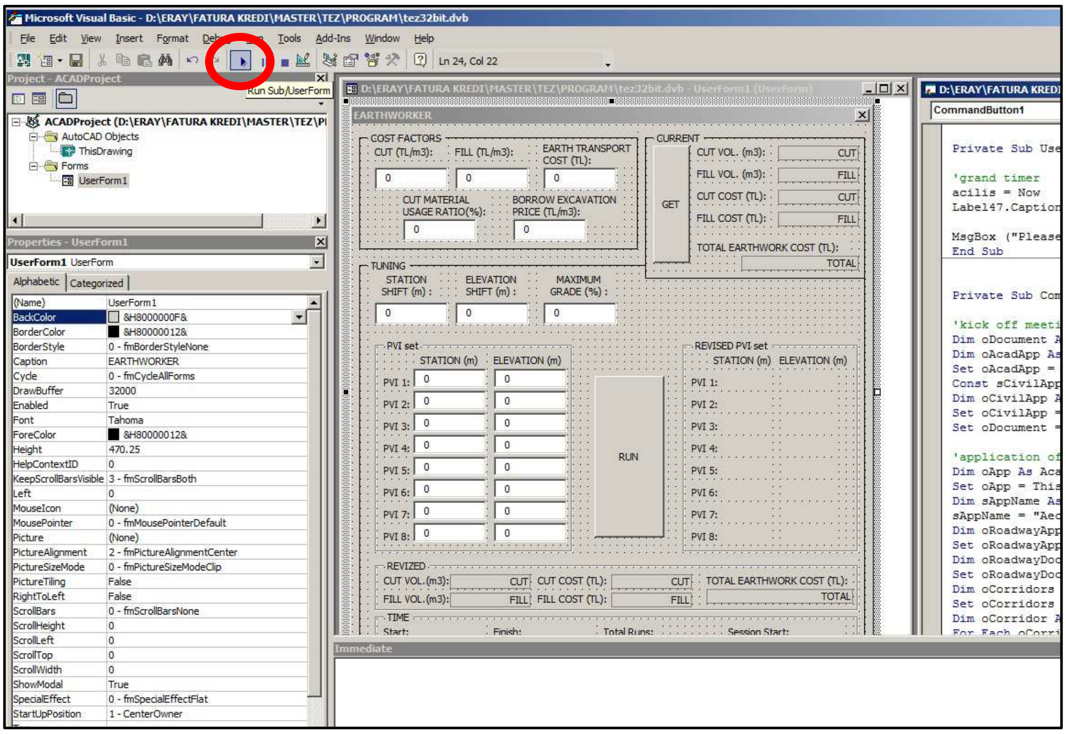


Figure 115: Macro run

Within the Visual Basic Editor, it is necessary to open the relevant libraries from tools tab. After the successful applications of above steps, the user form of the module shows up in the screen.

Then the input data should be inserted into the module. The input data is listed in Table 25 and the input cells are demonstrated in Figure 116.

Table 25: Input data

ITEM	DEFINITION
1	Cut Unit Price (TL/m3) = F(cut)
2	Fill Unit Price (TL/m3) = F(fill)
3	Earthwork Cost (TL) = C(earthwork)
4	Cut Material Usage Ratio (%)
5	Unit Price of Pit Excavation (TL/m3) = F(exc)
6	Station Shift Distance (m) = Δx
7	Elevation Shift Distance (m) = Δy
8	Maximum Allowable Grade of Vertical Alignment (%)
9	Station Km of the PVI from Current PVI set (x_i)
10	Elevation of the PVI from Current PVI set (y_i)

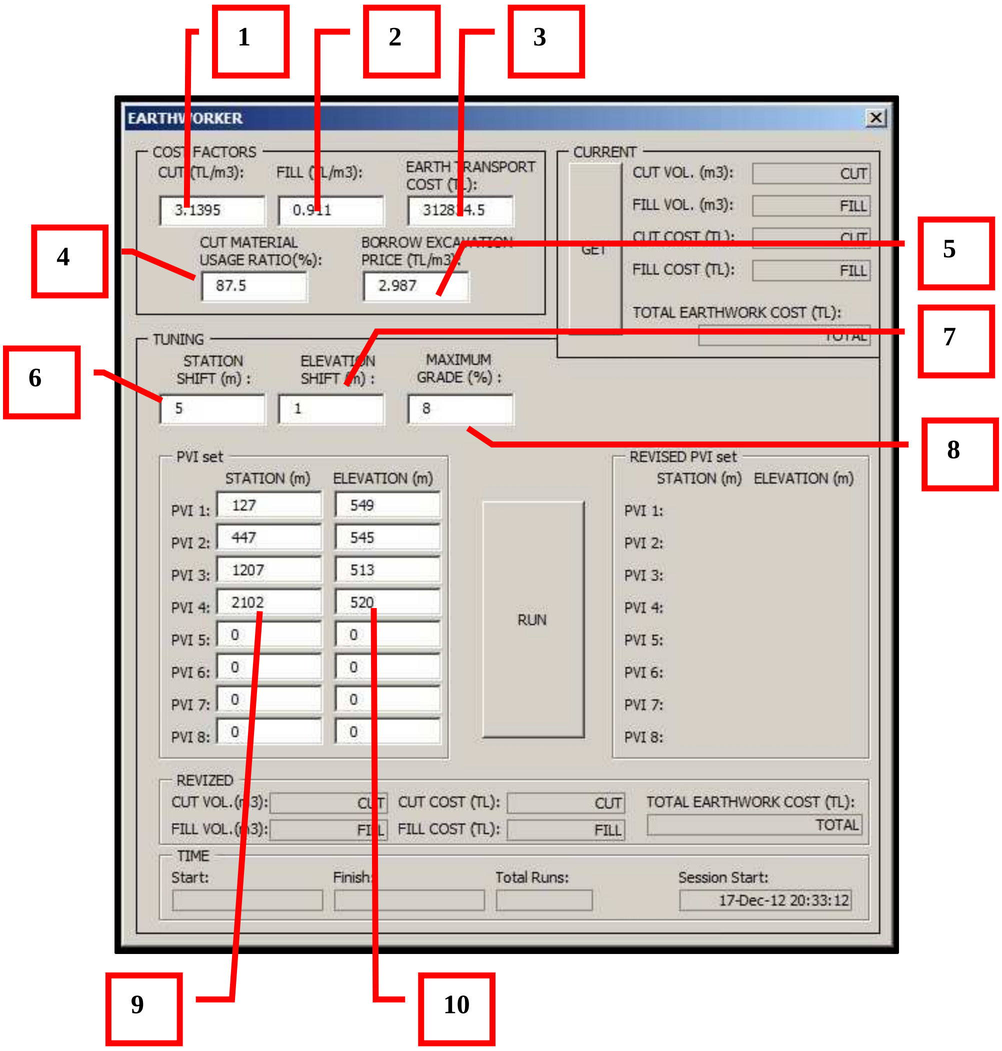


Figure 116: Input cells

When all the inputs are entered, the current volumes and the earthwork cost then can be calculated from the GET command. And the optimization is processed with the RUN command. The command buttons are highlighted in Figure 117.

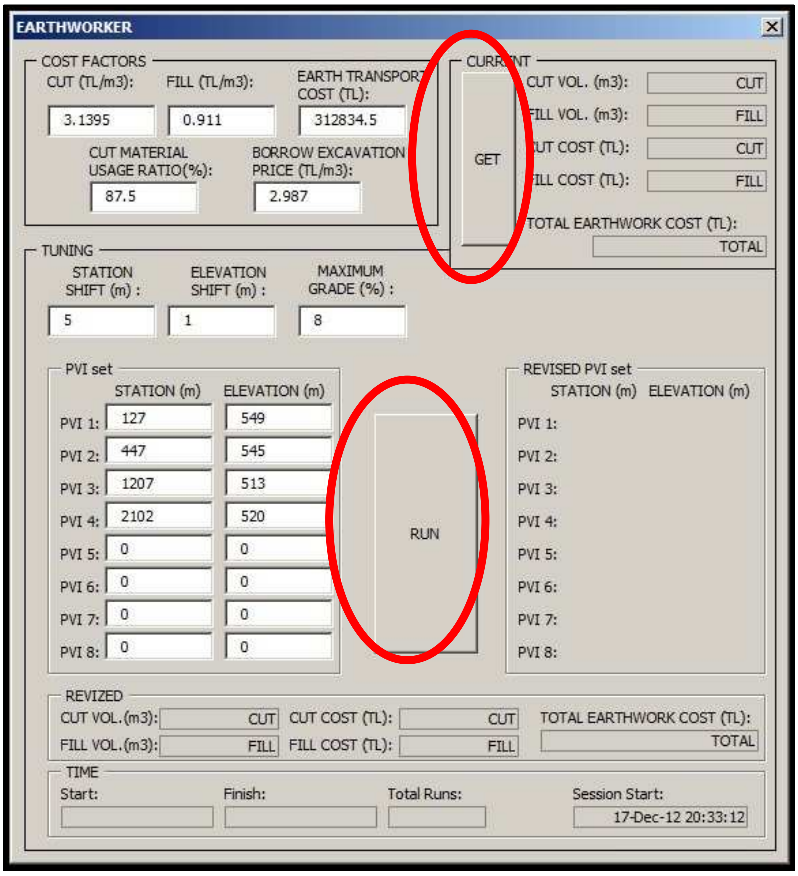


Figure 117: Commands of the module

After one step of successful application of the module, the outputs are printed into the interface of the module. The list of outputs is given in Table 26 and the output cells are demonstrated in Figure 118.

Table 26: Output data

ITEM	DEFINITION
1	Current Cut Volume (m3) = V(cut)
2	Current Fill Volume (m3) = V(fill)
3	Current Cut Cost (TL) = C(cut)
4	Current Fill Cost (TL) = C(fill)
5	Current Earthwork Cost (TL) = C(earthwork)
6	Station of the PVI from Revised PVI set (x_i^i)
7	Elevation of the PVI from Revised PVI set (y_i^i)
8	Revised Cut Volume (m3) = V(cut)
9	Revised Fill Volume (m3) = V(fill)
10	Revised Cut Cost (TL) = C(cut)
11	Revised Fill Cost (TL) = C(fill)
12	Revised Earthwork Cost (TL) = C(earthwork)
13	Start Time of Runs
14	Finish Time of Runs
15	Total Number of Runs
16	Module Start Time

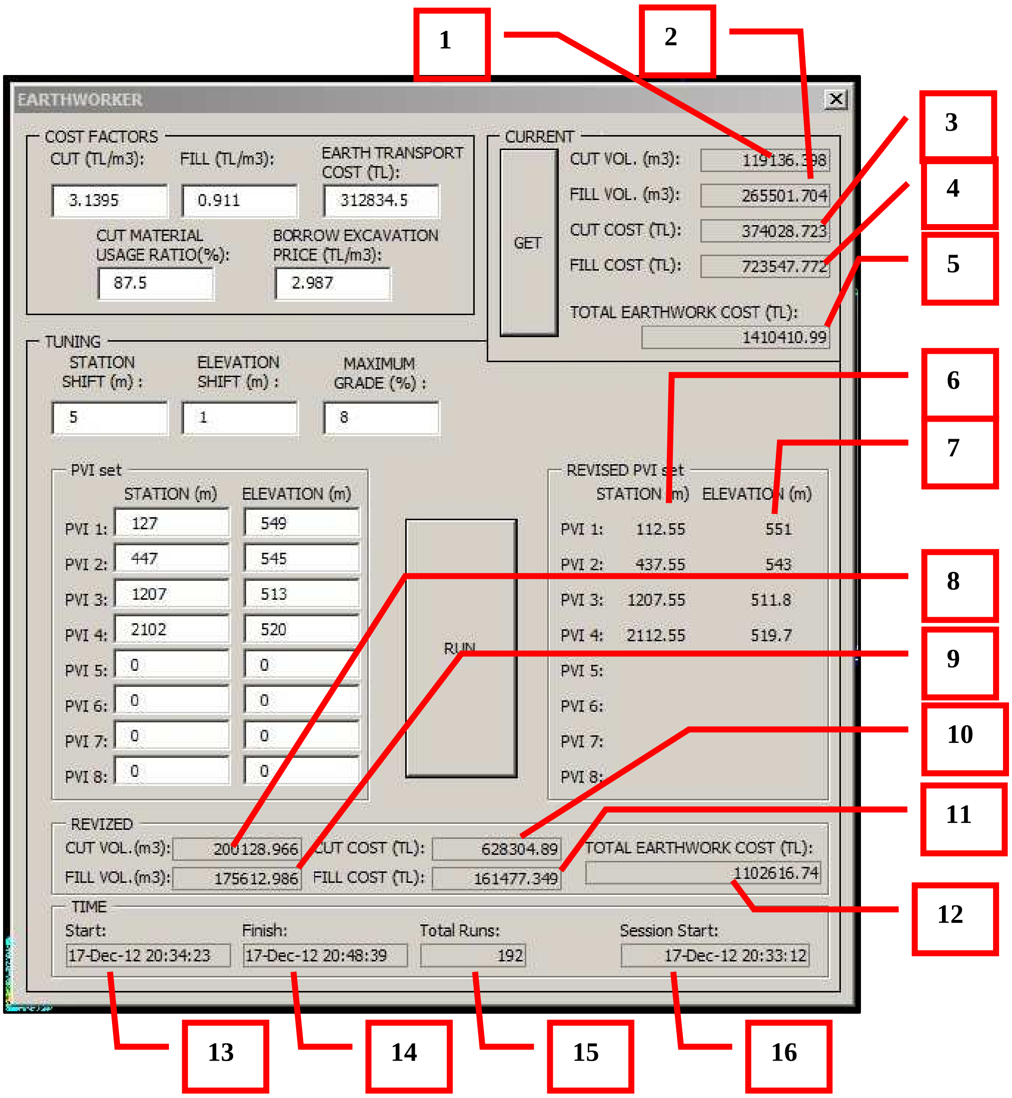
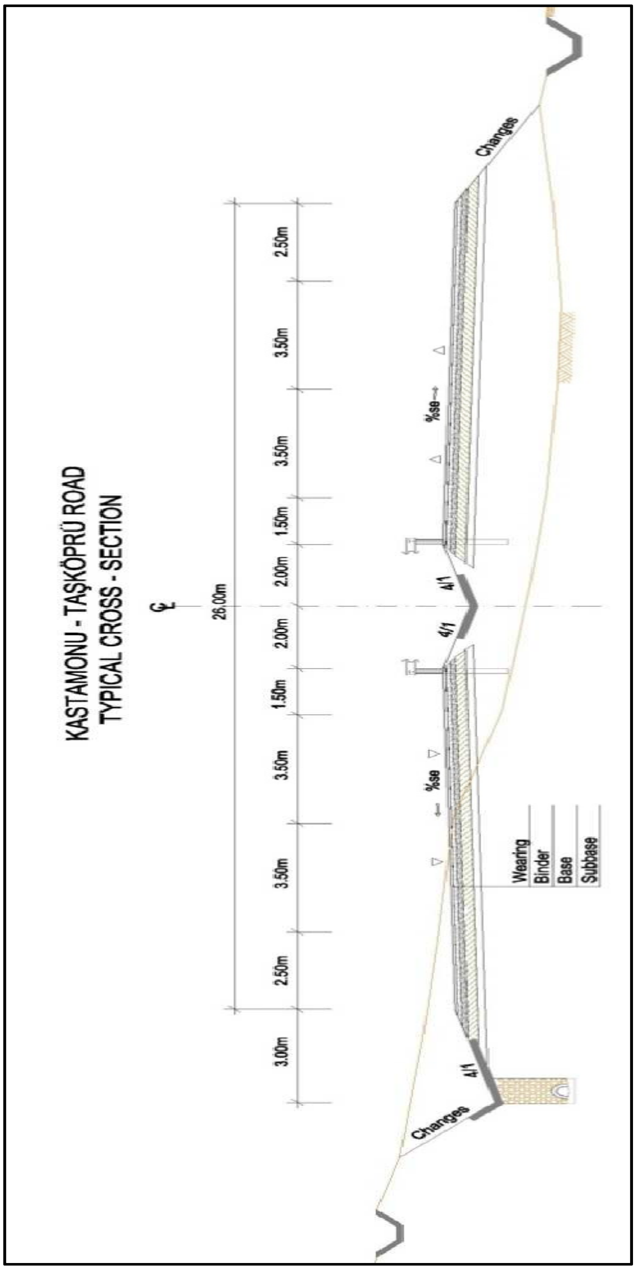


Figure 118: Output cells

APPENDIX D

KASTAMONU - TAŞKÖPRÜ ROAD

D1-CROSS SECTION



CUT SLOPE CHANGE	
depth	*slope*
0-1.5m	6/1
1.5m-3.0m	4/1
3m<	2/1

FILL SLOPE CHANGE	
depth	*slope*
0-1.5m	6/1
1.5m-3.0m	4/1
3m<	2/1

Figure 119: Cross section

D2-INITIAL PROFILE

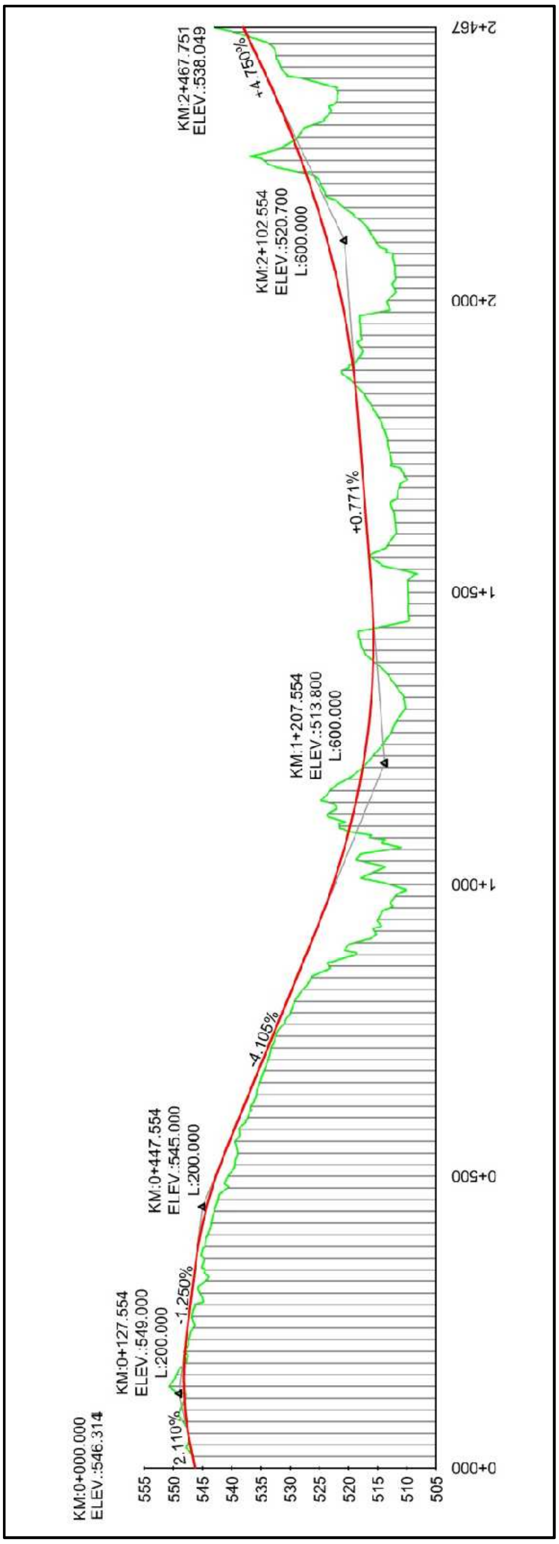


Figure 120: Initial Profile

D3-INITIAL VOLUME TABLE

Table 27 : Initial volume table

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+000.00	40.34	0.02	0.28	0.00	0.02	0.00	0.02
0+025.00	85.06	1567.41	0.00	3.48	1567.43	3.48	1563.95
0+027.55	94.11	228.79	0.00	0.00	1796.22	3.48	1792.75
0+050.00	96.95	2144.20	0.00	0.00	3940.42	3.48	3936.95
0+075.00	100.92	2473.38	0.00	0.00	6413.80	3.48	6410.33
0+100.00	147.74	3108.24	0.00	0.00	9522.04	3.48	9518.57
0+125.00	117.28	3312.68	0.00	0.00	12834.72	3.48	12831.25
0+150.00	159.62	3461.26	0.00	0.00	16295.98	3.48	16292.51
0+153.05	151.70	475.31	0.00	0.00	16771.29	3.48	16767.82
0+175.00	130.48	3096.40	0.00	0.00	19867.69	3.48	19864.22
0+200.00	74.04	2556.42	0.00	0.00	22424.12	3.48	22420.64
0+225.00	37.13	1389.54	0.08	1.00	23813.66	4.48	23809.18
0+227.55	35.26	92.43	0.07	0.20	23906.09	4.68	23901.41
0+250.00	22.91	652.84	12.14	137.06	24558.93	141.74	24417.19
0+275.00	0.94	298.12	17.90	375.43	24857.05	517.17	24339.88
0+300.00	11.24	152.21	31.55	618.11	25009.27	1135.28	23873.99
0+325.00	7.49	234.11	55.44	1087.45	25243.37	2222.72	23020.65
0+347.55	0.00	84.43	56.15	1258.39	25327.81	3481.11	21846.69
0+350.00	0.00	0.00	57.15	138.56	25327.81	3619.67	21708.13
0+353.13	0.00	0.00	59.71	182.95	25327.81	3802.62	21525.18
0+375.00	0.03	0.32	60.11	1310.18	25328.13	5112.80	20215.33
0+400.00	0.00	0.37	63.37	1543.41	25328.49	6656.21	18672.28
0+425.00	0.00	0.00	84.29	1845.77	25328.49	8501.98	16826.51
0+450.00	0.00	0.00	83.22	2093.87	25328.49	10595.85	14732.64
0+475.00	0.00	0.00	70.55	1922.13	25328.49	12517.98	12810.51
0+500.00	0.25	3.15	58.19	1609.37	25331.65	14127.35	11204.30
0+525.00	16.79	213.04	40.77	1237.02	25544.69	15364.37	10180.32
0+547.55	13.92	346.37	20.77	693.99	25891.05	16058.35	9832.70
0+550.00	17.80	38.80	16.47	45.54	25929.85	16103.89	9825.96
0+575.00	17.91	446.40	4.95	267.68	26376.25	16371.57	10004.68
0+600.00	27.91	572.73	9.35	178.72	26948.98	16550.29	10398.68
0+625.00	0.00	348.85	14.17	294.00	27297.82	16844.29	10453.53
0+650.00	0.00	0.00	10.31	306.02	27297.82	17150.32	10147.51
0+675.00	22.89	286.08	1.16	143.41	27583.91	17293.72	10290.19
0+700.00	27.25	626.66	0.93	26.11	28210.56	17319.84	10890.73
0+725.00	57.43	1058.43	0.00	11.59	29269.00	17331.43	11937.57
0+750.00	77.94	1692.14	0.00	0.00	30961.14	17331.43	13629.71
0+775.00	36.10	1425.48	3.48	43.45	32386.62	17374.88	15011.75
0+800.00	0.00	451.21	15.83	241.35	32837.83	17616.23	15221.60
0+825.00	28.70	358.72	31.82	595.68	33196.55	18211.91	14984.63
0+850.00	35.50	802.50	68.33	1251.91	33999.05	19463.83	14535.22
0+875.00	27.79	791.11	115.43	2297.03	34790.16	21760.86	13029.30
0+900.00	0.00	347.33	163.50	3486.65	35137.49	25247.51	9889.99
0+907.55	0.00	0.00	191.56	1341.07	35137.49	26588.58	8548.91

Table 27 (Continued):

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+925.00	0.00	0.00	210.03	3503.13	35137.49	30091.71	5045.78
0+944.08	0.00	0.00	259.52	4479.34	35137.49	34571.06	566.44
0+950.00	0.00	0.00	256.43	1527.48	35137.49	36098.54	-961.05
0+975.00	0.00	0.00	311.31	7096.73	35137.49	43195.27	-8057.78
1+000.00	0.00	0.00	298.23	7619.20	35137.49	50814.47	-15676.97
1+025.00	19.61	245.08	320.08	7728.93	35382.58	58543.40	-23160.82
1+050.00	28.42	600.37	246.74	7085.32	35982.95	65628.71	-29645.76
1+075.00	39.27	846.21	250.60	6216.81	36829.16	71845.52	-35016.37
1+100.00	135.28	2181.97	0.00	3132.54	39011.12	74978.06	-35966.94
1+125.00	231.97	4590.68	0.00	0.00	43601.81	74978.06	-31376.26
1+150.00	253.12	6063.64	0.00	0.00	49665.45	74978.06	-25312.61
1+175.00	253.39	6331.38	0.00	0.00	55996.83	74978.06	-18981.23
1+200.00	84.85	4227.99	1.59	19.91	60224.82	74997.97	-14773.15
1+225.00	14.58	1242.80	32.07	420.76	61467.62	75418.73	-13951.11
1+250.00	0.00	182.19	94.44	1581.32	61649.81	77000.06	-15350.25
1+275.00	0.00	0.00	150.63	3063.37	61649.81	80063.42	-18413.61
1+300.00	0.00	0.00	197.04	4345.86	61649.81	84409.29	-22759.48
1+325.00	0.00	0.00	179.91	4711.89	61649.81	89121.18	-27471.37
1+350.00	0.00	0.00	95.61	3444.06	61649.81	92565.24	-30915.43
1+375.00	24.46	305.75	1.75	1217.03	61955.56	93782.27	-31826.71
1+400.00	166.23	2383.68	0.00	21.90	64339.24	93804.17	-29464.93
1+412.69	191.44	2269.70	0.00	0.00	66608.94	93804.17	-27195.23
1+425.00	198.27	2398.35	0.00	0.00	69007.29	93804.17	-24796.88
1+450.00	0.00	2478.35	192.51	2406.39	71485.64	96210.56	-24724.92
1+475.00	0.00	0.00	226.76	5240.95	71485.64	101451.51	-29965.87
1+500.00	0.00	0.00	234.89	5770.70	71485.64	107222.22	-35736.58
1+507.55	0.00	0.00	236.58	1780.74	71485.64	109002.96	-37517.32
1+525.00	0.00	0.00	266.67	4389.79	71485.64	113392.75	-41907.11
1+535.03	0.00	0.00	247.52	2577.89	71485.64	115970.64	-44485.00
1+550.00	0.00	0.00	52.67	2247.32	71485.64	118217.95	-46732.31
1+575.00	0.00	0.00	81.41	1675.92	71485.64	119893.87	-48408.23
1+600.00	0.00	0.00	172.24	3170.58	71485.64	123064.45	-51578.81
1+625.00	0.00	0.00	173.94	4327.20	71485.64	127391.65	-55906.01
1+650.00	0.00	0.00	159.13	4163.32	71485.64	131554.97	-60069.33
1+675.00	0.00	0.00	185.04	4302.11	71485.64	135857.07	-64371.43
1+700.00	0.00	0.00	236.80	5273.05	71485.64	141130.12	-69644.48
1+725.00	0.00	0.00	182.82	5245.34	71485.64	146375.46	-74889.82
1+750.00	0.00	0.00	160.67	4293.63	71485.64	150669.09	-79183.45
1+775.00	0.00	0.00	141.97	3782.98	71485.64	154452.07	-82966.43
1+800.00	0.00	0.00	101.99	3049.57	71485.64	157501.64	-86016.00
1+802.55	0.00	0.00	95.73	252.50	71485.64	157754.14	-86268.50
1+825.00	0.00	0.00	48.99	1624.23	71485.64	159378.38	-87892.74
1+850.00	38.11	476.38	1.43	630.20	71962.02	160008.58	-88046.56
1+875.00	147.61	2321.53	0.00	17.82	74283.55	160026.40	-85742.85
1+900.00	66.38	2674.84	13.27	165.82	76958.39	160192.22	-83233.83
1+925.00	27.29	1170.79	27.22	506.01	78129.19	160698.23	-82569.04

Table 27 (Continued):

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
1+950.00	0.00	341.09	77.12	1304.25	78470.28	162002.48	-83532.20
1+975.00	0.00	0.00	142.97	2751.19	78470.28	164753.67	-86283.39
2+000.00	0.00	0.00	332.51	5943.46	78470.28	170697.12	-92226.85
2+025.00	0.00	0.00	406.85	9241.94	78470.28	179939.06	-101468.78
2+050.00	0.00	0.00	461.99	10860.46	78470.28	190799.51	-112329.24
2+075.00	0.00	0.00	442.54	11306.60	78470.28	202106.11	-123635.83
2+100.00	0.00	0.00	361.47	10050.11	78470.28	212156.22	-133685.94
2+125.00	0.00	0.00	300.18	8270.66	78470.28	220426.88	-141956.60
2+150.00	0.00	0.00	206.90	6338.53	78470.28	226765.41	-148295.13
2+175.00	7.79	97.36	64.37	3390.83	78567.64	230156.24	-151588.60
2+200.00	149.27	1963.26	42.11	1330.98	80530.90	231487.22	-150956.32
2+225.00	430.62	7248.67	1.95	550.71	87779.57	232037.93	-144258.36
2+250.00	571.61	12527.85	0.00	24.35	100307.42	232062.28	-131754.87
2+275.00	44.31	7698.90	0.05	0.57	108006.32	232062.86	-124056.54
2+300.00	0.00	553.83	114.85	1436.19	108560.15	233499.05	-124938.90
2+325.00	0.00	0.00	265.32	4752.11	108560.15	238251.16	-129691.01
2+350.00	0.00	0.00	446.26	8894.80	108560.15	247145.96	-138585.81
2+375.00	0.00	0.00	269.46	8946.60	108560.15	256092.56	-147532.41
2+400.00	0.00	0.00	96.43	4573.64	108560.15	260666.20	-152106.05
2+402.55	0.00	0.00	96.90	246.88	108560.15	260913.07	-152352.93
2+425.00	0.00	0.00	98.15	2189.01	108560.15	263102.08	-154541.94
2+450.00	291.98	3649.78	36.53	1683.51	112209.93	264785.60	-152575.67
2+467.75	740.22	9161.40	5.31	371.36	121371.33	265156.96	-143785.63

D4-INITIAL MASS HAUL DIAGRAM

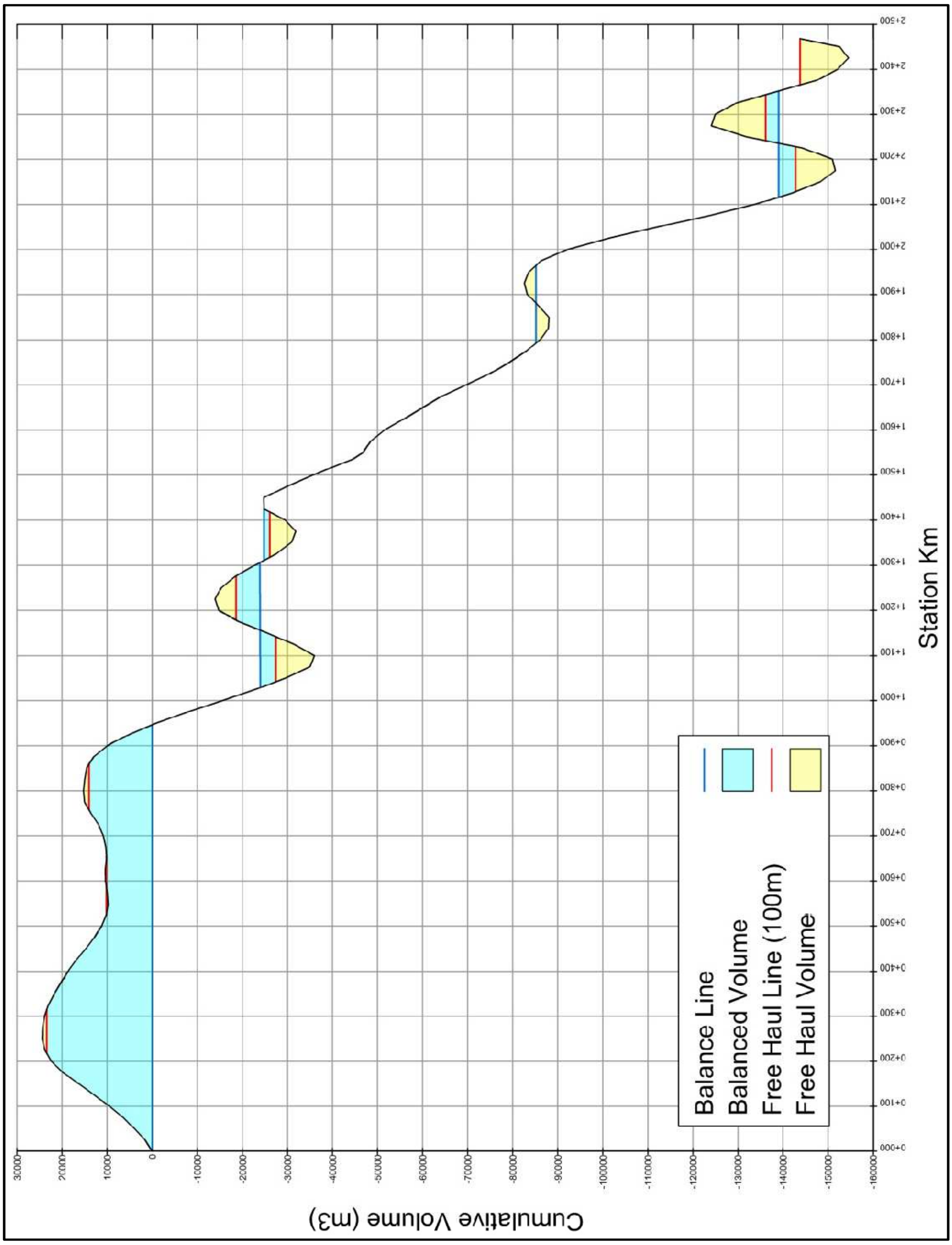


Figure 121: Initial mass haul diagram

D5-INITIAL HAULING COST CALCULCATIONS

ECONOMIC HAULING:

M_{BORROW}= 1,200 m

M_{WASTE}= 600 m   K= 176

F_B=F_w= 1,25x0,00034xKx√M-0,00425xK

F_H= 1,25x0,00046xKx√M-0,00575xK

↓

F_B= 1.843 TL/m^3

F_w= 1.084 TL/m^3

F_H=F_B+F_w → L_{EH}= 1,515.0

BALANCED VOLUMES:

	V (M3)	L (M)	√L	√L*V
1	14000	290	17.0	238000.0
2	10000	870	29.5	295000.0
3	4000	160	12.6	50400.0
4	5000	120	11.0	55000.0
5	4000	120	11.0	44000.0
6	1000	110	10.5	10500.0
7	3000	110	10.5	31500.0
8	2000	110	10.5	21000.0
∑	43000			745400.0

	BORROW (M3)	WASTE (M3)
1	32500	
2	2000	
3	60000	
4	53000	
5	5000	
∑	152500	0

√M_{AVG}= √L_{AVG}= 17.3 m

M_{AVG}= L_{AVG}= 299.3 m

F_H= 1,25x0,00046xKx√M-0,00575xK

F_H= 0.739 TL/m^3

C_T = F_H*V_H+F_B*V_B+F_W*V_W = 312,834.5 TL

Figure 122: Initial hauling cost calculations

D6- PROFILE AFTER FIRST STEP

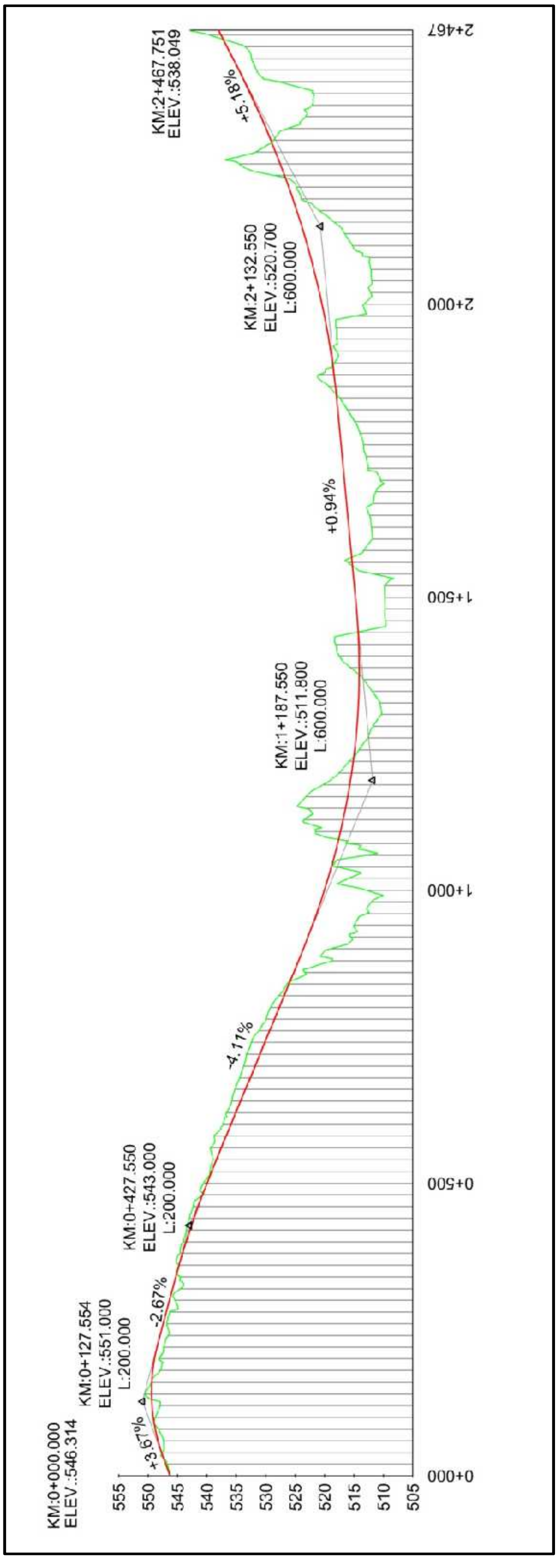


Figure 123: Profile after first step

D7- VOLUME TABLE AFTER FIRST STEP

Table 28: Volume table after first step

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+000.00	40.34	0.02	0.28	0.00	0.02	0.00	0.02
0+025.00	45.28	1070.23	0.00	3.48	1070.25	3.48	1066.77
0+027.55	55.36	128.52	0.00	0.00	1198.77	3.48	1195.29
0+050.00	64.55	1345.81	0.00	0.00	2544.58	3.48	2541.10
0+075.00	32.94	1218.62	2.35	29.36	3763.21	32.84	3730.37
0+100.00	54.11	1088.06	3.77	76.47	4851.27	109.30	4741.96
0+125.00	46.26	1254.67	10.34	176.42	6105.94	285.72	5820.22
0+150.00	106.99	1915.62	0.00	129.31	8021.56	415.03	7606.53
0+153.05	100.10	316.17	0.00	0.00	8337.73	415.03	7922.70
0+175.00	67.53	1839.40	0.00	0.00	10177.13	415.03	9762.10
0+200.00	21.97	1118.67	8.35	104.41	11295.80	519.43	10776.36
0+225.00	14.03	449.94	5.48	172.94	11745.74	692.37	11053.36
0+227.55	14.16	36.00	5.32	13.79	11781.74	706.17	11075.57
0+250.00	15.03	327.66	15.19	230.13	12109.39	936.30	11173.10
0+275.00	1.95	212.32	15.30	381.09	12321.71	1317.39	11004.32
0+300.00	22.19	301.82	29.01	553.85	12623.53	1871.24	10752.29
0+325.00	21.04	540.38	33.29	778.75	13163.91	2649.99	10513.92
0+347.55	36.93	653.70	27.25	682.70	13817.61	3332.70	10484.91
0+350.00	37.34	90.82	27.63	67.11	13908.43	3399.81	10508.62
0+353.13	37.50	117.15	28.25	87.48	14025.58	3487.29	10538.30
0+375.00	53.09	990.54	27.91	614.06	15016.13	4101.34	10914.78
0+400.00	57.37	1380.79	18.02	574.15	16396.92	4675.50	11721.42
0+425.00	57.87	1440.55	26.65	558.47	17837.47	5233.97	12603.49
0+450.00	60.98	1485.60	24.43	638.61	19323.07	5872.58	13450.49
0+475.00	70.34	1641.51	11.59	450.34	20964.58	6322.92	14641.66
0+500.00	76.25	1832.38	3.51	188.76	22796.96	6511.69	16285.27
0+525.00	121.46	2471.36	0.00	43.87	25268.32	6555.55	18712.77
0+547.55	142.61	2977.96	0.00	0.00	28246.27	6555.55	21690.72
0+550.00	150.48	358.45	0.00	0.00	28604.73	6555.55	22049.18
0+575.00	163.28	3922.06	0.00	0.00	32526.79	6555.55	25971.24
0+600.00	170.52	4172.50	0.00	0.00	36699.29	6555.55	30143.73
0+625.00	157.42	4099.22	0.00	0.00	40798.51	6555.55	34242.96
0+650.00	165.96	4042.20	0.00	0.00	44840.71	6555.55	38285.16
0+675.00	181.76	4346.43	0.00	0.00	49187.14	6555.55	42631.59
0+700.00	181.24	4537.53	0.00	0.00	53724.67	6555.55	47169.12
0+725.00	204.62	4823.33	0.00	0.00	58548.00	6555.55	51992.45
0+750.00	227.53	5401.85	0.00	0.00	63949.85	6555.55	57394.30
0+775.00	207.86	5442.30	0.00	0.00	69392.15	6555.55	62836.60
0+800.00	188.38	4953.01	0.00	0.00	74345.16	6555.55	67789.61
0+825.00	165.87	4428.12	0.00	0.00	78773.28	6555.55	72217.73
0+850.00	107.10	3412.13	1.12	13.94	82185.41	6569.49	75615.92
0+875.00	91.68	2484.78	58.95	750.85	84670.19	7320.33	77349.86
0+900.00	78.20	2123.49	68.56	1593.94	86793.68	8914.27	77879.40
0+907.55	44.27	462.56	100.40	638.17	87256.24	9552.44	77703.80

Table 28 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+925.00	0.00	386.15	102.83	1772.79	87642.39	11325.23	76317.16
0+944.08	43.10	411.13	147.36	2386.76	88053.52	13711.99	74341.53
0+950.00	45.26	261.59	145.61	867.36	88315.11	14579.35	73735.76
0+975.00	0.00	565.77	208.05	4420.85	88880.88	19000.20	69880.68
1+000.00	36.63	457.86	189.80	4973.15	89338.75	23973.36	65365.39
1+025.00	62.44	1238.32	213.43	5040.39	90577.07	29013.75	61563.32
1+050.00	86.90	1866.74	144.43	4473.35	92443.81	33487.09	58956.71
1+075.00	82.75	2120.64	126.49	3386.50	94564.45	36873.59	57690.86
1+100.00	247.34	4126.11	0.00	1581.07	98690.56	38454.66	60235.90
1+125.00	350.11	7468.11	0.00	0.00	106158.68	38454.66	67704.01
1+150.00	375.60	9071.37	0.00	0.00	115230.04	38454.66	76775.38
1+175.00	385.01	9507.58	0.00	0.00	124737.62	38454.66	86282.96
1+200.00	229.94	7686.86	0.00	0.00	132424.48	38454.66	93969.82
1+225.00	78.64	3857.27	0.25	3.11	136281.75	38457.77	97823.98
1+250.00	28.54	1339.73	20.25	256.20	137621.48	38713.97	98907.51
1+275.00	0.00	356.74	66.20	1080.54	137978.22	39794.50	98183.72
1+300.00	0.00	0.00	112.74	2236.69	137978.22	42031.19	95947.03
1+325.00	0.00	0.00	98.62	2641.93	137978.22	44673.12	93305.10
1+350.00	0.00	0.00	27.00	1570.14	137978.22	46243.26	91734.96
1+375.00	123.06	1538.30	0.00	337.45	139516.52	46580.71	92935.81
1+400.00	250.40	4668.33	0.00	0.00	144184.85	46580.71	97604.14
1+412.69	274.93	3333.60	0.00	0.00	147518.45	46580.71	100937.73
1+425.00	280.45	3417.92	0.00	0.00	150936.36	46580.71	104355.65
1+450.00	0.00	3505.61	124.04	1550.46	154441.97	48131.18	106310.79
1+475.00	0.00	0.00	156.95	3512.40	154441.97	51643.58	102798.39
1+500.00	0.00	0.00	167.65	4057.58	154441.97	55701.16	98740.81
1+507.55	0.00	0.00	169.83	1274.67	154441.98	56975.84	97466.14
1+525.00	0.00	0.02	201.32	3237.54	154441.99	60213.38	94228.61
1+535.03	0.00	0.00	184.33	1933.49	154441.99	62146.87	92295.12
1+550.00	3.27	24.49	10.65	1459.71	154466.49	63606.58	90859.91
1+575.00	12.55	197.80	26.59	465.41	154664.29	64071.99	90592.30
1+600.00	0.00	156.90	115.36	1774.29	154821.19	65846.28	88974.92
1+625.00	0.00	0.00	122.51	2973.39	154821.19	68819.67	86001.53
1+650.00	0.00	0.00	111.55	2925.82	154821.19	71745.49	83075.70
1+675.00	0.00	0.00	140.22	3147.13	154821.19	74892.62	79928.57
1+700.00	0.00	0.00	185.96	4077.21	154821.19	78969.83	75851.36
1+725.00	0.00	0.00	136.36	4028.95	154821.19	82998.78	71822.41
1+750.00	0.00	0.00	116.88	3165.54	154821.19	86164.32	68656.87
1+775.00	0.00	0.00	102.02	2736.24	154821.19	88900.56	65920.63
1+800.00	0.00	0.00	74.88	2211.26	154821.19	91111.82	63709.37
1+802.55	0.00	0.00	69.23	184.04	154821.19	91295.86	63525.33
1+825.00	0.00	0.00	21.00	1012.65	154821.19	92308.51	62512.68
1+850.00	94.30	1178.75	0.00	262.45	155999.94	92570.96	63428.99
1+875.00	185.66	3499.56	0.00	0.00	159499.50	92570.96	66928.54
1+900.00	93.74	3492.52	1.29	16.10	162992.02	92587.06	70404.95
1+925.00	51.70	1817.91	9.97	140.67	164809.92	92727.74	72082.18

Table 28 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
1+950.00	0.00	646.20	45.58	694.35	165456.12	93422.09	72034.03
1+975.00	0.00	0.00	105.11	1883.60	165456.12	95305.68	70150.43
2+000.00	0.00	0.00	288.15	4915.69	165456.12	100221.37	65234.74
2+025.00	0.00	0.00	359.46	8095.11	165456.12	108316.49	57139.63
2+050.00	0.00	0.00	413.25	9658.85	165456.12	117975.33	47480.78
2+075.00	0.00	0.00	395.82	10113.39	165456.12	128088.73	37367.39
2+100.00	0.00	0.00	319.04	8935.80	165456.12	137024.52	28431.59
2+125.00	0.00	0.00	261.51	7256.91	165456.12	144281.43	21174.68
2+150.00	0.00	0.00	173.83	5441.78	165456.12	149723.21	15732.91
2+175.00	16.58	207.22	46.46	2753.60	165663.33	152476.81	13186.52
2+200.00	172.16	2359.26	27.09	919.35	168022.59	153396.16	14626.44
2+225.00	463.88	7950.49	0.25	341.70	175973.08	153737.85	22235.23
2+250.00	615.62	13493.68	0.00	3.07	189466.76	153740.93	35725.84
2+275.00	84.50	8751.46	0.00	0.00	198218.22	153740.93	44477.30
2+300.00	0.00	1056.22	102.19	1277.36	199274.45	155018.29	44256.16
2+325.00	0.00	0.00	245.12	4341.37	199274.45	159359.65	39914.80
2+350.00	0.00	0.00	424.55	8370.83	199274.45	167730.48	31543.97
2+375.00	0.00	0.00	253.93	8481.01	199274.45	176211.48	23062.96
2+400.00	0.00	0.00	85.69	4245.36	199274.45	180456.85	18817.60
2+402.55	0.00	0.00	86.45	219.82	199274.45	180676.67	18597.78
2+425.00	0.00	0.00	90.58	1986.71	199274.45	182663.38	16611.07
2+450.00	295.63	3695.36	34.96	1569.17	202969.80	184232.55	18737.26
2+467.75	740.22	9193.76	5.31	357.37	212163.57	184589.92	27573.65

D8- MASS HAUL DIAGRAM AFTER FIRST STEP

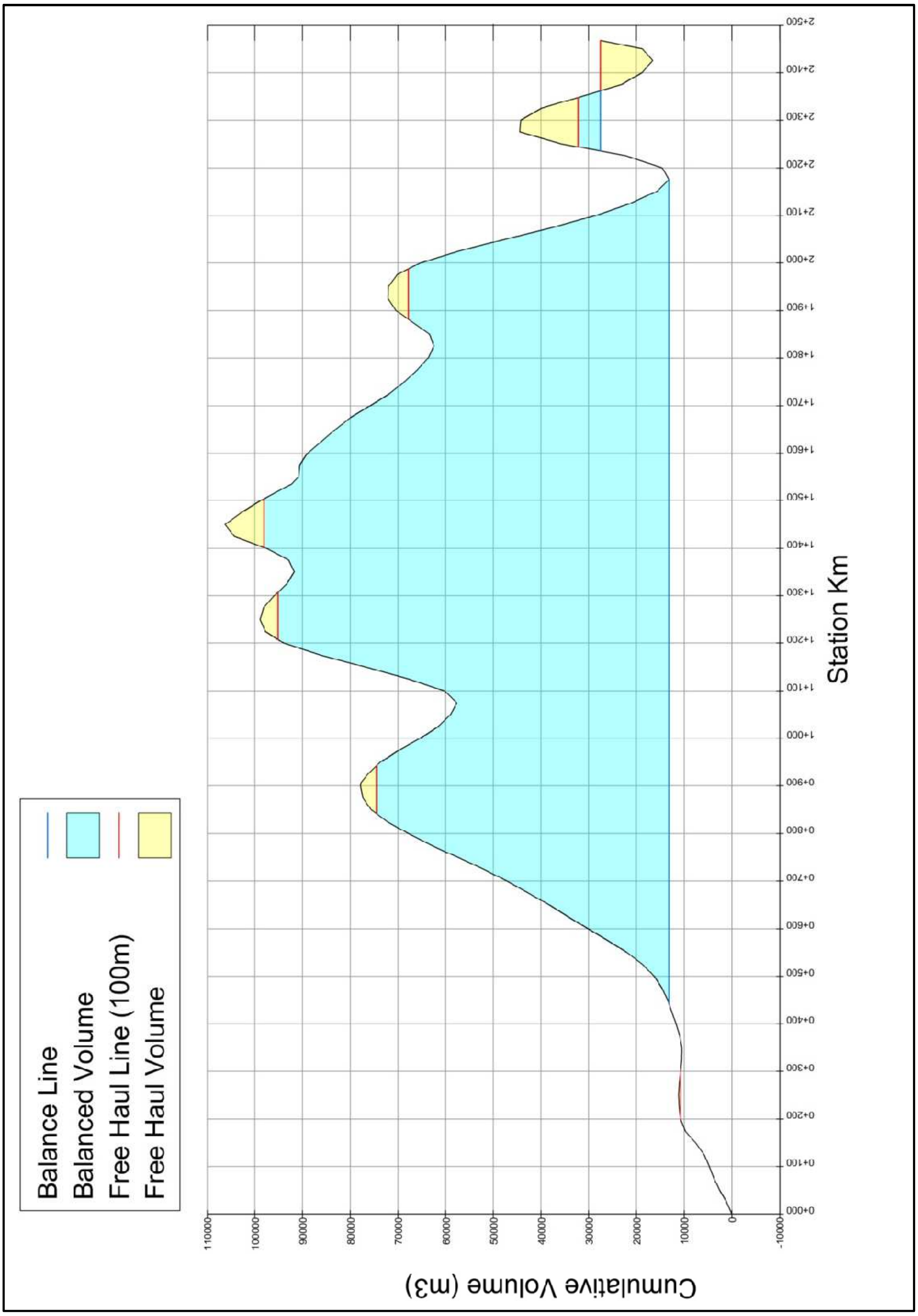


Figure 124: Mass haul diagram after first step

D9- HAULING COST CALCULCATIONS AFTER FIRST STEP

ECONOMIC HAULING:

M_{BARROW}= 1,200 m

M_{WASTE}= 600 m   K= 176

$F_B=F_w$= 1,25x0,00034xKx√M-0,00425xK

F_H= 1,25x0,00046xKx√M-0,00575xK

↓

F_B= 1.843 TL/m^3

F_w= 1.084 TL/m^3

$F_H=F_B+F_w$ → L_{EH}= 1,515.0

BALANCED VOLUMES:

	V (M3)	L (M)	√L	√L*V
1	12000	220	14.8	177600.0
2	3000	120	11.0	33000.0
3	6000	130	11.4	68400.0
4	29000	550	23.5	681500.0
5	6000	130	11.4	68400.0
6	45000	1450	38.1	1714500.0
7	5000	920	30.3	151500.0
8	6000	110	10.5	63000.0
9			0.0	0.0
∑	112000			2957900.0

	BARROW (M3)	WASTE (M3)
1		13000
2		14000
3		
4		
5		
∑	0	27000

$\sqrt{M_{AVG}}$= $\sqrt{L_{AVG}}$= 26.4 m

M_{AVG}= L_{AVG}= 697.0 m

F_H= 1,25x0,00046xKx√M-0,00575xK

F_H= 1.660 TL/m^3

C_T = $F_H*V_H+F_B*V_B+F_W*V_W$ = 215,188.0 TL

Figure 125: Hauling cost calculations after first step

D10- PROFILE AFTER SECOND STEP

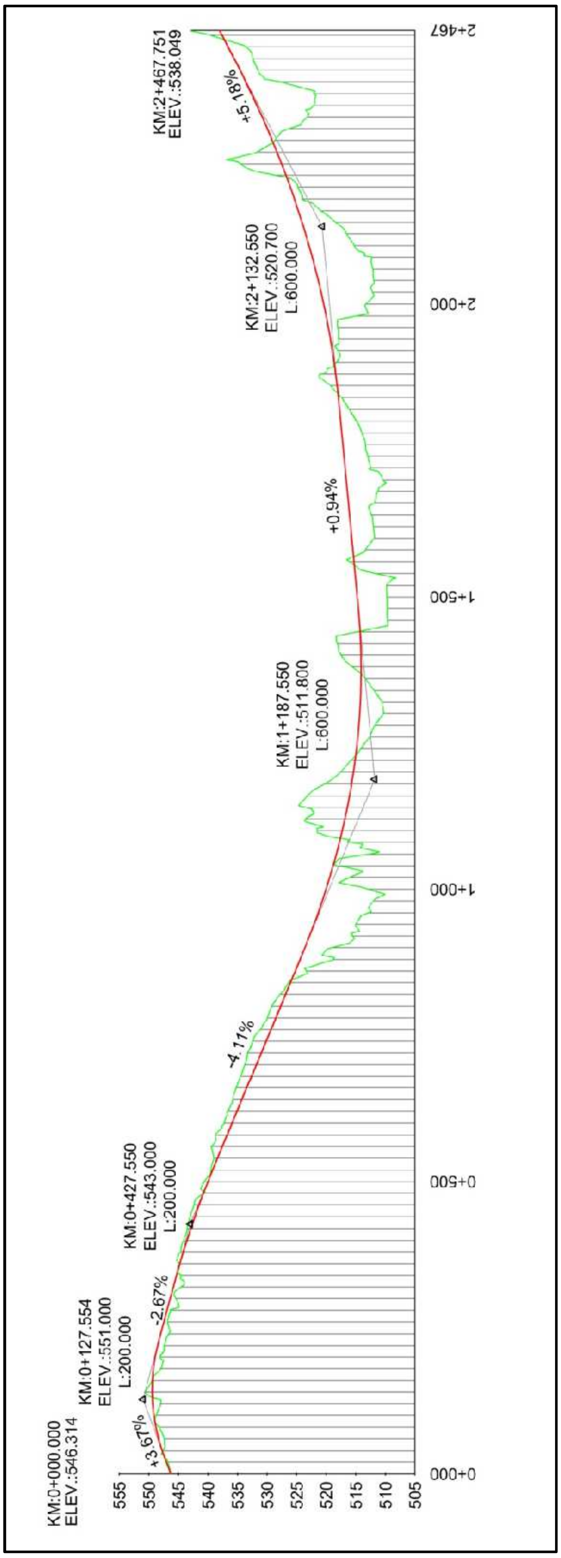


Figure 126: Profile after second step

D11- VOLUME TABLE AFTER SECOND STEP

Table 29 : Volume table after second step

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+000.00	40.34	0.02	0.28	0.00	0.02	0.00	0.02
0+025.00	45.28	1070.23	0.00	3.48	1070.25	3.48	1066.77
0+027.55	55.36	128.52	0.00	0.00	1198.77	3.48	1195.29
0+050.00	64.55	1345.81	0.00	0.00	2544.58	3.48	2541.10
0+075.00	32.94	1218.62	2.35	29.36	3763.21	32.84	3730.37
0+100.00	54.11	1088.06	3.77	76.47	4851.27	109.30	4741.96
0+125.00	46.26	1254.67	10.34	176.42	6105.94	285.72	5820.22
0+150.00	106.99	1915.62	0.00	129.31	8021.56	415.03	7606.53
0+153.05	100.10	316.17	0.00	0.00	8337.73	415.03	7922.70
0+175.00	67.53	1839.40	0.00	0.00	10177.13	415.03	9762.10
0+200.00	21.97	1118.67	8.35	104.41	11295.80	519.43	10776.36
0+225.00	14.03	449.94	5.48	172.94	11745.74	692.37	11053.36
0+227.55	14.16	36.00	5.32	13.79	11781.74	706.17	11075.57
0+250.00	15.03	327.66	15.19	230.13	12109.39	936.30	11173.10
0+275.00	1.95	212.32	15.30	381.09	12321.71	1317.39	11004.32
0+300.00	22.19	301.82	29.01	553.85	12623.53	1871.24	10752.29
0+325.00	21.04	540.38	33.29	778.75	13163.91	2649.99	10513.92
0+347.55	36.93	653.70	27.25	682.70	13817.61	3332.70	10484.91
0+350.00	37.34	90.82	27.63	67.11	13908.43	3399.81	10508.62
0+353.13	37.50	117.15	28.25	87.48	14025.58	3487.29	10538.30
0+375.00	53.09	990.54	27.91	614.06	15016.13	4101.34	10914.78
0+400.00	57.37	1380.79	18.02	574.15	16396.92	4675.50	11721.42
0+425.00	57.87	1440.55	26.65	558.47	17837.47	5233.97	12603.49
0+450.00	60.98	1485.60	24.43	638.61	19323.07	5872.58	13450.49
0+475.00	70.34	1641.51	11.59	450.34	20964.58	6322.92	14641.66
0+500.00	76.25	1832.38	3.51	188.76	22796.96	6511.69	16285.27
0+525.00	121.46	2471.36	0.00	43.87	25268.32	6555.55	18712.77
0+547.55	142.61	2977.96	0.00	0.00	28246.27	6555.55	21690.72
0+550.00	150.48	358.45	0.00	0.00	28604.73	6555.55	22049.18
0+575.00	163.28	3922.06	0.00	0.00	32526.79	6555.55	25971.24
0+600.00	170.52	4172.50	0.00	0.00	36699.29	6555.55	30143.73
0+625.00	157.42	4099.22	0.00	0.00	40798.51	6555.55	34242.96
0+650.00	165.96	4042.20	0.00	0.00	44840.71	6555.55	38285.16
0+675.00	181.76	4346.43	0.00	0.00	49187.14	6555.55	42631.59
0+700.00	181.24	4537.53	0.00	0.00	53724.67	6555.55	47169.12
0+725.00	204.62	4823.33	0.00	0.00	58548.00	6555.55	51992.45
0+750.00	227.53	5401.85	0.00	0.00	63949.85	6555.55	57394.30
0+775.00	207.86	5442.30	0.00	0.00	69392.15	6555.55	62836.60
0+800.00	188.38	4953.01	0.00	0.00	74345.16	6555.55	67789.61
0+825.00	165.87	4428.12	0.00	0.00	78773.28	6555.55	72217.73
0+850.00	107.10	3412.13	1.12	13.94	82185.41	6569.49	75615.92
0+875.00	91.68	2484.78	58.95	750.85	84670.19	7320.33	77349.86
0+900.00	78.20	2123.49	68.56	1593.94	86793.68	8914.27	77879.40
0+907.55	44.27	462.56	100.40	638.17	87256.24	9552.44	77703.80

Table 29 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+925.00	0.00	386.15	102.83	1772.79	87642.39	11325.23	76317.16
0+944.08	43.10	411.13	147.36	2386.76	88053.52	13711.99	74341.53
0+950.00	45.26	261.59	145.61	867.36	88315.11	14579.35	73735.76
0+975.00	0.00	565.77	208.05	4420.85	88880.88	19000.20	69880.68
1+000.00	36.63	457.86	189.80	4973.15	89338.75	23973.36	65365.39
1+025.00	62.44	1238.32	213.43	5040.39	90577.07	29013.75	61563.32
1+050.00	86.90	1866.74	144.43	4473.35	92443.81	33487.09	58956.71
1+075.00	82.75	2120.64	126.49	3386.50	94564.45	36873.59	57690.86
1+100.00	247.34	4126.11	0.00	1581.07	98690.56	38454.66	60235.90
1+125.00	350.11	7468.11	0.00	0.00	106158.68	38454.66	67704.01
1+150.00	375.60	9071.37	0.00	0.00	115230.04	38454.66	76775.38
1+175.00	385.01	9507.58	0.00	0.00	124737.62	38454.66	86282.96
1+200.00	229.94	7686.86	0.00	0.00	132424.48	38454.66	93969.82
1+225.00	78.64	3857.27	0.25	3.11	136281.75	38457.77	97823.98
1+250.00	28.54	1339.73	20.25	256.20	137621.48	38713.97	98907.51
1+275.00	0.00	356.74	66.20	1080.54	137978.22	39794.50	98183.72
1+300.00	0.00	0.00	112.74	2236.69	137978.22	42031.19	95947.03
1+325.00	0.00	0.00	98.62	2641.93	137978.22	44673.12	93305.10
1+350.00	0.00	0.00	27.00	1570.14	137978.22	46243.26	91734.96
1+375.00	123.06	1538.30	0.00	337.45	139516.52	46580.71	92935.81
1+400.00	250.40	4668.33	0.00	0.00	144184.85	46580.71	97604.14
1+412.69	274.93	3333.60	0.00	0.00	147518.45	46580.71	100937.73
1+425.00	280.45	3417.92	0.00	0.00	150936.36	46580.71	104355.65
1+450.00	0.00	3505.61	124.04	1550.46	154441.97	48131.18	106310.79
1+475.00	0.00	0.00	156.95	3512.40	154441.97	51643.58	102798.39
1+500.00	0.00	0.00	167.65	4057.58	154441.97	55701.16	98740.81
1+507.55	0.00	0.00	169.83	1274.67	154441.98	56975.84	97466.14
1+525.00	0.00	0.02	201.32	3237.54	154441.99	60213.38	94228.61
1+535.03	0.00	0.00	184.33	1933.49	154441.99	62146.87	92295.12
1+550.00	3.27	24.49	10.65	1459.71	154466.49	63606.58	90859.91
1+575.00	12.55	197.80	26.59	465.41	154664.29	64071.99	90592.30
1+600.00	0.00	156.90	115.36	1774.29	154821.19	65846.28	88974.92
1+625.00	0.00	0.00	122.51	2973.39	154821.19	68819.67	86001.53
1+650.00	0.00	0.00	111.55	2925.82	154821.19	71745.49	83075.70
1+675.00	0.00	0.00	140.22	3147.13	154821.19	74892.62	79928.57
1+700.00	0.00	0.00	185.96	4077.21	154821.19	78969.83	75851.36
1+725.00	0.00	0.00	136.36	4028.95	154821.19	82998.78	71822.41
1+750.00	0.00	0.00	116.88	3165.54	154821.19	86164.32	68656.87
1+775.00	0.00	0.00	102.02	2736.24	154821.19	88900.56	65920.63
1+800.00	0.00	0.00	74.88	2211.26	154821.19	91111.82	63709.37
1+802.55	0.00	0.00	69.23	184.04	154821.19	91295.86	63525.33
1+825.00	0.00	0.00	21.00	1012.65	154821.19	92308.51	62512.68
1+850.00	94.30	1178.75	0.00	262.45	155999.94	92570.96	63428.99
1+875.00	185.66	3499.56	0.00	0.00	159499.50	92570.96	66928.54
1+900.00	93.74	3492.52	1.29	16.10	162992.02	92587.06	70404.95
1+925.00	51.70	1817.91	9.97	140.67	164809.92	92727.74	72082.18

Table 29 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
1+950.00	0.00	646.20	45.58	694.35	165456.12	93422.09	72034.03
1+975.00	0.00	0.00	105.11	1883.60	165456.12	95305.68	70150.43
2+000.00	0.00	0.00	288.15	4915.69	165456.12	100221.37	65234.74
2+025.00	0.00	0.00	359.46	8095.11	165456.12	108316.49	57139.63
2+050.00	0.00	0.00	413.25	9658.85	165456.12	117975.33	47480.78
2+075.00	0.00	0.00	395.82	10113.39	165456.12	128088.73	37367.39
2+100.00	0.00	0.00	319.04	8935.80	165456.12	137024.52	28431.59
2+125.00	0.00	0.00	261.51	7256.91	165456.12	144281.43	21174.68
2+150.00	0.00	0.00	173.83	5441.78	165456.12	149723.21	15732.91
2+175.00	16.58	207.22	46.46	2753.60	165663.33	152476.81	13186.52
2+200.00	172.16	2359.26	27.09	919.35	168022.59	153396.16	14626.44
2+225.00	463.88	7950.49	0.25	341.70	175973.08	153737.85	22235.23
2+250.00	615.62	13493.68	0.00	3.07	189466.76	153740.93	35725.84
2+275.00	84.50	8751.46	0.00	0.00	198218.22	153740.93	44477.30
2+300.00	0.00	1056.22	102.19	1277.36	199274.45	155018.29	44256.16
2+325.00	0.00	0.00	245.12	4341.37	199274.45	159359.65	39914.80
2+350.00	0.00	0.00	424.55	8370.83	199274.45	167730.48	31543.97
2+375.00	0.00	0.00	253.93	8481.01	199274.45	176211.48	23062.96
2+400.00	0.00	0.00	85.69	4245.36	199274.45	180456.85	18817.60
2+402.55	0.00	0.00	86.45	219.82	199274.45	180676.67	18597.78
2+425.00	0.00	0.00	90.58	1986.71	199274.45	182663.38	16611.07
2+450.00	295.63	3695.36	34.96	1569.17	202969.80	184232.55	18737.26
2+467.75	740.22	9193.76	5.31	357.37	212163.57	184589.92	27573.65

D12- MASS HAUL DIAGRAM AFTER SECOND STEP

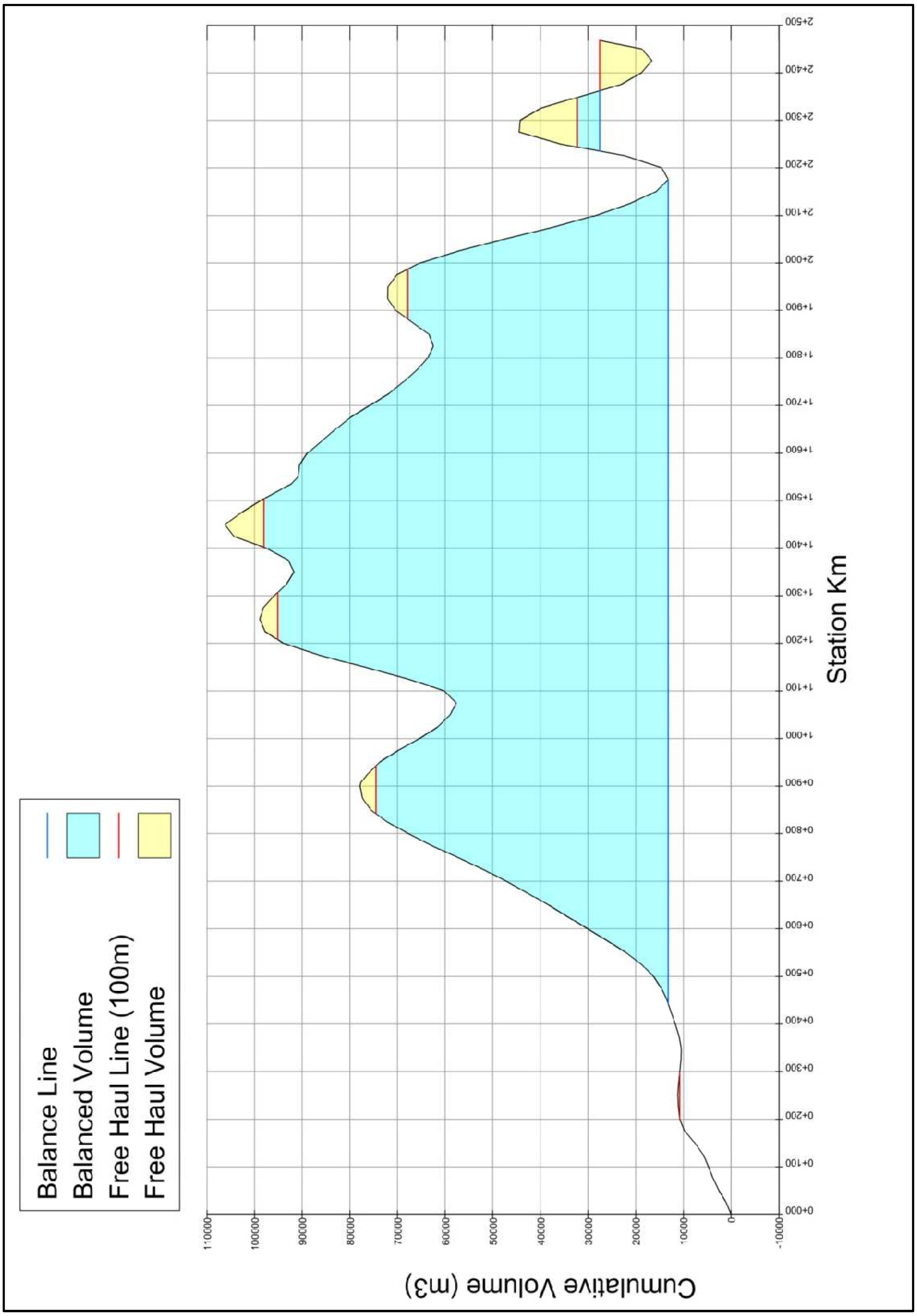


Figure 127: Mass haul diagram after second step

D13- HAULING COST CALCULCATIONS AFTER SECOND STEP

ECONOMIC HAULING:

M_{BARROW}= 1,200 m

M_{WASTE}= 600 m   K= 176

$F_B=F_w$= 1,25x0,00034xKx√M-0,00425xK

F_H= 1,25x0,00046xKx√M-0,00575xK

↓

F_B= 1.843 TL/m^3

F_w= 1.084 TL/m^3

$F_H=F_B+F_w$ → L_{EH}= 1,515.0

BALANCED VOLUMES:

	V (M3)	L (M)	√L	√L*V
1	12000	220	14.8	177600.0
2	3000	120	11.0	33000.0
3	6000	130	11.4	68400.0
4	29000	550	23.5	681500.0
5	6000	130	11.4	68400.0
6	45000	1450	38.1	1714500.0
7	5000	920	30.3	151500.0
8	6000	110	10.5	63000.0
9			0.0	0.0
∑	112000			2957900.0

	BARROW (M3)	WASTE (M3)
1		13000
2		14000
3		
4		
5		
∑	0	27000

$\sqrt{M_{AVG}}$= $\sqrt{L_{AVG}}$= 26.4 m

M_{AVG}= L_{AVG}= 697.0 m

F_H= 1,25x0,00046xKx√M-0,00575xK

F_H= 1.660 TL/m^3

C_T = $F_H*V_H+F_B*V_B+F_W*V_W$ = 215,188.0 TL

Figure 128: Hauling cost calculations after second step

D14- PROFILE AFTER THIRD STEP

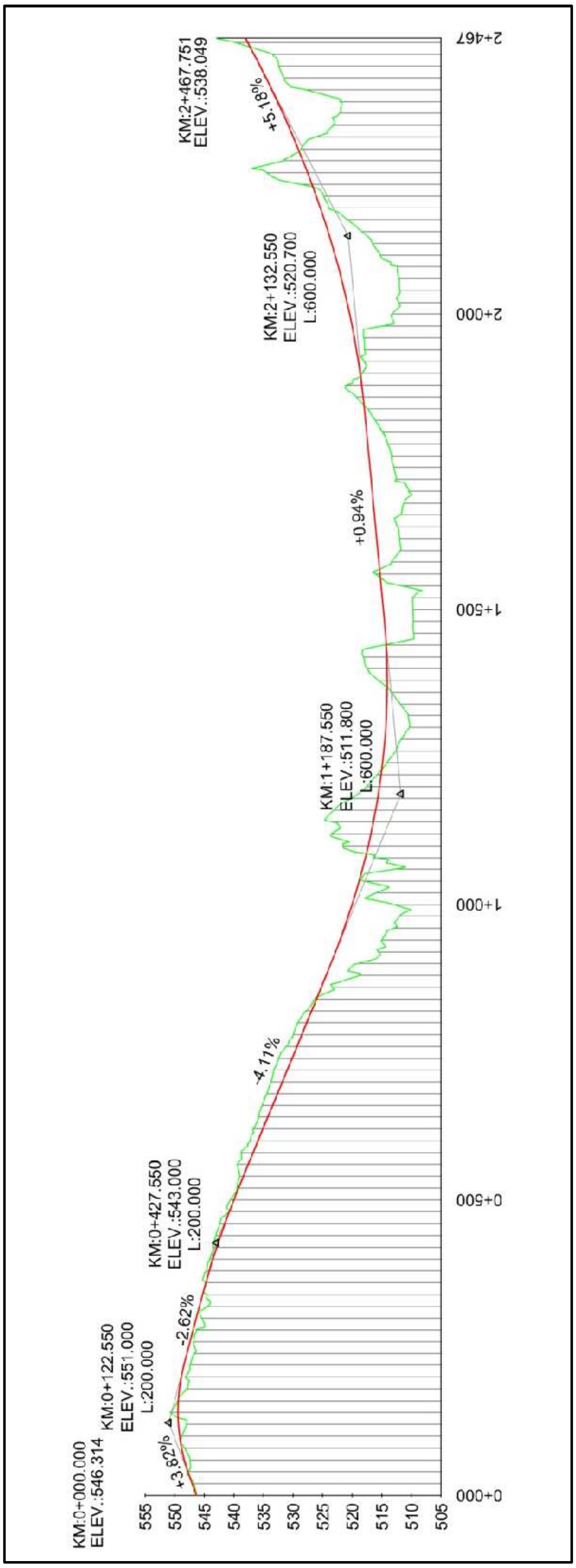


Figure 129: Profile after third step

D15-VOLUME TABLE AFTER THIRD STEP

Table 30: Volume table after third step

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+000.00	40.34	0.02	0.28	0.00	0.02	0.00	0.02
0+025.00	43.83	1052.05	0.02	3.76	1052.07	3.76	1048.32
0+027.55	50.80	120.83	0.00	0.03	1172.91	3.79	1169.12
0+050.00	62.77	1274.57	0.00	0.00	2447.47	3.79	2443.69
0+075.00	32.10	1185.96	2.62	32.73	3633.43	36.51	3596.92
0+100.00	53.62	1071.51	3.95	82.10	4704.94	118.62	4586.32
0+125.00	46.24	1248.16	10.36	178.94	5953.10	297.55	5655.55
0+150.00	107.86	1926.17	0.00	129.56	7879.27	427.11	7452.16
0+153.05	101.14	319.08	0.00	0.00	8198.35	427.11	7771.24
0+175.00	69.47	1872.15	0.00	0.00	10070.51	427.11	9643.39
0+200.00	23.71	1164.76	7.52	93.97	11235.27	521.09	10714.18
0+225.00	16.51	502.72	4.07	144.81	11737.99	665.89	11072.10
0+227.55	16.66	42.36	3.97	10.26	11780.35	676.16	11104.19
0+250.00	17.17	379.70	13.63	197.59	12160.05	873.75	11286.30
0+275.00	21.42	482.29	12.93	332.02	12642.34	1205.77	11436.57
0+300.00	23.89	566.26	27.73	508.17	13208.60	1713.94	11494.66
0+325.00	21.89	572.21	38.86	832.27	13780.81	2546.21	11234.60
0+347.55	37.90	674.30	26.60	738.19	14455.11	3284.40	11170.71
0+350.00	38.35	93.25	27.09	65.67	14548.37	3350.07	11198.30
0+353.13	38.48	120.27	27.73	85.82	14668.64	3435.89	11232.75
0+375.00	53.89	1009.99	27.51	603.99	15678.63	4039.88	11638.75
0+400.00	57.98	1398.37	17.76	565.85	17076.99	4605.73	12471.26
0+425.00	58.25	1452.88	26.47	552.86	18529.87	5158.59	13371.29
0+450.00	61.19	1493.00	24.30	634.69	20022.88	5793.28	14229.60
0+475.00	70.45	1645.45	11.54	448.07	21668.32	6241.34	15426.98
0+500.00	76.27	1834.00	3.50	188.05	23502.32	6429.39	17072.93
0+525.00	121.46	2471.70	0.00	43.76	25974.03	6473.15	19500.88
0+547.55	142.61	2977.96	0.00	0.00	28951.99	6473.15	22478.84
0+550.00	150.48	358.45	0.00	0.00	29310.44	6473.15	22837.29
0+575.00	163.28	3922.06	0.00	0.00	33232.50	6473.15	26759.35
0+600.00	170.52	4172.50	0.00	0.00	37405.00	6473.15	30931.85
0+625.00	157.42	4099.22	0.00	0.00	41504.22	6473.15	35031.07
0+650.00	165.96	4042.20	0.00	0.00	45546.42	6473.15	39073.28
0+675.00	181.76	4346.43	0.00	0.00	49892.85	6473.15	43419.70
0+700.00	181.24	4537.53	0.00	0.00	54430.38	6473.15	47957.24
0+725.00	204.62	4823.33	0.00	0.00	59253.72	6473.15	52780.57
0+750.00	227.53	5401.85	0.00	0.00	64655.56	6473.15	58182.42
0+775.00	207.86	5442.30	0.00	0.00	70097.86	6473.15	63624.71
0+800.00	188.38	4953.01	0.00	0.00	75050.87	6473.15	68577.73
0+825.00	165.87	4428.12	0.00	0.00	79478.99	6473.15	73005.84
0+850.00	107.10	3412.13	1.12	13.94	82891.12	6487.08	76404.03
0+875.00	91.68	2484.78	58.95	750.85	85375.90	7237.93	78137.97
0+900.00	78.20	2123.49	68.56	1593.94	87499.39	8831.87	78667.52
0+907.55	44.27	462.56	100.40	638.17	87961.95	9470.04	78491.91

Table 30 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
0+925.00	0.00	386.15	102.83	1772.79	88348.10	11242.82	77105.28
0+944.08	43.10	411.13	147.36	2386.76	88759.23	13629.59	75129.65
0+950.00	45.26	261.59	145.61	867.36	89020.82	14496.95	74523.88
0+975.00	0.00	565.77	208.05	4420.85	89586.59	18917.80	70668.80
1+000.00	36.63	457.86	189.80	4973.15	90044.46	23890.95	66153.51
1+025.00	62.44	1238.32	213.43	5040.39	91282.78	28931.34	62351.44
1+050.00	86.90	1866.74	144.43	4473.35	93149.52	33404.69	59744.83
1+075.00	82.75	2120.64	126.49	3386.50	95270.16	36791.19	58478.98
1+100.00	247.34	4126.11	0.00	1581.07	99396.28	38372.26	61024.02
1+125.00	350.11	7468.11	0.00	0.00	106864.39	38372.26	68492.13
1+150.00	375.60	9071.37	0.00	0.00	115935.76	38372.26	77563.50
1+175.00	385.01	9507.58	0.00	0.00	125443.33	38372.26	87071.08
1+200.00	229.94	7686.86	0.00	0.00	133130.19	38372.26	94757.93
1+225.00	78.64	3857.27	0.25	3.11	136987.46	38375.37	98612.10
1+250.00	28.54	1339.73	20.25	256.20	138327.19	38631.56	99695.63
1+275.00	0.00	356.74	66.20	1080.54	138683.93	39712.10	98971.83
1+300.00	0.00	0.00	112.74	2236.69	138683.93	41948.79	96735.15
1+325.00	0.00	0.00	98.62	2641.93	138683.93	44590.72	94093.21
1+350.00	0.00	0.00	27.00	1570.14	138683.93	46160.86	92523.07
1+375.00	123.06	1538.30	0.00	337.45	140222.23	46498.31	93723.92
1+400.00	250.40	4668.33	0.00	0.00	144890.56	46498.31	98392.25
1+412.69	274.93	3333.60	0.00	0.00	148224.16	46498.31	101725.85
1+425.00	280.45	3417.92	0.00	0.00	151642.08	46498.31	105143.77
1+450.00	0.00	3505.61	124.04	1550.46	155147.68	48048.77	107098.91
1+475.00	0.00	0.00	156.95	3512.40	155147.68	51561.17	103586.51
1+500.00	0.00	0.00	167.65	4057.58	155147.68	55618.76	99528.92
1+507.55	0.00	0.00	169.83	1274.67	155147.69	56893.43	98254.26
1+525.00	0.00	0.02	201.32	3237.54	155147.70	60130.97	95016.73
1+535.03	0.00	0.00	184.33	1933.49	155147.70	62064.46	93083.24
1+550.00	3.27	24.49	10.65	1459.71	155172.20	63524.17	91648.02
1+575.00	12.55	197.80	26.59	465.41	155370.00	63989.58	91380.42
1+600.00	0.00	156.90	115.36	1774.29	155526.90	65763.87	89763.03
1+625.00	0.00	0.00	122.51	2973.39	155526.90	68737.26	86789.64
1+650.00	0.00	0.00	111.55	2925.82	155526.90	71663.08	83863.82
1+675.00	0.00	0.00	140.22	3147.13	155526.90	74810.22	80716.69
1+700.00	0.00	0.00	185.96	4077.21	155526.90	78887.43	76639.48
1+725.00	0.00	0.00	136.36	4028.95	155526.90	82916.38	72610.52
1+750.00	0.00	0.00	116.88	3165.54	155526.90	86081.92	69444.99
1+775.00	0.00	0.00	102.02	2736.24	155526.90	88818.16	66708.75
1+800.00	0.00	0.00	74.88	2211.26	155526.90	91029.42	64497.49
1+802.55	0.00	0.00	69.23	184.04	155526.90	91213.46	64313.45
1+825.00	0.00	0.00	21.00	1012.65	155526.90	92226.11	63300.80
1+850.00	94.30	1178.75	0.00	262.45	156705.66	92488.55	64217.10
1+875.00	185.66	3499.56	0.00	0.00	160205.21	92488.55	67716.66
1+900.00	93.74	3492.52	1.29	16.10	163697.73	92504.66	71193.07
1+925.00	51.70	1817.91	9.97	140.67	165515.63	92645.33	72870.30

Table 30 (Continued) :

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Cum. Net Vol. (Cu.m.)
1+950.00	0.00	646.20	45.58	694.35	166161.83	93339.68	72822.14
1+975.00	0.00	0.00	105.11	1883.60	166161.83	95223.28	70938.55
2+000.00	0.00	0.00	288.15	4915.69	166161.83	100138.97	66022.86
2+025.00	0.00	0.00	359.46	8095.11	166161.83	108234.08	57927.75
2+050.00	0.00	0.00	413.25	9658.85	166161.83	117892.93	48268.90
2+075.00	0.00	0.00	395.82	10113.39	166161.83	128006.32	38155.51
2+100.00	0.00	0.00	319.04	8935.80	166161.83	136942.12	29219.71
2+125.00	0.00	0.00	261.51	7256.91	166161.83	144199.03	21962.80
2+150.00	0.00	0.00	173.83	5441.78	166161.83	149640.80	16521.02
2+175.00	16.58	207.22	46.46	2753.60	166369.04	152394.40	13974.64
2+200.00	172.16	2359.26	27.09	919.35	168728.31	153313.75	15414.55
2+225.00	463.88	7950.49	0.25	341.70	176678.80	153655.45	23023.35
2+250.00	615.62	13493.68	0.00	3.07	190172.48	153658.52	36513.95
2+275.00	84.50	8751.46	0.00	0.00	198923.94	153658.52	45265.41
2+300.00	0.00	1056.22	102.19	1277.36	199980.16	154935.88	45044.28
2+325.00	0.00	0.00	245.12	4341.37	199980.16	159277.25	40702.91
2+350.00	0.00	0.00	424.55	8370.83	199980.16	167648.07	32332.09
2+375.00	0.00	0.00	253.93	8481.01	199980.16	176129.08	23851.08
2+400.00	0.00	0.00	85.69	4245.36	199980.16	180374.44	19605.72
2+402.55	0.00	0.00	86.45	219.82	199980.16	180594.27	19385.90
2+425.00	0.00	0.00	90.58	1986.71	199980.16	182580.98	17399.19
2+450.00	295.63	3695.36	34.96	1569.17	203675.52	184150.14	19525.38
2+467.75	740.22	9193.76	5.31	357.37	212869.28	184507.52	28361.77

D16- MASS HAUL DIAGRAM AFTER THIRD STEP

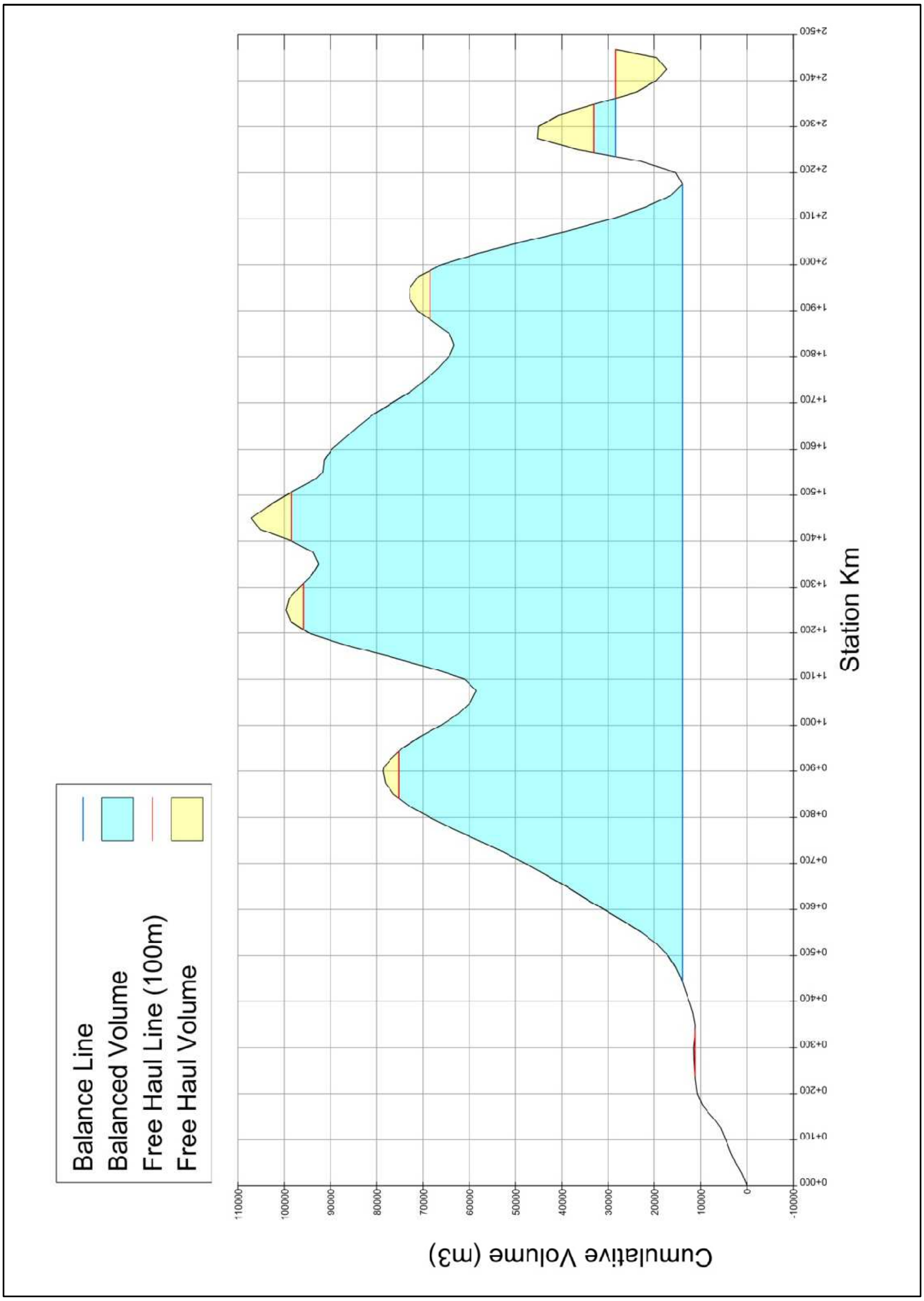


Figure 130: Mass haul diagram after third step

D17- HAULING COST CALCULCATIONS AFTER THIRD STEP

ECONOMIC HAULING:

M_{BARROW}= 1,200 m

M_{WASTE}= 600 m K= 176

F_B=F_w= 1,25x0,00034xKx√M-0,00425xK

F_H= 1,25x0,00046xKx√M-0,00575xK

↓

F_B= 1.843 TL/m^3

F_w= 1.084 TL/m^3

F_H=F_B+F_w → L_{EH}= 1,515.0

BALANCED VOLUMES:

	V (M3)	L (M)	√L	√L*V
1	16500	220	14.8	244200.0
2	2500	120	11.0	27500.0
3	6000	130	11.4	68400.0
4	29000	540	23.2	672800.0
5	5000	150	12.2	61000.0
6	44000	1450	38.1	1676400.0
7	5000	920	30.3	151500.0
8	5000	120	11.0	55000.0
9			0.0	0.0
∑	113000			2956800.0

	BARROW (M3)	WASTE (M3)
1		13000
2		14000
3		
4		
5		
∑	0	27000

$\sqrt{M_{AVG}}$= $\sqrt{L_{AVG}}$= 26.2 m

M_{AVG}= L_{AVG}= 686.4 m

F_H= 1,25x0,00046xKx√M-0,00575xK

F_H= 1.639 TL/m^3

C_T = F_H*V_H+F_B*V_B+F_W*V_W = 214,475.0 TL

Figure 131: Hauling calculations after third step