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Optimizing Land Leveling by Applying Warped Surface

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Earthwork optimization,
Linear programming,
Plane shape,
Curved surface,
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ABSTRACT

In this paper we develop a new approach for land leveling in order to improve the topology of a large area for irrigation or civil projects. The objective in proposed model is to minimize the total volume of cutting so that technical requirements of land leveling such as suitable slope and standard ratio of cutting to filling and maximum penstock point's height are considered. We develop a warped surface pattern and apply a linear programming model to determine the land optimal topology. Our approach is more practical to apply, in comparison with the existing "fit to plane" methods which apply bivariate regression statistical techniques because in these methods finding optimal solution, considering technical requirements, needs trial and error. Our proposed method does not need any trial and error, furthermore its results is global optimum. Also the warped surface pattern is adoptable to plane or curved patterns, and it is applicable for any land with any magnitude.

1. Introduction

Land leveling refers to the methodology of improving the topology of a natural land which is usually large with ups and downs. The aim is to make a large natural land suitable for agricultural purposes. In order to achieve this goal, the land should be smooth enough to make a uniform flow of water possible, by considering the requirements of irrigation such as appropriate slopes in different directions, penstock point or desired cut to fill ratio. Land leveling also can be applied for other large civil projects such as new residential or industrial complex, roads and airports.

Alteration in ups and downs of a natural landin direction of two perpendicular axis of X and Y, is called land leveling, land grading, or land forming. The following steps are used for land leveling:

1. Designing land network
2. Identifying the existing land topography by measuring some specified point's heights.
3. Designing the desirable leveling pattern by considering technical requirements.
4. Implementing the pattern.

Due to very high expense of land leveling which is caused by expensive heavy

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machinery, it is vital to minimize the cost of cutting and filling. A near optimal plan can decrease the total cost significantly.

In the literature, one can find several models for land leveling design. Most of the existing models have been developed within the framework of least square techniques. However, in these methods frequent trial and errors must be carried out to obtain desirable cut to fill ratio and acceptable slope range. Therefore, applying these approaches need heavy calculations and is time consuming. Some mathematical models also have been developed for land leveling by making some simplifying assumptions, such as plane shape for graded surface.

The first systematic procedures for land leveling were introduced by Givan (1940) for rectangular fields and by Chugg (1947) with irregularly shaped fields. Both authors applied least-square methods to define a plane surface that fits the natural ground surface with minimum earthwork. The method proposed by Chugg (1947) requires graphical determination of distances and is considered to be too complicated (Shih et al. 1973). Raju (1960) proposed a method, called the "fixed-volume-center method" to compute the optimal slope of the graded plane. The underlying criterion for this method is that the total volume of earth and the center of the volume are the same, before and after leveling. Shih and Kriz (1971a) concluded that the fixed-volume-center method is not as efficient as the least square method. Harris et al. (1966) proposed the warped surface method, which takes advantage of the natural ground slope. Hamad and Ali (1990) contend that such a design restricts irrigation direction and makes it impossible to change the irrigation direction from season to season or as desired. Hamad and Ali (1990) proposed a method by using the box-complex approach. Although their method can handle curved surfaces and other constraints, it has also some disadvantages. It does not handle bounds on the cut to fill ratio directly, although, after obtaining the optimal graded surface, the volumes of earthwork are estimated to compute cut to fill ratio. If this cut to fill ratio is not within the permissible limits, the curved surface is either raised or lowered on a trial and error basis, accordingly.

The disadvantages of the method were pointed out by Reddy (1996). T. Zissis& I. Telglou (1994) used a computer program based on least squares method for agricultural land leveling. This method uses statistical and regression techniques for leveling. Reddy (1996) developed an optimal land grading design method based on genetic algorithm. Reddy’s model can be used to obtain both plane and curved surfaces. The optimization model uses an objective function in which the total volume of cut is minimized. EbneJalal(2004) also proposed a method for land grading design based on the theory of the least squares and the statistical properties of the best statistic with an unbiased estimate and minimum variance.

Li Xiaoyong(2010) presented a calculation method for the design plane by considering not only the balance of cut and fill but also the minimum of the total earthwork quantity. In this paper,we introduce a new idea for land leveling by developing warped surface pattern and modeling with linear programming. This method can result in the best possible pattern for land leveling while all technical requirements are considered. Therefore, since this method is not based on trial and error approach, it is more practical and the optimal solution can be obtained relatively fast.

The mathematical equation for Plane shape is as follows:

$$H(x,y) = a + bx + cy \qquad (1)$$

This equation includes 3 parameters a, b, and c.

The mathematical equation for curved surface is as follows:

$$H(x,y) = a + bx^r + cy^s \qquad (2)$$

This equation includes 5 parameters a, b, c, r, and s.

Warped surface pattern cannot be formulated inone specific equation. The rest of the paper is organized as follows. In Section 2, the problem and its assumptions are stated. In Section 3, we present the mathematical model for land leveling. In Section 4 we illustrate the approach through two real examples and present its advantages and then compare its results with those of the existing methods.GAMS and Excel are used for solving these models.

2. Problem Statement

The land can be represented as a grid in which the nodes and arcs are identified. The coordinate of a node is identified as (i, j). The goal is to determine the height of each node, by cutting and filling while the following technical considerations are considered.

1. Object function. The total volume of cuts and fills must be minimized.
2. Up and down limit for lands slope in the X axis direction. Lands slope in the X axis direction must lie within specified range. In other words,the slope in X axis direction should not be less than a specified amount (e.g. 1%) and exceed a specified amount (e.g. 5%).
3. Up and down limit for lands slope in the Y axis direction. The same as X axis direction.
4. Cut to fill ratio constraint. It is observed in practice that filled holes subside after moisture absorption. Therefore, it is necessary that the amount of filling be more than cutting. Thus, in many projects the ratio of total volume of cuts to total volume of fill sum need to fit within a specified range (e.g. 1.1 to 1.2).
5. The maximum penstock point's height constraint.If land is leveled for surface irrigation for agricultural purpose, it is necessary that penstock point's height be not more than the specified amount in order to make water pumping dispensable.

3. Mathematical Modeling

In some cases earth bulge is such that applying plane or curved model for leveling may be economical, because of high volume of cut-fill operations. In these lands, warped surface model can reduce cut depth. The main specification of this model is that the slope of the land between each two pieces can be different but it must lie in defined range (e.g. more than .01 and less than .05). The slopes are calculated by following formula:

$$SX(i,j) = \big(Z(i,j) - Z(i+1,j)\big)/D \qquad (3)$$

$$SY(i,j) = \big(Z(i,j) - Z(i,j+1)\big)/D \qquad (4)$$

The penstock point is a special case and identified as node (1, 1). So the mathematical modeling is as follows:

Sets:	
i	*set of network nodes in X axis direction i={1, 2, 3, …, m}*
j	*set of network nodes in Y axis direction j={1, 2, 3, …, n}*
Parameters	
H(i , j)	*level of node (i, j) before leveling*
MAX_SX	*Maximum permissible slope in X axis direction*
MIN_SX	*Minimum permissible slope in X axis direction*
MAX_SY	*Maximum permissible slope in Y axis direction*
MIN_SY	*Minimum permissible slope in Y axis direction*
Dim	*Square side length*
MAX_Z	*Maximum permissible penstock point height*
MAX_CUT	*Maximum permissible cut depth*
MAX_RATIO	*Maximum permissible cut to fill ratio*
MIN_RATIO	*Minimum permissible cut to fill ratio*
Decision Variables	
SX(i , j)	*lands slope in X axis direction at node (i,j) after leveling*
SY(i , j)	*lands slope in Y axis direction at node (i,j) after leveling*
Cut(i , j)	*cut depth at node (i,j)*
Fill(i , j)	*fill depth at node (i,j)*
Z(i , j)	*land's level at node (i,j) after leveling*

$$\text{Minimize: } \sum_{i=1}^{m}\sum_{j=1}^{n} CUT(i,j) \quad (5)$$

Subject to:

$$Z(i,j) = H(i,j) + FIL(i,j) - CUT(i,j) \quad \forall i,j \quad (6)$$

$$Z("1","1") \leq MAX_Z \quad (7)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} CUT(i,j) \leq MAX\_RATIO * \sum_{i=1}^{m}\sum_{j=1}^{n} FIL(i,j) \quad (8)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} CUT(i,j) \geq MIN\_RATIO* \sum_{i=1}^{m}\sum_{j=1}^{n} FIL(i,j) \quad (9)$$

$$SX(i,j) = \frac{\left(Z(i,j) - Z(i+1,j)\right)}{D} \quad \forall i - \{m\}, j \quad (10)$$

$$SY(i,j) = \frac{\left(Z(i,j) - Z(i,j+1,j)\right)}{D} \quad \forall i, j - \{n\} \quad (11)$$

$$MIN_{SX} \leq SX(i,j) \leq MAX_{SX} \quad \forall i - \{m\} \quad (12)$$

$$MIN_{SY} \leq SY(i,j) \leq MAX_{SY} \quad \forall j - \{n\}, i \quad (13)$$

$$CUT(i,j) \leq MAX_{CUT} \quad \forall i,j \quad (14)$$

$$CUT(i,j) \geq 0 \quad \forall i,j \quad (15)$$

$$FIL(i,j) \geq 0 \quad \forall i,j \quad (16)$$

4. Illustrative Examples And Comparisons

To illustrate the proposed approach and its advantage and effectiveness, in this section we implement the model for obtaining the optimal solution for two different lands.

The following parameters are used for leveling:

MIN_SX =	.001
MAX_SY=	.050
MIN_SY =	.001
Dim =	10
MAX_Z =	32.6
MAX_CUT =	unlimited
MAX_RATIO =	1.3
MIN_RATIO =	1.1

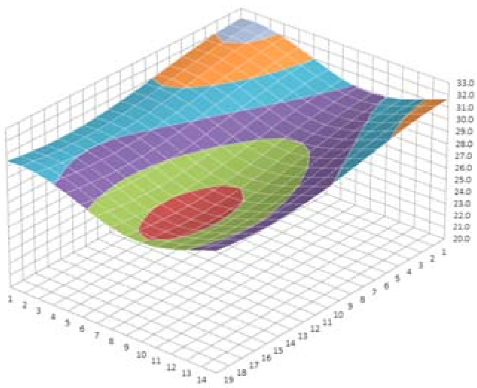

Fig 1. Land1 3D graph before leveling

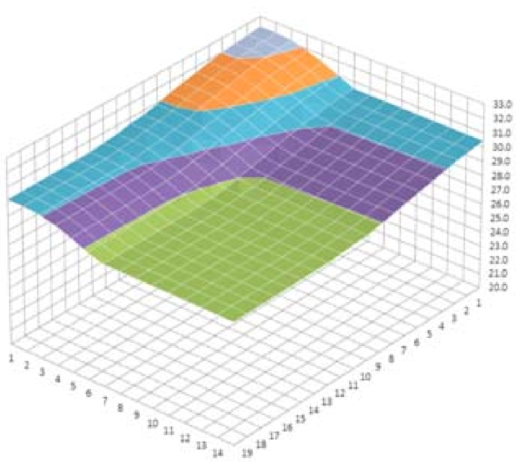

Fig 2. Land1 3D graph after leveling by warped surface

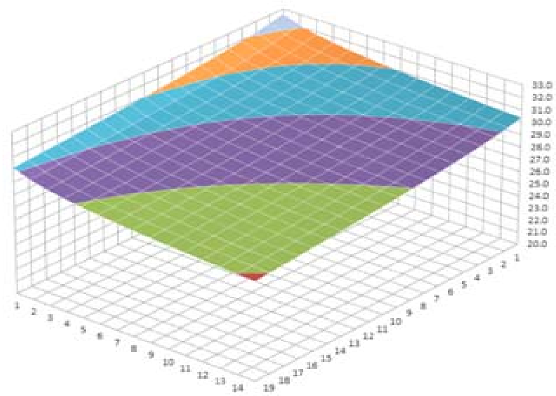

Fig 3. Land1 3D graph after leveling by curved surface

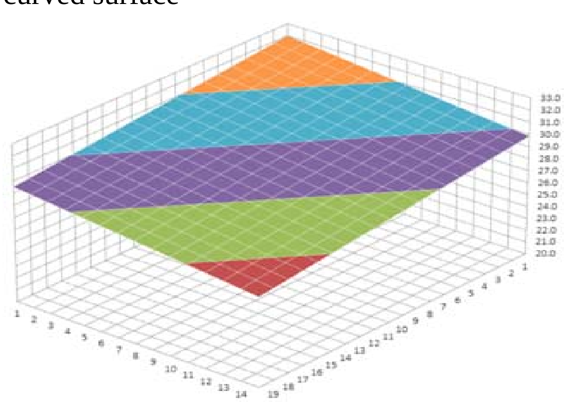

Fig 4. Land1 3D graph after leveling by plane shape

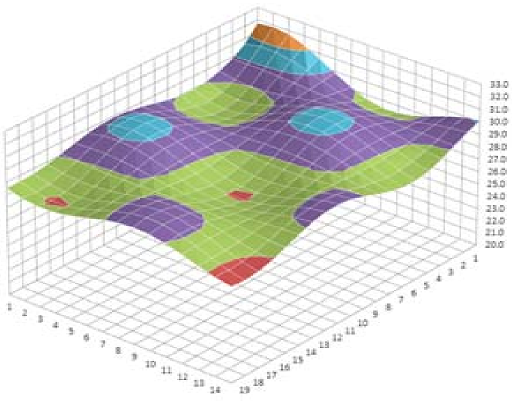

Fig 5. Land2 3D graph before leveling

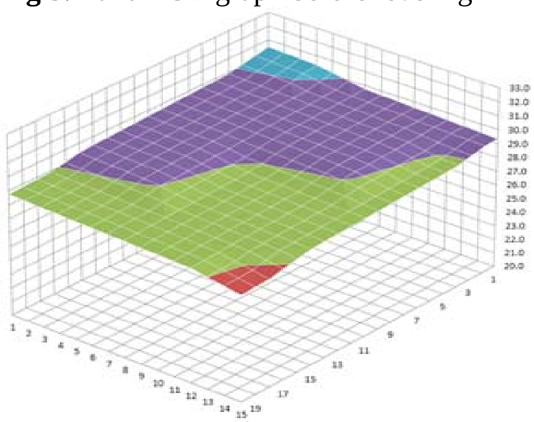

Fig 6. Land2 3D graph after leveling by warped surface

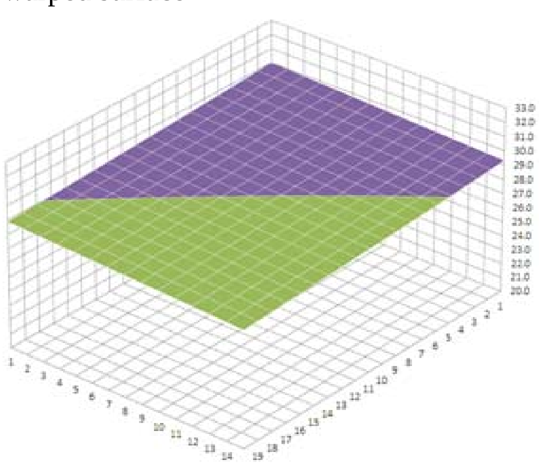

Fig 7. Land2 3D graph after leveling by curved surface

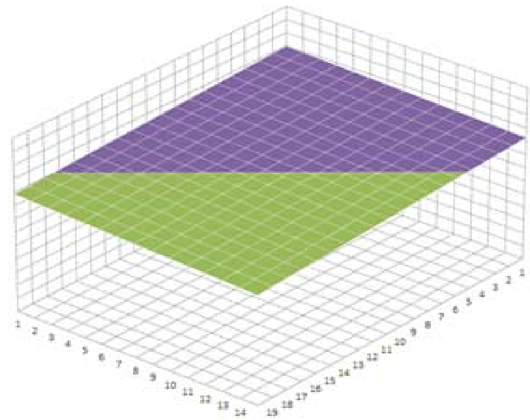

Fig 8. Land2 3D graph after leveling by plane shape.

Table 1 summarizes the results of leveling for two sample lands by curved surface, plane, and warped surface.

TAB 1. The comparison of results

	Total Cut heights (meter)	
Model	Land1	Land2
Warped surface	49.72	67.13
Curved surface	84.91	73.97
Plane shape	96.98	73.98

5. Conclusion

We developed an approach for land leveling by applying linear programming model, while the resulted warped surface requirements are satisfied. This model in special cases can transform to plane shape or curved surface. Thus, its result will never be worse than the results of plane shape or curved surface models and in most cases it will be better. Even if it is necessary to design leveling pattern according to plane shape or curved surface model, this model can obtain the desires result. So this pattern is more comprehensive and more flexible than plane shape and curved surface models. Also, due to the fact that with using linear programming, the optimal solution is detectable, the optimal solution can be obtained in short time with high accuracy by applying effective commercial software.

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