APPROPRIATE DESIGN OF LOESS DOMINANT DUMPING AREA AT OPEN PIT COAL MINE IN CHINA

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APPROPRIATE DESIGN OF LOESS DOMINANT DUMPING AREA AT OPEN PIT COAL MINE IN CHINA

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ABSTRACT

In China, the excavation depth of coal seams becomes higher and higher and the production of open pit coal mine becomes larger and larger with the increasing the national economic. Since 1987, open pit coal mines focused on excavating flat dipping coal seam that situated at the depth of 200 m to 600 m. In 1987, Antaibao open pit coal mine was established in Shuozhou city, Shanxi province as the first large scale open pit coal mine with production more than 10 Mt/y. The increase of excavation depth resulted in new open pit mining areas were formed. In the new open pit mining areas, the loess distributed in 6 major open pit mining areas of total 9 major open pit mining areas. At present, numerous dominant loess dumping areas were formed and will be formed. Meanwhile, the first large scale dominant loess dumping area in China, South external dumping area of Antaibao open pit coal mine occurred failure on October 29th, 1991. On the other hand, systematic studies on stability of dominant loess dumping area were limited. Therefore, research on appropriate design of loess dominant dumping area at open pit coal mine in China is valuable and urgent. In order to achieve research interest, this thesis consists of 6 Chapters as follows.

Chapter 1: This Chapter describes the background of open pit mining including the production and consumption of coal, loess distribution in China, coal resources distribution in China, and loess distribution in open pit mining area. And then, introduces previous research about stability of dominant loess dumping area. After that, presents the objectives of this research and outline of the dissertation.

Chapter 2: To clarify failure mechanism of South external dumping area, a site investigation was carried out at Antaibao open pit coal mine firstly. Meanwhile, the engineering properties of loess, and the characteristics of dominant loess dumping area were summarized. After that, a geological model by Phase^{2D} software was established. The accident and characteristics of sliding mass were described. The dumping area sliding constituted by multi-stages. The safety factor of dumping area decreases dramatically from 1.74 to 1.01 with increasing the piezometric line from 50 m to 5 m below the surface. The structural strength of floor loess would be disapeared as the height of dumping area reaches 78.4 m. From these results, the changes in the mechanical

properties of loess by the elevation of the groundwater level associated with rainfall and a weak loess floor layer may lead to this large slope failure at dumping areas. These two main factors must be considered for the construction of dumping areas in order to develop specific guidelines for the appropriate designs of stable dumping areas in areas where loess is dominant near the surface, along with countermeasures to improve the stability of these dumping areas.

Chapter 3: Based on results of Chapter 2, this Chapter focus on clarification of the effect of water content of loess on stability of dominant loess dumping area. At first, a field investigation was carried out at East open pit coal mine. The site investigation indicated gullies formed in the edge of bench due to erosion, and water accumulation results in cracks formation and subsidence occurrence. And then, series laboratory tests with loess come from East open pit coal mine were carried out at laboratory as different water content. The relationship between water content of loess and density, Young's modulus, internal friction angle, and cohesion of loess were tested. The laboratory results were used in the geological model to analyze the relationship between water content of loess and safety factor, total slope angle of dumping area, and volume capacity of dumping area. It turned out that the safety factor, total slope angle, and volume capacity of dumping area increases with decreasing of the water content of loess. From these results, guidelines for the improvement of stability are suggested, indicating the importance of drainage systems to decrease the groundwater level and water content of loess in order to maintain the stability of the dominant loess dumping area and its dumping capacity.

Chapter 4: After these results of Chapter 3, this Chapter studies improvement of stability of dumping area by compacted layer. A site investigation was carried out firstly. The basic properties of the materials were tested in laboratory to numerical simulation. And then, the laboratory results were used in the geological model of Phase^{2D} software to analyze the the effect of weak floor layer on the stability of dumping area when the thickness and dip of floor are changed, and the effect of a compacted layer built using heavy equipment on the stability of dumping area. The results show that the safety factor of dumping area decreases dramatically with increasing the thickness of weak floor from

0 to 20 m. The volume capacity of the dumping area decreases dramatically with increasing the dip of floor. Improvement of stability of the dumping area was achieved by compaction floor. The safety factor of dumping area is more than 1.62 as the minimum thickness conditions of the compacted layer at the mine. After that, the applications of dominant loess dumping area based on these research were discussed. The installation of drainage holes and the formation of compacted layer on top of weak floor layers are proposed as countermeasures to improve the stability of the dumping area. As a result of numerical analysis, it was concluded that the application of this countermeasure improves the safety factor of a dumping area from 1.38 to 1.51.

Chapter 5: After researched important influential factor on stability of dumping area, formation mechanism of benches on stability of dumping area was researched to design optimum dumping area. At first, a site investigation was carried out at Heidaigou open pit coal mine. The site investigation indicated different dumping operations have different operational and geotechnical issues. Series of laboratory tests with gravel were carried out based on research site conditions to simulate formation of a single bench and of multiple benches. Meanwhile, the relationship between efficiency of dumping operation and interval distance was simulated in laboratory. After that, the relationship between safety factor of the dumping area and dumping height, angle of bench, bulk factor, and truck transport were simulated by $Phase^{2D}$ software. The design of blasting can be modified to make the particle size of waste smaller. Height of bench can be as high as possible, up to the allowed safety values of workers and equipment working. Angle of bench is not important to dumping operation. Bulk factor of waste loess should be as small as possible to improve dumping operation stability. The activity of truck transport in dumping area has a beneficial effect on stability of dumping area. Design of the dumping operation must consider the total efficiency of ground leveling operation work and forming dumping area work.

Chapter 6: Main conclusions abstracted from discussion are briefly summarized.

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TABLE OF CONTENTS

ABSTRACT ... **III**
ACKNOWLEDGEMENTS ... **VI**
TABLE OF CONTENTS ... **VII**
LIST OF FIGURES ... **X**
LIST OF TABLES ... **XV**
SYMBOLIC REPRESENTATION ... **XVI**
CHAPTER 1 ... **1**
INTRODUCTION ... **1**
1.1 Background ... 1
1.2 Literature review ... 5
1.2.1 Water effect on stability of dumping area ... 5
1.2.2 Dumping operation effect on stability of dumping area ... 6
1.2.3 Floor effect on stability of dumping area ... 7
1.3 Objective ... 8
1.4 Dissertation outline ... 9
References ... 9
CHAPTER 2 ... **14**
FAILURE MECHANISM OF DOMINANT LOESS DUMPING AREAS ... **14**
2.1 Site investigation at Antaibao open pit coal mine ... 15
2.1.1 Geological overview ... 15
2.1.2 Climate ... 16
2.1.3 Hydrological condition ... 17
2.1.4 Floor condition ... 17
2.2 Mechanical properties of loess and characteristics of dominant loess dumping area ... 18
2.2.1 Engineering properties of loess ... 18
2.2.2 Characteristics of dominant loess dumping area ... 23
2.3 Accident analyses by Phase^{2D} software ... 24
2.3.1 Numerical analysis model ... 24
2.3.2 Describe accident ... 26
2.3.3 Characteristics of sliding ... 28
2.3.4 Cause of sliding ... 29
2.4 Sliding process of dominant loess dumping area ... 32
2.4.1 Compression stage ... 32

2.4.2 Rise of groundwater level 33

2.4.3 Formation of sliding surface 34

2.4.4 Floor deformation 35

2.4.5 Occurance of sliding 35

2.5 Summary 36

References 37

CHAPTER 3 41

STABILITY EFFECT OF WATER CONTENT OF LOESS ON DOMINANT LOESS DUMPING AREAS 41

3.1 Field investigation at East open pit coal mine 41

3.1.1 Geological overview 42

3.1.2 Hydrological condition 43

3.1.3 Water content of waste loess 44

3.1.4 Floor condition of external dumping areas 44

3.1.5 Stable problem statements 45

3.2 Laboratory tests with loess 46

3.2.1 Process of laboratory tests 46

3.2.2 Results and discussions 49

3.3 Numerical simulation for East open pit coal mine 53

3.3.1 Build a geological model based on East open pit coal mine 54

3.3.2 Results and discussions 55

3.4 Summary 58

References 59

CHAPTER 4 61

IMPROVEMENT OF STABILITY OF DUMPING AREA BY COMPACTION OF FLOOR 61

4.1 Effect of the thickness of weak floor on the stability of dumping area 61

4.2 Dip of weak floor on the stability of dumping area 68

4.3 Thickness of the compacted layer on the stability of dumping area 72

4.4 Applications of drainage system and compacted layer on dominant loess dumping area 78

4.5 Summary 83

References 86

CHAPTER 5 88

FORMATION MECHANISM OF BENCHES ON STABILITY OF DUMPING AREA 88

5.1 Field investigations at Heidaigou open pit coal mine 88

5.1.1 Overview of geology at Heidaigou open pit coal mine........ 89
5.1.2 Dumping operation at Heidaigou open pit coal mine........ 90
5.1.3 Waste particle size distributions........ 94
5.1.4 Stable problems statement at Heidaigou open pit coal mine........ 95
5.1.5 Setting of tests........ 96
5.2 Experiment methods and results........ 99
5.2.1 Single bench........ 99
5.2.2 Multiple benches........ 103
5.2.3 Efficiency of dumping operation design........ 107
5.3 Simulation for the effect of dumping operation on stability of dumping area........ 109
5.4 Summary........ 113
References........ 115
CHAPTER 6........ **117**
CONCLUSIONS........ **117**

LIST OF FIGURES

Figure	Title	Page
1.1	Overview of South external dumping area failure from the coal bunker point	1
1.2	Production and consumption of raw coal from 1952 to 2012 in China	2
1.3	Loess distribution in China	3
1.4	Coal resources distribution in China	4
1.5	Cohesion and frictional angle of loess in consolidated quick shear test	6
2.1	Slide of the dumping area and the trucks were trapped in the sliding mass	14
2.2	Location of Antaibao open pit coal mine from google map	15
2.3	Plan view of Antaibao open pit coal mine	16
2.4	Content of soluble salt in loess collapsible under overburden pressure and loess noncollapsible under overburden pressure	18
2.5	Relationship between void ratio and pressure of collapsible loess in water	20
2.6	Geological model of external dumping area at Antaibao open pit coal mine	26
2.7	Safety factor and maximum shear strain of dumping area	26
2.8	Plan of dumping area sliding and monitoring engineering	27
2.9	Geological model and slope failure modes of section 2	28
2.10	Relationship between safety factor of dumping area and piezometric line	30
2.11	Relationship between total height of dumping area and safety factor, and cross sectional area of dumping area	31
2.12	Schemat of groundwater level rose due to water freeze	33
2.13	Schemat of water rose due to rainwater seeps	34
2.14	Schemat of groundwater level rise due to suction of waste loess on water	34
2.15	Schemat of sliding surface before sliding	35
2.16	Schemat of floor deformation	35
2.17	Schemat of of sliding step by step	36
3.1	Location of East open pit coal mine from google map	42
3.2	Overview of East open pit coal mine	43
3.3	A gully in bench at East open pit coal mine	45

3.4 Water accumulates in dumping area and in the top of bench 46
3.5 Overview of the shear apparatus 47
3.6 Overview of loess sample and the oven 47
3.7 Sample for test 48
3.8 Compactor, sample, and soil cut knife 48
3.9 Density of waste loess under the conditions of different water contents 49
3.10 Unit transport cost of waste loess under different water contents 50
3.11 Maximum total height of dumping area under different water contents of waste loess 51
3.12 Water spray in the road of the dumping area 52
3.13 Geological model of external dumping area at East open pit coal mine 55
3.14 Safety factor and maximum shear strain of geological model 55
3.15 Safety factor of dumping area under different water contents of loess 56
3.16 Total slope angle of the dumping area under different water contents of loess 56
3.17 Volume capacity of the dumping area under different water contents of loess 57
4.1 Geological model of external dumping area 63
4.2 Safety factor and the maximum shear strain of geological model under the thickness of weak floor is 20 m, the dip of floor is 0 degree 63
4.3 Absolute vertical displacement of geological model 64
4.4 Maximum shear strains when the thickness of weak floor is 0 m 64
4.5 Maximum shear strains when the thickness of weak floor is 5 m 65
4.6 Maximum shear strains when the thickness of weak floor is 10 m 65
4.7 Maximum shear strains when the thickness of weak floor is 15 m 65
4.8 Maximum shear strains when the thickness of weak floor is 25 m 66
4.9 Maximum shear strains when the thickness of weak floor is 30 m 66
4.10 Maximum shear strains when the thickness of weak floor is 35 m 66
4.11 Maximum shear strains when the thickness of weak floor is 40 m 67
4.12 Maximum shear strains when the thickness of weak floor is 45 m 67
4.13 Maximum shear strains when the thickness of weak floor is 50 m 67
4.14 Safety factor of dumping area under the different thickness of weak floor 68
4.15 Geological model when the dip of floor is 3 degrees 69

4.16 Maximum shear strains when the dip of floor is 1 degree 69
4.17 Maximum shear strains when the dip of floor is 2 degrees 70
4.18 Maximum shear strains when the dip of floor is 3 degrees 70
4.19 Maximum shear strains when the dip of floor is 4 degrees 70
4.20 Maximum shear strains when the dip of floor is 5 degrees 71
4.21 Maximum shear strains when the dip of floor is 6 degrees 71
4.22 Relationship between dip of floor and safety factor, and volume capacity of the dumping area 72
4.23 Relationship between coefficient of permeability and pressure under the optimum moisture content 73
4.24 Relationship between coefficient of permeability and pressure under the plastic limit 74
4.25 Relationship between coefficient of permeability and pressure under the nature water content 74
4.26 Geological model when the thickness of the compacted layer and weak floor are 3 m and 15 m, respectively 75
4.27 Maximum shear strains when the thickness of the compacted layer and weak floor are 1.5 m and 15 m, respectively 76
4.28 Maximum shear strains when the thickness of the compacted layer and weak floor are 3.0 m and 15 m, respectively 76
4.29 Maximum shear strains when the thickness of the compacted layer and weak floor are 4.5 m and 15 m, respectively 77
4.30 Maximum shear strains when the thickness of the compacted layer and weak floor are 6.0 m and 15 m, respectively 77
4.31 Safety factor of dumping area under the different thickness of compacted layer 78
4.32 Geological model when the thickness of the compacted layer is 6 m and the piezometric line is 8 m 79
4.33 Safety factor of dumping area under the different thickness of compacted layer and thicknesses under different piezometric line 80
4.34 Geological model when the water content of waste loess is 20% and the thickness of compacted layer is 6 m 80

4.35 Safety factor of dumping area under the different thickness of compacted layer and the different water content of waste loess 81
4.36 Proposed for drainage system 82
4.37 Dewatering well in the floor close to toe of dumping area and a compacted layer is formed in the floor 82
5.1 Location of the Heidaigou open pit coal mine from Google map 88
5.2 Overview of the Heidaigou open pit coal mine 89
5.3 Bucket wheel excavator-belt-stacker dumping operation 90
5.4 Dumping area of bucket wheel excavator-belt-stacker dumping operation 91
5.5 Shovel-truck-bulldozer dumping operation 92
5.6 Dumping area of shovel-truck-bulldozer dumping operation 92
5.7 Dragline dumping operation 93
5.8 Dumping area of shovel-truck-bulldozer dumping operation 93
5.9 Yinwan external dumping area next to a reservoir 95
5.10 High working slope bench in dragline operation 96
5.11 Small sliding after rained in dominant loess dumping area in 2011 96
5.12 Overview of the experimental device 97
5.13 Process to measure the height and the repose angle 98
5.14 Process to measure the length and width 99
5.15 Relationship between pile height and drop height 100
5.16 Relationship between slope angle and drop height 100
5.17 Relationship between pile height/slope angle and drop volume 101
5.18 Diagram of length, height and repose of angle of bench 102
5.19 Diagram of dumping order and interval distance 104
5.20 Diagram of elevation difference and pile height measurements 104
5.21 Relationship between the increase of pile height and the pile number 105
5.22 Relationship between the increase height of the fifth pile and drop interval 106
5.23 Ratio of increase height – ratio of interval of drop point to volume 107
5.24 Process of ground leveling operation work 107
5.25 Relationship between the elevation difference and interval distance (200cm^3) 108
5.26 Geological model under the height of bench is 30 m 110

5.27 Relationship between bench height and safety factor of dumping area 110
5.28 Geological model under the angle of bench is 40 degrees 111
5.29 Relationship between angle of bench and safety factor of dumping area, volume capacity of the dumping area 111
5.30 Relationship between bulk factor of waste loess and volume capacity increase, safety factor of dumping area 112
5.31 Geological model as the truck load force is 0.2 MN/m 113
5.32 Relationship of truck load and safety factor of dumping area 113

LIST OF TABLES

Table	Title	Page
1.1	Characteristics and exploitation situation of open pit mining area in China	4
2.1	Soil separates by diameter limits	19
2.2	Properties of red clay in Guiyang city, China	19
2.3	Parameters of South external dumping area	24
2.4	Physical and mechanical properties of coal and rocks of external dumping Area	25
3.1	Water contents of waste loess sample in dumping areas at East open pit coal mine	44
3.2	Relationship of water contents of loess and Young's modulus, cohesion, and internal friction angle	51
3.3	Parameters of external dumping area	54
3.4	Physical and mechanical properties of coal and rock of external dumping area	54
4.1	Parameters of external dumping area	62
4.2	Basic properties of materials	62
4.3	Test results of optimum moisture content, plastic limit, and natural water content	73
5.1	Main parameters for bucket wheel excavator-belt-stacker dumping operation	91
5.2	Parameters for shovel-truck-bulldozer dumping operation	92
5.3	Main parameters for dragline dumping operation	94
5.4	Analysis results of waste particle size distribution for the shovel-truck-bulldozer and dragline dumping areas	94
5.5	Relationship between dips of floor and bench shape	103
5.6	Relationship between the amount of grading work and pile numbers	108

SYMBOLIC REPRESENTATION

δ_s – Coefficient of collapsible.

δ_{si} – The coefficient of collapsible of number i loess seam.

δ_{sz} – Coefficient of collapsible under overburden pressure of loess.

δ_{zsi} – The coefficient of collapsible under overburden pressure of number i loess seam.

β – Correction coefficient based on lateral extrusion. β is 1.5 as the loess is from surface to 5 m depth below the surface. β is 1 as the loess is from deeper at underground 5 m.

β_o – Correction coefficient based on different area. β_o is 1.5 as the loess in the west of Gansu pronvince. β_o is 1.2 as the loess in the east of Gansu pronvince or in north of Shananxi pronvince. β_o is 0.7 as the loess in the Guanzhong. β_o is 0.5 as the loess in the other area.

E_r – Evaporation rate, m/hour.

h_i – Height of number i loess seam, m.

h_p – Height of sample under constant pressure as nature water content and initial structure, m.

h'_p – Height of sample under constant pressure in the water as nature water content and initial structure, m.

h_o – Height of sample as nature water content and initial structure, m.

h_z – Height of sample under saturation overburden pressure as nature water content and initial structure, m.

h'_z – Height of sample under saturation overburden pressure in the water as nature water content and initial structure, m.

Δ_h – Amount of subsidence in a period time, m.

H – Height of bench, m.

ΔH – Increment of fifth pile height, m.

H_o – Height of the first pile, m.

H_m – Maximum total height of dumping area, m.

H_t – Maximum total height of dumping area by depth below the surface, m.

I – Drop interval, m.

L – Length of road, m.

Δ_s – Total collapsible deformation of loess noncollapsible under overburden pressure, m.

Δ_{zs} – Total collapsible deformation of loess noncollapsible under overburden pressure, m.

P_t – Ultimate bearing capacity, Pa.

P_m – Ultimate bearing capacity, Pa.

ρ - Gravity

γ – Density of waste loess, kg/m^3.

ψ_1 – Coefficient of loose at the begin.

ψ_2 – Coefficient of loose at the end.

V – Volume, m^3.

W_a – Water spray rate, m^3/hour.

W_r – Width of road, m.

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CHAPTER 1

INTRODUCTION

1.1 Background

The first large scale dominant loess dumping area in China, South external dumping area of Antaibao open pit coal mine, occurred failure on October 29th, 1991. **Figure 1.1** shows the overview of South external dumping area failure from the coal bunker point. The process lasted approximately 10 minutes. The volume of sliding mass was approximately 11 Mm^3 (Zhu, 1994; Duan et al., 1999). The accident caused 6 persons' death and a huge property loss to Antaibao open pit coal mine. Antaibao coal mine is the first large scale open pit coal mine in China. The coal production is more than 10 Mt/y. This mine is located in Shuozhou city, Shanxi province.

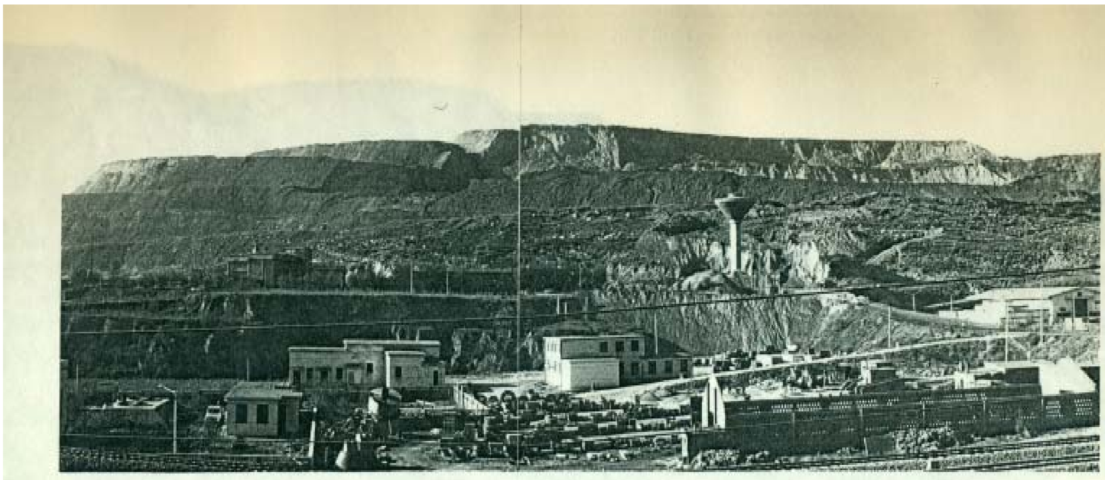
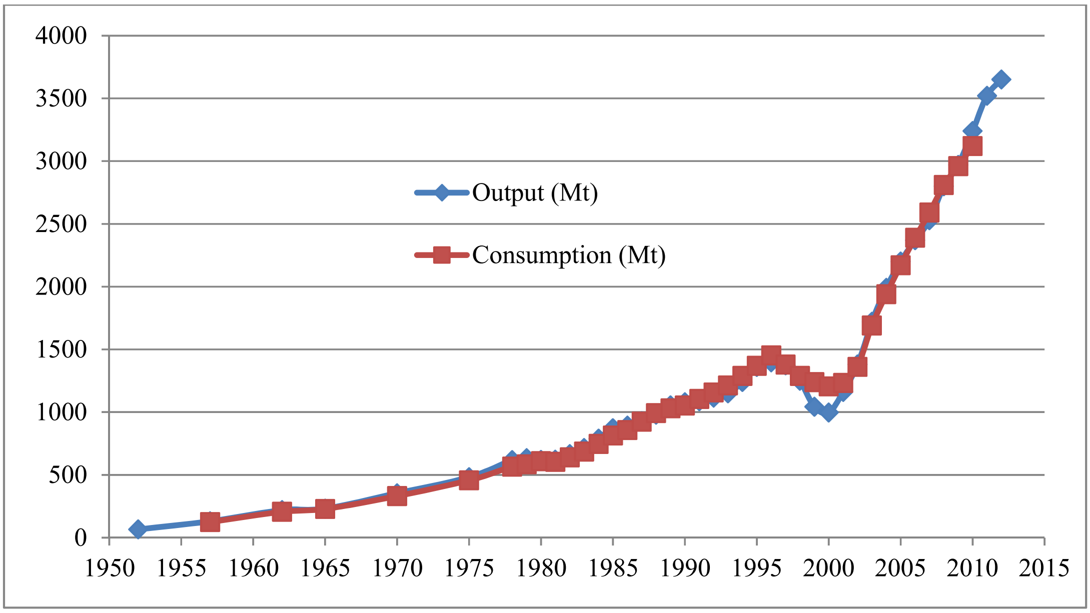


Figure 1.1 Overview of South external dumping area failure from the coal bunker point

The excavation depth of coal seams at China increases with increasing national coal demand. Before 1987, when Chinese coal has not been massively exploited yet, the open pit coal mines only focused on excavating the inclined coal seam at shallow depth. However, after 1987 the shallow coal deposit had almost been diminished, therefore the mining activity continued to the deeper deposits with mining depth were vary from 200 m to 600 m. In 1986, the first internal dumping area of open pit mine in China was established at Yimabei open pit coal mine.

Regarding to the coal industry in China, shovel and truck operation is major operation system at open pit coal mine. The overall level of mechanization of coal mine is 42% at the end of 2007 (Kong, 2011). China is the largest user of coal-derived electricity. It is about 68.7%, equals to 1.95 trillion kilowatt-hours per year, of electricity is generated by coal. Recently, the demand of coal for energy generation increases with growing the national economy and industry. In order to fulfill the demand of coal, the Chinese government has issued a policy to import the coal and prohibit coal export. The environmental impacts may increase with increasing coal production. In order to minimize the environmental impact, the Chinese government has pushed the mining company to optimize the mining process by paying their attention for safety, recovery ratio and environment. China is one of the biggest coal users in the world. Its coal is supplied from national coal production as well as from the other coal production countries. It is noted that China accounts for about 13% of the world's proven reserve and the biggest coal producer and importer in the world. **Figure 1.2** shows the production and consumption of raw coal from 1952 to 2012 in China (National Bureau of Statistics of China, 1997; National Bureau of Statistics of China, 2002; National Bureau of Statistics of China, 2005; National Bureau of Statistics of China, 2013).



Note: In original source, the unit is 10,000 tons standard coal equivalent (SCE). In this figure, the unit is million tons raw coal. One ton raw coal is equal to 0.7143 ton standard coal equivalent.

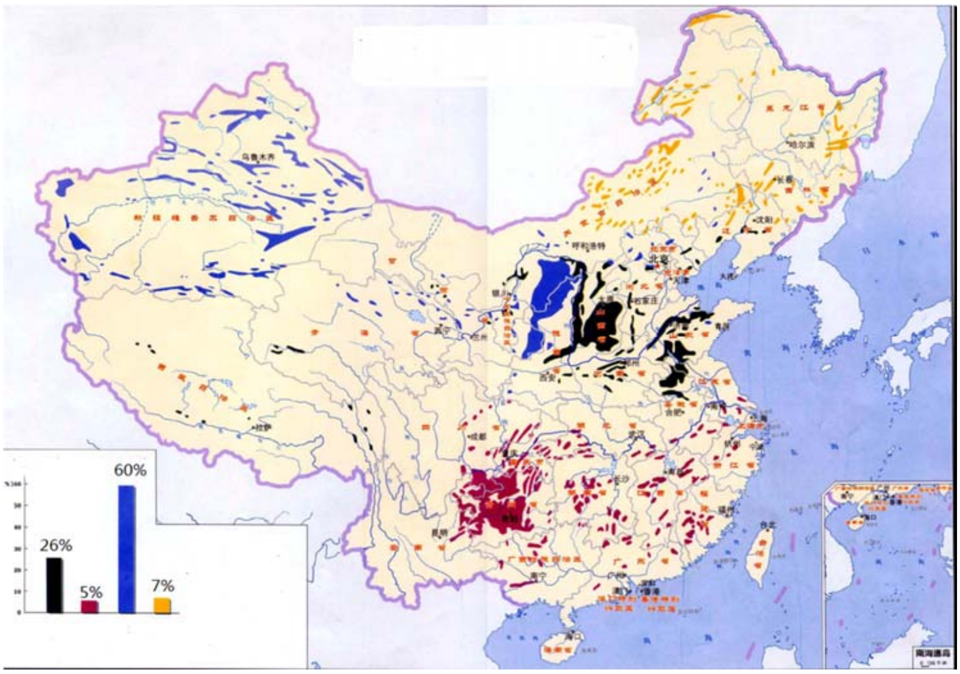
Figure 1.2 Production and consumption of raw coal from 1952 to 2012 in China

Figure 1.2 shows the production and consumption of raw coal have increased dramatically since 2002. Numerous large scale open pit coal mines had been developed that has production more than 10 Mt/y since 1987 as Antaibao open pit coal mine was established. After that the production and consumption of raw coal on 2002 started to escalate dramatically. In accordance to the increase of coal production, the higher open pit and larger dumping areas were also formed. Thus, the research on the stabilities of open pit slope and dumping area had become important.

China is known as one of the countries that has large coal resources. The total area of loess distribution in China was 0.63 Mkm^2, accounts for about 6.6% of land area of China (Wang et al., 1990). The Chinese loess is mostly concentrated in Loess Plateau. In the Loess Plateau, northeastern part of China, Xinjiang Uygur Autonomous Region is covered by loess seam. Meanwhile in other areas, it distributes sporadically. The loess distribution in China is shown in **Figure 1.3** (Smalley, 1975). Meanwhile, the coal resources distribution in China is given in **Figure 1.4**.

Figure 1.3 Loess distribution in China

Figures 1.3 and **1.4** show loess distribution and coal resources distribution have a great conformity degree. **Table 1.1** shows the characteristics and exploitation situation of major open pit mining area in China. It shows that loess seam are distributed in 6 major open pit mining areas of total 9 major open pit mining areas. Numerous dominant loess dumping areas have been formed and will be done more in the near future.



Source: China National Administration of Coal Geology, 2000.

Figure 1.4 Coal resources distribution in China

Table 1.1 Characteristics and exploitation situation of open pit mining area in China

Representative Mines	Design capability (Mt/Y)	Loess distribution	Put into production	Open pits	Rock stripping operation	Coal dip angle (°)
Antaibao	22	Yes	1987	3	Shovel-truck	3
Huolinhe	8	No	1992	2	Shovel-truck-belt-stacker	7
Yiminhe	5	Yes	1998	3	Shovel-truck	5
Yuanbaoshan	10	Yes	1989	2	Bucket wheel excavator Shovel-truck-belt-stacker	8
Shengli-1	20	Yes	2007	5	Shovel-truck	4
Xiaolongtan	5	No	1995	2	Shovel-truck	8
Hongshaquanbei	3	No	2010	≥7	Shovel-truck-belt-stacker	3-6
Baiyinhua-1	15	Yes	2005	4	Shovel-truck-belt-stacker	5
Hedaigou	23	Yes	1999	2	Bucket wheel excavator Dragline & Truck-shovel	6

Unfortunately, systematic studies on stability of dumping area were limited especially in China. The code for design of open pit coal mine of coal industry in China mentioned only about how to select dumping area, how to set up the parameters of dumping operation, and for stability of dumping area (China National Coal Construction Association, 2005). In open pit mining handbook, the contents about stability of dumping area are few and special attention is not paid to loess (Peng, 1996). However, open pit coal mines do not pay enough attention to stability of dumping area. For example, in Heidaigou open pit coal mine, the department of geomechanics was set up in 2010. In Haerwusu, Antaibao, Anjialing, and East open pit coal mines, they do not have any geotechnician or geology technicians. Therefore, the research on the appropriate design of loess dominant dumping area at open pit coal mine in China is valuable and urgent.

1.2 Literature review

1.2.1 Water effect on stability of dumping area

The water has a detrimental effect on stability of dumping area (Dunc an & Christopher, 2004). Increasing water pressure reduces the stability of the slopes by diminishing the shear strength of potential failure surfaces. Changes in water content of soil, particularly loess, decrease soil strength and then dumping area may colapse. Freezing of ground water can cause wedging in water-filled fissures due to temperature-dependent volume changes in the ice. Erosion of soil by surface water flow and low strength infillings by ground water can result in local instability where the toe of a slope is undermined, or a block of rock is loosened. The effect of water content due to the water pressure on the stability of dumping area has to be made clear.

In China, serial tests about the effect of water contents on the properties of loess were performed by using the oedometer (Feng & Zheng, 1982; Qian et al., 1985) and triaxial tests (Tan, 1988). Morever in these studies, the conditions were limited to water contents exceed 5% and no information was provided on the scatter of the data. **Figure 1.5** shows the cohesion and frictional angle of loess in consolidated quick shear test (Liu, 1997). It can be seen that the Cohesion of Lishi loess is the biggest compared with that of the loess of Holocence and Malan loess and the Malan loess is the lowest. The internal frictional angle of Malan loess is the biggest compared with the loess of Holocence and Lishi loess and loess of Holocene is the lowest.

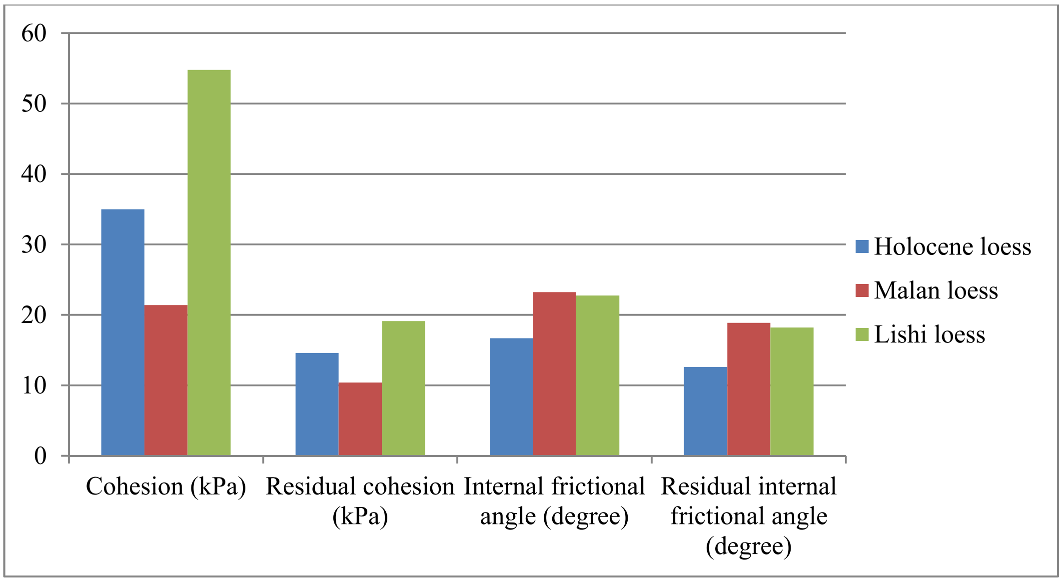


Figure 1.5 Cohesion and frictional angle of loess in consolidated quick shear test

1.2.2 Dumping operation effect on stability of dumping area

Dumping work is one of the important components of open pit mining operation (Kennedy, 1990; Wang et al., 2011; Golder, 1976; Blight, 2008). Overburden is stripped, excavated and transported to dumping areas in order to expose and extract coal seams. Waste embankments typically have little if any practical use and may represent a long-term liability as a potential pollution source or stability hazard (Huang & Li, 2007; Luo, 1995; Byrnes and Färe, 1988). Several factors from dumping operation have important effect to dumping area stability. It consists of equipment, height of bench, width of safety bench, and total height of dumping area (Li & Dai, 2013). Meanwhile, material distribution, particle size distribution and compaction of bench depend on mining and dumping operation.

There was a maximum height of bench in regard to avoiding the subsidence. This subsidence may cause the truck trapped, because of different level of the ground. According Wu (2010) and Wang (2011), the optimum of height of bench was depending on equipment and waste materials. For example, the maximum height of bench is 20 m for slate waste material and the truck that suitable for this condition is MT3700B (Wu, 2010). Safety bench is important to keep the safety of workers and equipment. The minimum widths of safety bench depend on waste materials and height of bench. Moreover, the safety bench promotes the stability of dumping area. In this term, width of safety bench depends on the stability of dumping area. For example, the minimum width of safety bench is 5 m for 5 m height of bench in dominant loess dumping area. Total height of dumping area depends on bearing capacity of floor, area of floor and stability of dumping area.

The particle size distribution was investigated and the properties of waste rocks under the conditions of different particle sizes were measured. It turned out that the small particle was concentrated in upper part and the big particle was accumulated in bottom part. The cohesive strength and internal friction angle increase with increasing the particle size, coefficient of non-uniformity of grading and density. The subsidence of the bench and the effect of distribution of particle size on stability of dumping area were simulated with Flac^{3D} software (Wang et al., 2011). According to Wang et al (2007), the void ratio and coefficient of permeability can be decreased and density cohesive strength and internal friction angle can be increased by compaction.

1.2.3 Floor effect on stability of dumping area

The floor of dumping area is an important influential factor to the stability of dumping area. The total height of dumping area depends on the ultimate bearing capacity of floor. The floor of dumping area has a maximum compression deformation or maximum shear strength as standards request. The bearing capacity of floor depends on the soil seam because the thickness of topsoil is high. The bearing capacity of floor depends on soil seam and base rock as the thickness of topsoil is very thin. The ultimate bearing capacity of floor should be calculated by the properties and thickness of floor layer (Zhou, 2002). Meanwhile, the bearing capacity of floor at Antaibao open pit coal mine was calculated in various water contents. The deformation process of water-saturated loess floor was simulated with laboratory tests and Flac3D software (Wang, 2014). The results show that the water content of floor has an obvious impact on the stability of dumping area. Moreover, the dip of floor also has an important effect on volume capacity and stability of dumping area. The failure mechanism of inclined floor dumping area was analyzed by Su et al (1997) and Wang et al (2009).

1.3 Objective

This thesis focuses on the appropriate design of loess dominant dumping area at open pit coal mine in China. Numerous dominant loess dumping areas were formed continuously. Numerous researchers have been engaged in the study on appropriate design of loess dominant dumping areas at open pit coal mines in China. However, these studies are not enough and further studies still needed.

The failure mechanism of dominant loess dumping area needs to be clarified further. Characteristics of sliding mass, factors that cause sliding and sliding process should be discussed.

The stability effect of water content on the stability of dominant loess dumping area needs to be researched further. The relationship between water content and properties of loess needs to be more detail investigated. As the mechanical properties of loess are very sensitive to water, the relationship between water content and mechanical properties of loess has to be made clear. Afterthat, the effect of water contents on the stability of dominant loess dumping area is discussed.

The loess has very weak and soft physical characteristic, thus the floor that is made by loess likely to decrease the stability of dumping area. Hence, the effect of the weak floor on the dumping area is discussed. To improve the stability, the construction of compacted layer for loess floor was proposed and then compacted layer effect on the stability of dumping area was discussed.

Formation mechanism of benches on stability of dumping area should be researched. The formation process of bench, efficiency of dumping operation, dimension of dumping area and truck transport on stability of dumping area should be clarified.

1.4 Dissertation outline

This thesis consists of six Chapters as follows.

Chapter 1 introduces the research background of open pit coal mines in China and previous studies of dominant loess dumping area. Moreover, the objective and outline of dissertation are proposed.

Chapter 2 discusses the failure mechanism of dominant loess dumping area in order to make clear the causing factors of the failure. It consists of site investigation at Antaibao open pit coal mine, engineering properties of loess and characteristics of dominant loess dumping area, numerical simulation by Phase^{2D} software, sliding process of dumping area based on the series of site investigation and numerical analysis.

Chapter 3 studies the effect of water content on the stability of loess dumping area. It consists of field investigations at East open pit coal mine, laboratory tests on loess under the conditions of different water content. Numerical simulation for East open pit coal mine by Phase^{2D} software is conducted in order to optimize design for dominant loess dumping area.

Chapter 4 discusses the improvment of stability of dumping area by compaction of floor. It consists of the effect of weak floor layer on the stability of dumping area when the thickness and dip of floor are changed, and the effect of a compacted layer built using heavy equipment on the stability of dumping area.

Chapter 5 discusses the formation mechanism of benches on dumping area. It consists of a field investigation at Heigaigou open pit coal mine, experiment methods and results, and simulation for the effect of dumping operation on stability of dumping area.

Chapter 6 concludes the results of this research.

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CHAPTER 2

FAILURE MECHANISM OF DOMINANT LOESS DUMPING AREAS

The first large scale dominant loess dumping area in China, South external dumping area of Antaibao open pit coal mine occurred failure on October 29th, 1991. The dumping area sliding caused big damage to Antaibao open pit coal mine. The loss consists of 6 persons'death, 14 devices, car wash area, guard room of mine, 2 houses of citizen, 0.73 km highway, 0.44 km drainage channel, highway in the industrial area (Duan et al., 1999; Zhu, 1994). **Figure 2.1** shows the slide of the dumping area and the trucks were trapped in the sliding mass.

Figure 2.1 Slide of the dumping area and the trucks were trapped in the sliding mass

In order to investigate the failure mechanism of dominant loess dumping area, an site investigation at Antaibao open pit coal mine was carried out firstly, and then, the mechanical properties of loess and the charateristics of dominant loess dumping area were described. After that, the numerical simulation was conducted by means of Phase^{2D} software in order to clarify the mechanism of this slide an its major factors. Finally, the sliding process of dominant loess dumping area was summarized.

2.1 Site investigation at Antaibao open pit coal mine

2.1.1 Geological overview

Field investigations were conducted at the dumping areas (Siegel et al., 1990; Xie & Pang, 2003; Costa&Schuster, 1988; Machado&Fard, 2010). Antaibao open pit coal mine is located in Shouzhou City, Shanxi province. **Figure 2.2** shows the location of Antaobao open pit coal mine. The open pit mine put into production in 1987. The designed production of raw coal is 22 Mt/Y. Shovel – truck – bulldozer dumping operation is adopted. The average stripping ratio is 5.6 m^3/t.

Figure 2.2 Location of Antaibao open pit coal mine from google map

Figure 2.3 shows the plan view of Antaibao open pit coal mine. It shows that the South external dumping area is located close to the industrial area and situated on the above Anjialing-1 underground coal mine. The dimension of South dumping area is about 1 km width from south to north and 1.5 km length from east to west.

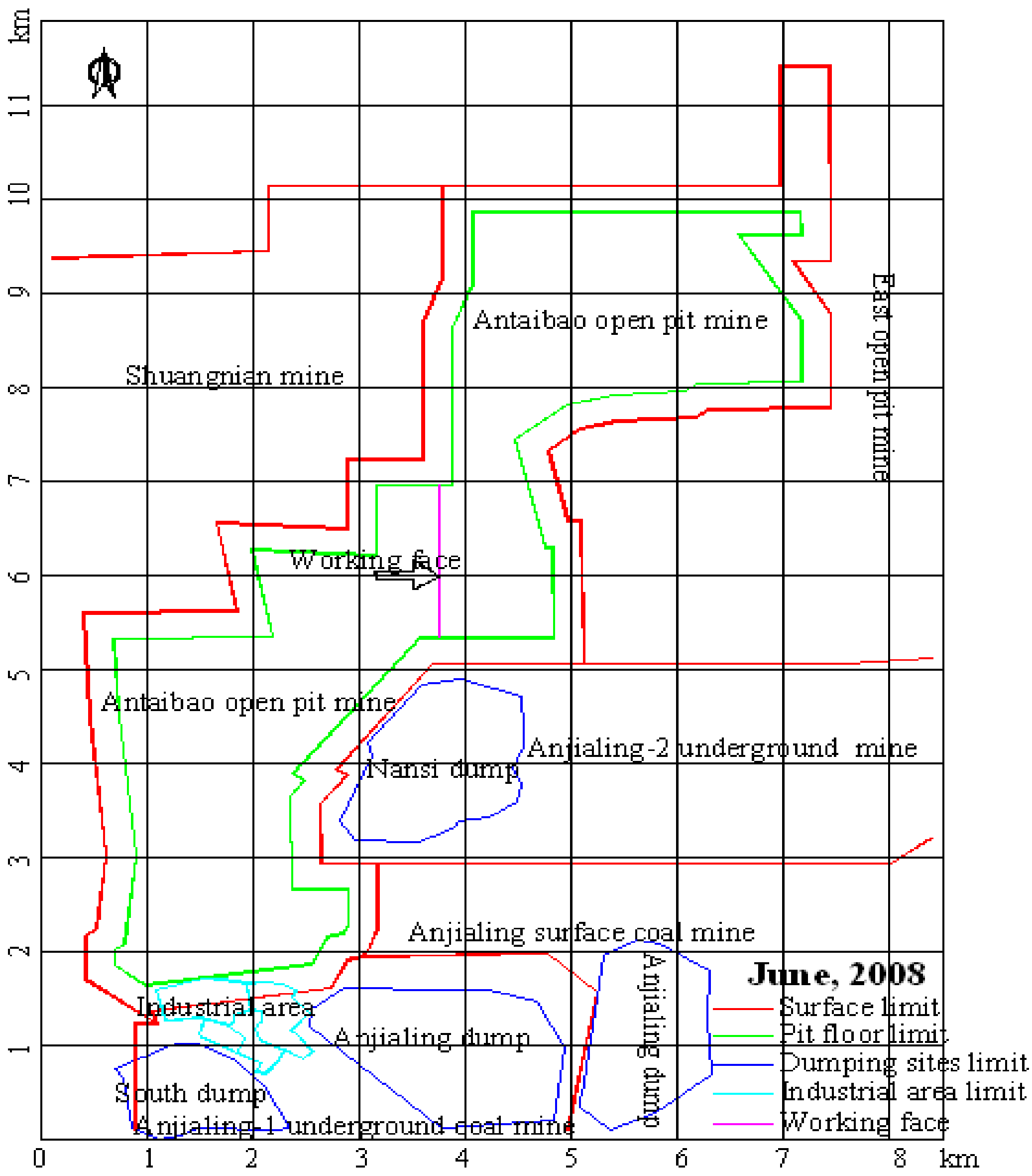


Figure 2.3 Plan view of Antaibao open pit coal mine

2.1.2 Climate

The annual temperature of Antaibao open pit coal mine is from 5.4 to 13.8 ^{O}C with the highest temperature of 37.9 ^{O}C and the lowest temperature of -32.4 ^{O}C. The winter usually starts on the second week of September and be over on the first week of June. The frost period starts from the second week of October to the second week in April. The thickness of ice on the surface is usually up to 1 m.

2.1.3 Hydrological condition

The annual rainfall is from 428.2 to 489.16 mm. Whereas, the annual evaporation is from 1,735.6 to 2,598.0 mm. Rainfall season starts from July to September. Generally, it is a rainstorm. The maximum rainfall intensity is about 87 mm/d, and the groundwater level is 20 m depth below the surface. The highest value of groundwater level is appeared from October 15^{th} to November 1^{th}, and it is noted a dangerous period for the stability of dumping area.

There is the Qili river in the mining area. Mostly rainfall water flows into the Qili river. Outflow method of groundwater is mainly natural evaporation. Intake method of groundwater is rainfall and water carrier. At the toe of dumping area, there is water outflow. It is supposed that rainfall has an important effect on stability of dumping area at Antaibao open pit coal mine.

The aquifer of floor from bottom to top include 2 seams. The first seam is zone of weathering bedrock, which is weak aquifer, unconfined aquifer or micro-confined aquifer. The second seam is loess, which is strong aquifer. The watertight is clay layer, which is a good watertight and wide distribution.

2.1.4 Floor condition

The dip of floor is from 5 to 7 degrees. The strata of Antaibao coal mine from top to bottom is as follows:

The first stratum is diluvium. It consists of loess, sand, and gravel. The thickness of diluvium is 0 to 40 m with the average thickness of 10 m. This stratum is uncomformable contact with underlying stratum.

The second stratum is loess. The thickness is from 3 to 47 m with the average thickness of 24 m. This stratum is regional unconformity contact with underlying stratum.

The third stratum is clay. The thickness is from 0 to 77 m with the average thickness of 15 m. This stratum is unconformable contact with underlying stratum.

The fourth stratum is weathered bed stone. It consists of sandstone and mudstone, and contains some coal. The thickness is from 0 to 115 m with the average thickness of 47 m. This stratum is comformable contact with underlying stratum.

2.2 Mechanical properties of loess and characteristics of dominant loess dumping area

2.2.1 Engineering properties of loess

Before analysis of the accident, the engineering properties of loess and characteristics of dominant loess dumping area were introduced in this section. Loess is aeolian deposit which is generally composed of homogeneous and angular particles. Loess is classified into three groups i.e. silt, clay, and sand groups (Liu et al., 2006). The size of particles is often similar to silt (50-90%) and they are accompanied by illite clay and sometimes sand (Qiao & Li, 1990). **Figure 2.4** shows the content of soluble salt in loess collasible under overburden pressure and loess noncollasible under overburden pressure (Liu, 1997). It shows that the content of $CaCO_3$ in loess accounts for 6-14%. This high content of $CaCO_3$ makes loess high structure strength. Meanwhile, the other contents such as $MgSO_4$, Na_2SO_4, Na_2CO_3, NaCl, and $CaSO_4.2H_2O$ make loess collapsibility. Due to chemical corrosion of iron minerals, loess is observed in yellow or brown color. The void ratio is up to 50% (Liu, 1997).

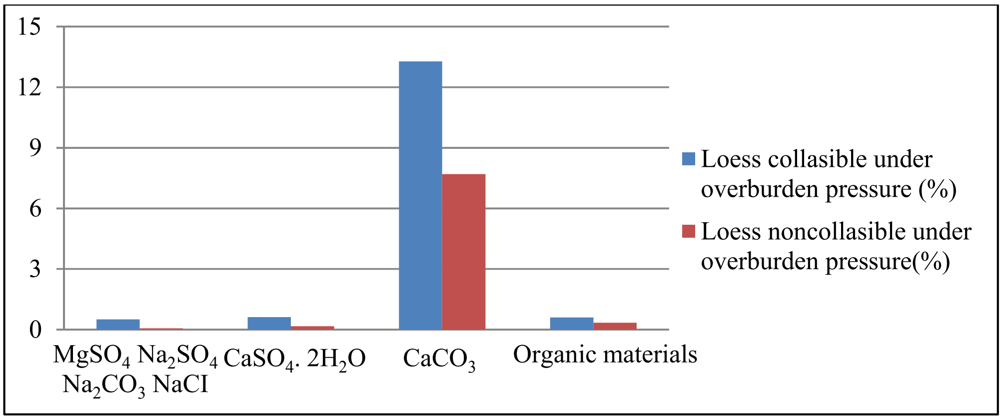


Figure 2.4 Content of soluble salt in loess collapsible under overburden pressure and loess noncollapsible under overburden pressure

Soil separates are specific ranges of particle sizes. The particle size of loess is mainly from 0.005 mm to 0.05mm, generally this range of particle is more than 60% (Liu, 1997). **Table 2.1** shows soil separates by diameter limits from Wikipedia. The size of loess more than the size of clay and smaller than the size of coarse sand.

Table 2.1 Soil separates by diameter limits

Name of soil separate	Diameter limits (mm)(USDA classification)
Clay	less than 0.002
Silt	0.002–0.05
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

The properties of loess are different with clay or sand. For instance, **Table 2.2** shows the properties of red clay in Guiyang city, China (Yi et al, 2011). By comparison with **Figure 1.5**, the friction angle of clay is smaller than loess, and the cohesion of clay is more than loess.

Table 2.2 Properties of red clay in Guiyang city, China

	Amount of samples	Minimum value	Maximum value	Average value
Water content (%)	1055	15.8	79	52.7
Density (g/cm^3)	1055	1.52	2.26	1.67
Void ratio (%)	1055	0.37	2.26	1.52
Plasticity index	1055	16.0	61.0	33.9
Friction angle (degrees)	1055	0.5	100.6	10.5
Cohesion (kPa)	1055	4.3	123.3	46.0

In engineering behavior, loess soils are considered as problematic materials and the collapse phenomenon is a common risk in this type of soil (Sariosseiri & Muhunthan, 2009). Loess is arid or semi-arid regions sediments. It is formed in a specific environment that it has different characteristics compared with the general clay. At first, loess is rich in carbonates and with obvious structural strength, compressive deformation, collapsible deformation, and osmotic deformation (Yuan, 2003; Zhang, 1995; Derbyshire et al., 1988). Secondly, most of loess is partial saturation and big void. Thirdly, it is very sensitive to water content. Numerous studies have been carried out in this regard, including the effect of soil structure on behavior of loess (Gerard et al., 2007), the effect of intergranular cement on mechanical strength of loess (Sariosseiri &Muhunthan, 2009), the influence of climate and secondary changes (Derbyshire, 1997) and study on the effect of physical characteristics on their deformation properties (Reznik., 2007).

The collapsible loess can be defined as susceptibility to a large and sudden loss of volume when either water is added or the stress increased. The noncollapsible loess does not have or have a small loss of volume. **Figure 2.5** shows the relationship between void ratio and pressure of collapsible loess in water. The line ab is compressive deformation. The line bc represents collapsing deformation. The line cd shows consolidate deformation (Liu, 1997).

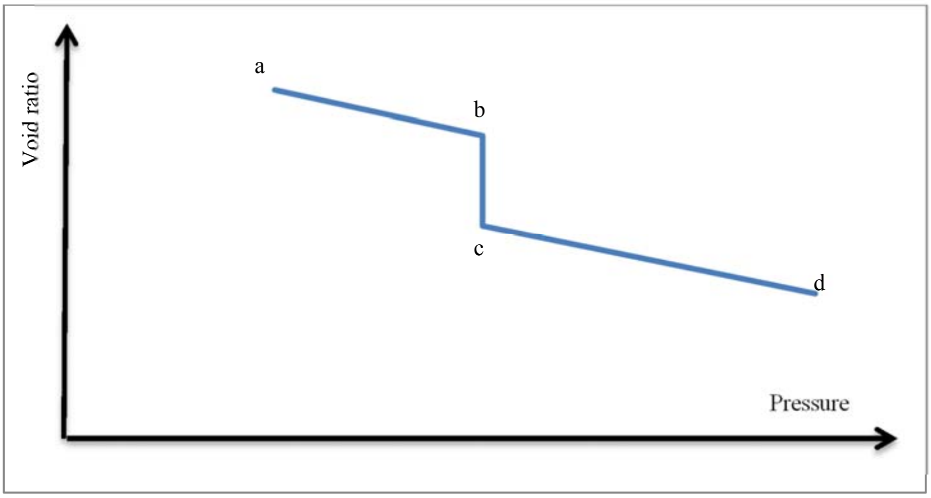


Figure 2.5 Relationship between void ratio and pressure of collapsible loess in water

In the Code for Building Construction in Collapsible Loess Regions of China, 2004, the coefficient of collapsible of loess δ_s can be expressed as as **Equation** [2.1] (Code for Building Construction in Collapsible Loess Regions of China,2004).

$$\delta_s = \frac{h_p - h'_p}{h_o} \quad [2.1]$$

δ_s– Coefficient of collapsible.

h_p– Height of sample under constant pressure as nature water content and initial structure, m.

h'_p– Height of sample under constant pressure in the water as nature water content and initial structure, m.

h_o– Height of sample as nature water content and initial structure.

The loess could be called noncollapsible loess when the $\delta_s < 0.15$. The loess would be called collapsible loess when the $\delta_s \geq 0.15$.

In the Code for building construction incollapsible loess regions of China in 2004, the coefficient of collapsiblity under overburden pressure of loess δ_{sz} can be expressed as as **Equation** [2.2].

$$\delta_{sz} = \frac{h_z - h'_z}{h_o} \qquad [2.2]$$

δ_{sz}– Coefficient of collapsible under overburden pressure of loess.

h_z– Height of sample under saturation overburden pressure as nature water content and initial structure, m.

h'_z– Height of sample under saturation overburden pressure in the water as nature water content and initial structure, m.

The loess noncollapsible under overburden pressure is categorized as noncollapsible loess when the $\delta_s < 0.15$. The loess collapsible under overburden pressure is categorized as collapsible loess when the $\delta_s \geq 0.15$.

In the Code for building construction incollapsible loess regions of China, 2004, the total collapsible deformation of loess noncollapsible under overburden pressure Δ_s can be expressed as **Equation** [2.3].

$$\Delta_s = \sum_{i=1}^{n} \beta \delta_{si} h_i \qquad [2.3]$$

Δ_s– Total collapsible deformation of loess noncollapsible under overburden pressure, m.

δ_{si}– The coefficient of collapsible of number i loess seam, m.

β– Correction coefficient based on lateral extrusion. β is 1.5 as the loess is from surface to 5 m depth below the surface. β is 1 as the loess is 5 m depth below the surface.

h_i– Height of number i loess seam, m.

The loess noncollapsible under overburden pressure is called noncollapsible loess when the $\delta_s < 0.15$. The loess collapsible under overburden pressure is called collapsible loess when the $\delta_s \geq 0.15$.

In the Code for building construction incollapsible loess regions of China, 2004, the total collapsible of loess collapsible under overburden pressure Δ_{zs} can be expressed as **Equation** [2.4].

$$\Delta_{zs} = \sum_{i=1}^{n} \beta_o \delta_{zsi} h_i \quad [2.4]$$

Δ_{zs} – Total collapsible deformation of loess noncollapsible under overburden pressure, m.

β_o– Correction coefficient based on different area. β_o is 1.5 as the loess in the west of Gansu pronvince. β_o is 1.2 as the loess in the east of Gansu pronvince or in north of Shananxi pronvince.β_o is 0.7 as the loess in the Guanzhong. β_o is 0.5 as the loess in the other area.

δ_{zsi}– The coefficient of collapsible under overburden pressure of number i loess seam.

The characteristic of carbonate cementation and the compaction degree has taken place helps to explain the brittle failure of these two loess units (Billard et al., 1993; Derbyshire et al., 1994). Given their age and relatively low stratigraphical position, these loesses have undergone long-term consolidation and compaction, and subsequently suffered to a certain extent from unloading arising from denudation, a process which has resulted in the formation of extensive joint systems in the loess deposits. During shearing the interparticle friction and the resistance to shearing resulting from the cementation bonds are gradually mobilized until the limit strength threshold values for both are reached and brittle failure occurs. Hereafter the term apparent cohesion will be used, a term which includes the shearing resistance of the cementation bonds and the influence of adsorbed water.

Stability analysis of these slopes require information of the remoulded strength. In the case of stability analyses of slopes lacking visible deformation or weathering, peak strength values may be used. For those slopes characterized by fissures, salt efflorescences, steps in the terrain or other indicators of internal weathering and/or movement, a combination of peak strength and residual strength values is necessary in order to obtain realistic stability analyses (Dijkstra et al., 1994). Residual strength parameters are dependent only on the final water content. A linear relationship exists between the apparent effective cohesion and the moisture content, whereas the relationship between the effective internal friction angle and the increasing moisture content is more complex.

2.2.2 Characteristics of dominant loess dumping area

Most of dominant loess dumping area are located in Loess Plateau. Based on the distribution of dominant loess dumping areas and characteristics of loess, the characteristics of dominant loess dumping area in China were summarized as follows.

a) The climate belongs to semi-arid or arid types. Heavy rain occurred frequently in this area. Rainfall concentrates in July, August, and September. Thus, the drainage operation is necessary. Generally, the groundwater level lay on 20 m deep below the surface. Meanwhile, loess has a high permeability.

b) It is located in cold region. The water will be freezing and frozen soil will be formed. Freezing of surface water on dumping area can block drainage paths, causing a build-up of water pressure. Freezing of ground water can destroy the structure of loess due to temperature-dependent volume changes in the ice.

c) One open pit has two external dumping areas or more in initial stage. Internal dumping area served in middle stage and late stage. One external dumping area consists of waste soil. Other one external dumping area consists of soil and rock. In the beginning of excavating, the soil must be excavated. Meanwhile, the waste loess must be stored for land reclaiming. After that, waste rock would be excavated, the second external dumping area is formed to store waste rock and waste soil. After coal has been excavated, a large space is formed as an internal dumping area.

d) Coal seam is flat. The dip angle of coal seam is mostly 3-8 degrees. There is no obvious geological structure in Loess Plateau, such as fold and fault. The strength of rock layers is higher and joint cracks are not developed (Chen, 2013).

e) The topsoil is loess seam mostly. The thickness of loess is 20-150 m. Below loess seam is clay seam. Below clay seam is weathered sandstone seam.

f) Loess Plateau belongs to low mountains and hills. Soil erosion by rain and wind is a serious problem here. Mostly surface is covered with loess. Loess Terrace cutting by erosion, has many gully. The shape of gully is “V”, the cutting depth is from 40 m to 70m.

2.3 Accident analyses by Phase^{2D} software

2.3.1 Numerical analysis model

A geological model was built by Phase^{2D} software based on geological conditions of South external dumping area at Antaibao open pit coal mine. Phase^{2D} software is a two dimensional elasto-plastic finite element method for calculating stresses and displacements around slope and underground openings, and it can be used to solve a wide range of mining, geotechnical and civil engineering problems (Gillie et al., 2010; Chakraborti et al., 2012; Che et al., 2011; Guo et al., 2012). **Table 2.3** shows the parameters of South external dumping area. This datas come from design document of Antaibao open pit coal mine.

Table 2.3 Parameters of South external dumping area

Bench height	15 m	Total height of dumping area	135 m
Angle of bench	30 degrees	Total slope angle of dumping area	19 degrees
Length of safety bench	20 m	Angle of floor	6 degrees
Piezometric line	20 m depth below the surface		

The physical and mechanical properties of coal and rocks of South external dumping area at Antaibao open pit coal mine were shown in **Table 2.4**. This datas come from design document of Antaibao open pit coal mine.

Table2.4 Physical and mechanical properties of coal and rocks of South external dumping area

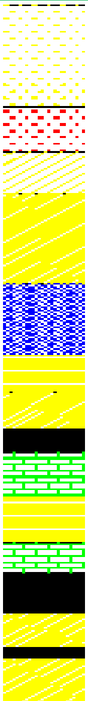
Lithology	Depth (m)	Average thickness (m)	Columnar	Unit weight (kN/m^3)	Young's modulus (MPa)	Poisson's ratio	Cohesion (MPa)	Friction angle (degrees)	Tensile strength (MPa)
Waster loess	135			17.6	15	0.42	0.04	25	0.006
Loess	34	34		19.6	15	0.42	0.085	28	0.013
clay	49	15		19.8	10.5	0.36	0.131	20	0.18
Weathered sandstone	63	14		23.0	2,000	0.36	2.5	38	0.75
Sandstone	93	30		23.8	4,200	0.32	3.0	39	0.9
Mudstone	117	24		24.9	2,800	0.34	2.0	38	0.6
Siltite	129	12		23.2	4,600	0.32	3.5	36	1.0
Sandstone	141	12		23.8	4,000	0.30	4.0	40	1.2
No. 4 coal seam	149	8		14.4	1,000	0.38	1.62	36	0.7
Shale	164	15		24.5	2,400	0.33	3.0	42	0.9
Siltite	179	15		26.0	4,800	0.32	5.0	38	1.2
Shale	189	10		25.8	3,500	0.35	5.0	38	1.0
No. 9 coal seam	202	13		13.3	1,200	0.36	1.62	36	0.7
Sandstone	214	12		23.8	2,900	0.28	5.0	41	1.2
No. 11 coal seam	217	3		14.0	1,300	0.35	1.62	36	0.7
bedrock	405	188		23.8	2,900	0.28	5.0	41	1.2

Figure 2.6 shows the geological model of external dumping area at Antaibao open pit coal mine. **Figure 2.7** shows the safety factor and the maximum shear strain of dumping area. It shows that the safety factor of dumping area is 1.37, and meets the request of Code for design of open pit coal mine of coal industry in China (China Coal Construction Association ,2005). According to the Code for Design of Open Pit Coal Mine of Coal Industry in China, the safety factor is required to be 1.2-1.5 for external dumping area when its service life is more than 20 years.

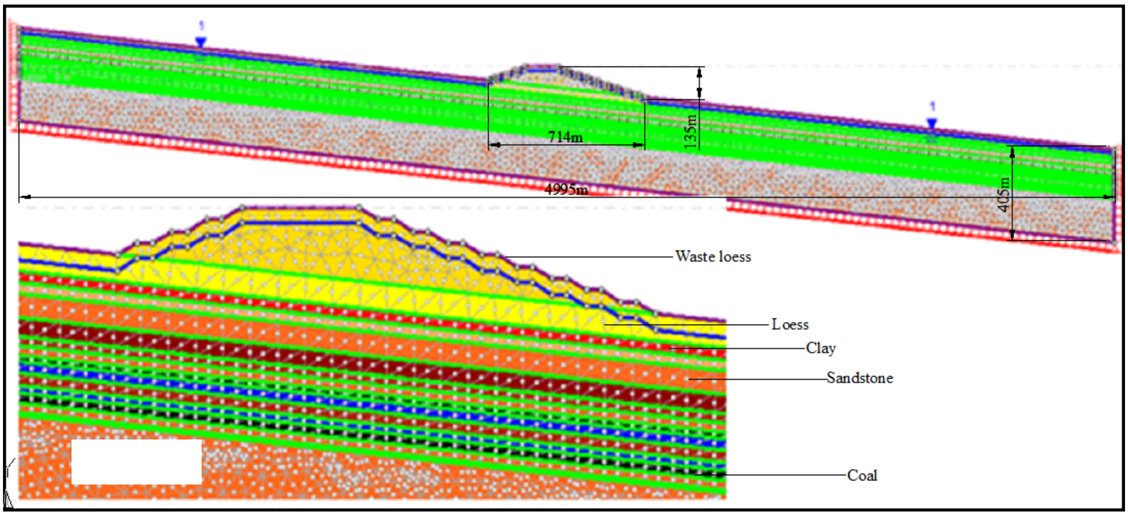


Figure 2.6 Geological model of external dumping area at Antaibao open pit coal mine

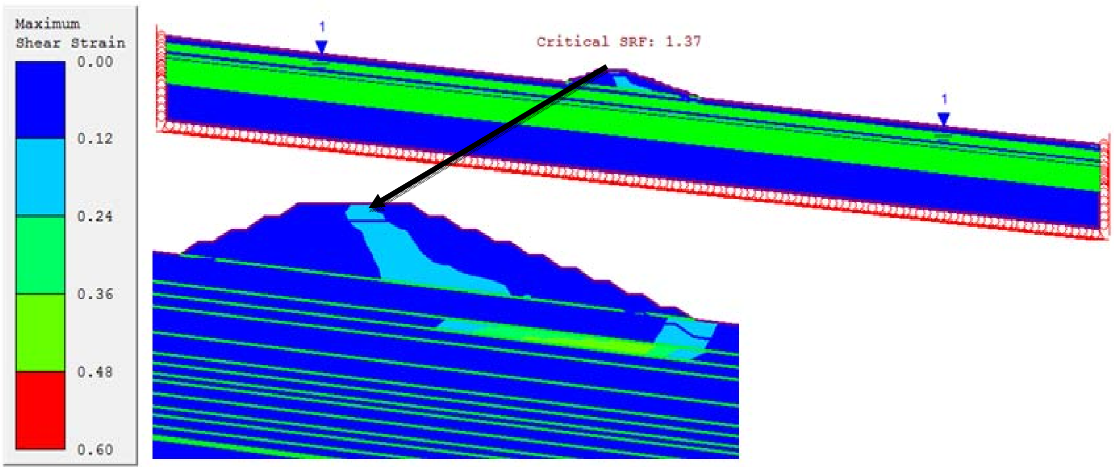


Figure 2.7 Safety factor and maximum shear strain of dumping area

2.3.2 Describe accident

Figure 2.8 shows the plan of dumping area sliding and monitoring engineering. The monitoring points are K_1, K_2, K_3, K_4, K_5, K_6, K_7, and K_8 respectively. The monitoring sections are Section 1, Section 2, Section 3, and Section A_4 respectively.

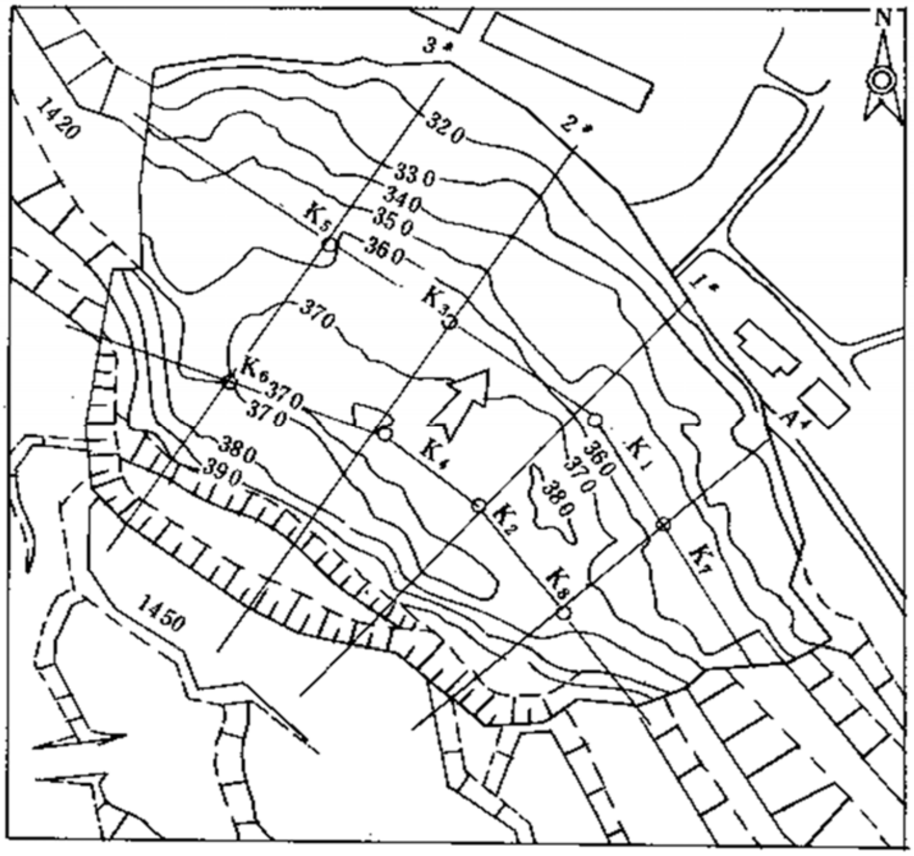


Figure2.8 Plan of dumping area sliding and monitoring engineering

In the east-part of Section 2, the sliding mass width of elevation pile of 1,450 in was 45-60 m width. It is located at elevation of 1,363-1,375 m. The drop height was from 75 m to 88 m. In the middle part of sliding mass, the destruction of bencheshape was small. In the lower part, the sliding mass was constituted by waste loess and loess of floor. The traveled distance in the horizontal direction was from 50 m to 85 m.

In the west of Section 2, the sliding mass width of elevation pile of 1,450 in was 95 m width. Edge part of the sliding mass was from 30 m to 50 m. It is located at elevation of 1,380. The drop height was approximately 70 m. The drop height of other rest part of sliding mass was approximately 50 m. It is located at elevation of 1,415 m. The drop height was 35 m. Between top part and middle part there is a deep channel with depth 20 m. In the middle part of sliding mass, the destruction of bencheshape was obvious. The sliding distance in the horizontal direction was from 130 m to 145 m. In the lower part, the sliding distance in the horizontal direction was 200 m approximately.

2.3.3 Characteristics of sliding

Figure 2.9 shows the geological model and slope failure modes of Section 2. The characteristics of sliding summarized as follows.

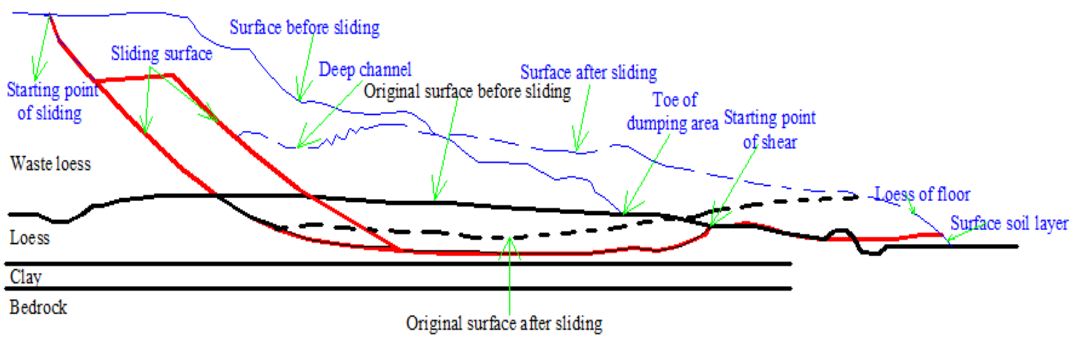


Figure2.9 Geological model and slope failure modes of section 2

a) The failure model is circular failure along the floor because of the shape of sliding surface and the lower part of sliding mass have floor loess. Meanwhile, **Figure 2.7** shows the failure model is circular failure. The maximum shear strain has reached 0.5 m that centralized in clay seam and waste loess seam.

b) The floor has an obvious deformation. It consists of subsidence and floor heave.

c) The total slope angle of dumping area was from 19° to 21° before sliding. The total slope angle of dumping area was approximately 11°.

d) The sliding surface is in the waste loess and loess seam of floor along the top of clay seam.

e) The sliding of dumping area is constituted by multi-stages. After a sliding mass was moved, a steep slope surface was formed. The steep slope surface results in the failure of next sliding mass. The width of each sliding mass was from 45 m to 50 m width.

f) The maximum distance between toe of dumping area and starting point of shear was from 65 m to 70 m length.

2.3.4 Cause of sliding

The causes of sliding are as follows.

a) The rise of groundwater level

There was water seepage at the toe of the dumping area. On October 29th, 1991, the frost day was coming, and the frozen day had just come. The water in the toe of the dumping area was frozen. Then, the water of dumping area cannot flow out from toe of the dumping area. Therefore, the groundwater level rose. Moreover, rainfall made the groundwater level rose. The statistical data showed that the groundwater level was very high on October 29th. Before the dumping area was formed, most rainfall flowed into the Qili river. After the dumping area was done, most rainwater flowed into the ground. The clay seam is watertight layer. Meanwhile, the waste loess is a strong aquifer. This suction of waste loess on water caused the rise of the groundwater level. The groundwater level increased with incresing the height of total dumping area due to the suction of waste loess on water.

To clarify the effect of groundwater level on the stability of dumping area, a series of numerical simulation was conducted. We assumed that the piezometric line was from 5 m to 50 m deep below the surface. The other parameters are maintained on constant value. **Fiugure 2.10** shows that the relationship between safety factor of dumping area and piezometric line. It is shown that the safety factor of dumping area decreases dramatically from 1.74 to 1.01 with increasing the height of piezometric line from 50 m to 5 m under the surface. In the South external dumping area at Antaibao open pit coal mine, the stability of dumping area is in a critical state as the piezometric line 5 m depth below the surface. The stability of dumping area cannot meet the code for design of open pit coal mine of coal industry in China as the piezometric line is higher than 11 m depth below the surface. The groundwater level does not have an obvious effect when the piezometric line is lower than 30 m depth below the surface. It indicates that the piezometric line has an obvious effect on stability of dumping area.

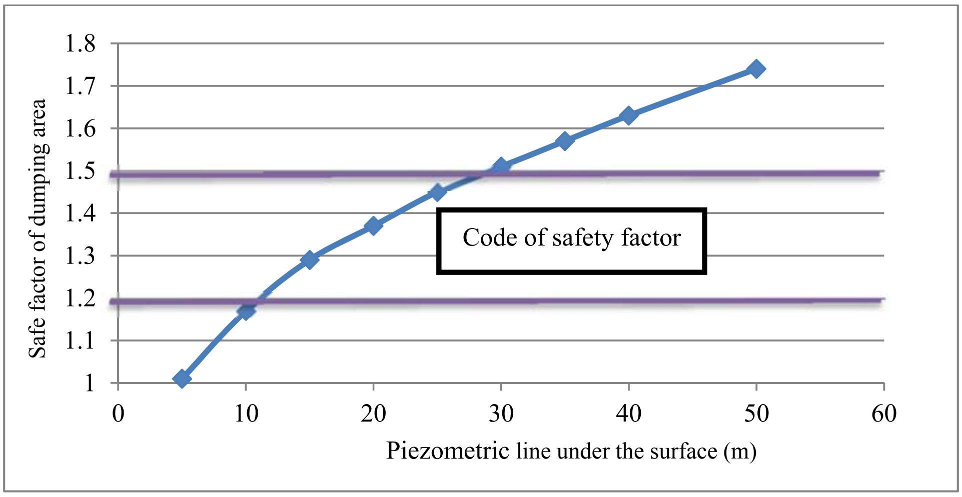


Figure2.10 Relationship between safety factor of dumping area and piezometric line

b) High water contents of loess decreases the strength of floor layer. The rose of groundwater level results in that the water content of loess of dumping area in high. The properties of loess decrease with increasing the water content.

c) The clay seam is a watertight layer. It causes that the groundwater level was in loess seam, and the clay seam is in zone of saturation. On a rainy day, this situation will cause piezometric level of underground water rise. **Figure 2.10** shows the importance of groundwater level on the stability of dumping area. Meanwhile, the saturated clay seam and loess laid below groundwater level were weak seam and to be sliding easily.

d) High dumping area decrease the shear strength of loess in floor. There is structural strength in the loess. The structural strength of loess would disappeared as the pressure is more than the structural strength of loess. It results in compressive strength and shear strength dramatically decreases. The maximum total height of dumping area by structural strength of loess Ht can be expressed as **Equation**[2.5] (Peng, 2010):

$$H_t = \frac{P_t}{\rho \times \gamma} \qquad [2.5]$$

H_t – Maximum total height of dumping area by structural strength of loess, m.

P_t – Structural strength of loess, Pa.

ρ - Gravity

γ – Density of waste loess, kg/m^3.

The structural strength of loess in floor was 1.38 MPa at Antaibao open pit coal mine (Xu et al., 2007). The density of waste loess is 1.76×10^3 kg/m^3. The maximum total height by ultimate bearing capacity of floor of dumping area can be calculated as follows.

$$\mathrm{H}_t = \frac{1.38 \times 10^6}{10 \times 1.76 \times 10^3} = 78.4\ \mathrm{m}$$

The dumping area height was 135 m and it was more than the maximum total height by structural strength of loess. The loess of floor was compacted and the structural strength was disappeared. As a result, the shear strength of loess seam in floor was decreased. It should be pointed out that the compressive strength and the reductions of shear strength of floor loess decreases do not represent dumping area failure.

We assumed that the total heights of dumping area are 105 m, 120 m, 135 m, and 150 m, repectively in order to clarify the effect of dumping area height on stability of dumping area. Other parameters maintain constant values. **Figure 2.11** shows the relationship between the total height of dumping area and the safety factor, and the cross sectional area of dumping area. It shows that the safety factor of dumping area decreases obviously with increasing the total height of dumping area. Meanwhile, the cross section area of dumping area increases with increasing the total height of dumping area. The total height of dumping area has an obvious effect on the stability of dumping area.

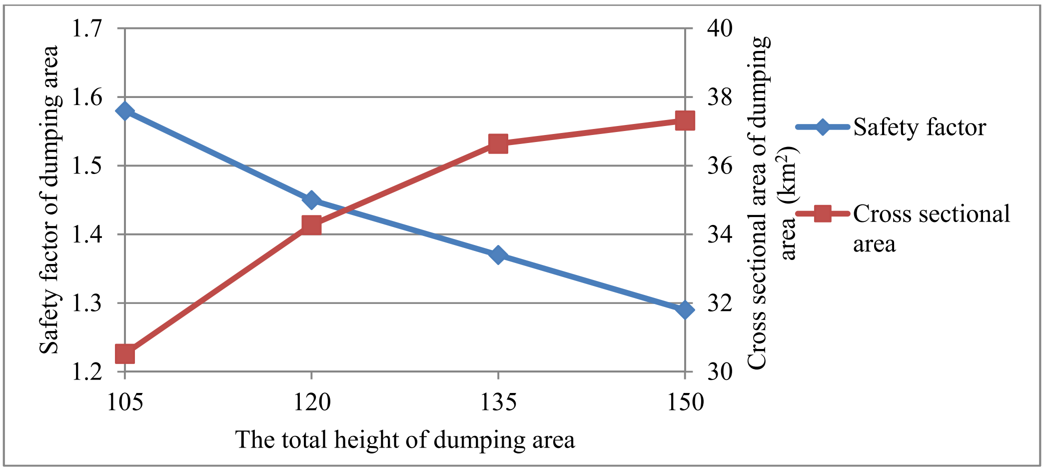


Figure2.11 Relationship between total height of dumping area and safety factor, and cross sectional area of dumping area

In summary, the primary cause of sliding was the rise of groundwater level because the water in the toe of the dumping area was frozen, rainwater seeped into the ground, and the suction of waste loess on water. Subsequently the height of dumping area increases. High water content of loess decreases the strength of floor layer. Thus, it could be concluded that the groundwater level is the most important influential factor to the stability of dumping area.

2.4 Sliding process of dominant loess dumping area

2.4.1 Compression stage

In the dumping area, the waste loess and floor is compacted by overburden pressure or equipment. The amount of subsidence increases with increasing the total height of dumping area over time. The waste loess was loose, thus the subsidence is easy to occure. The amount of subsidence Δ_h in a period time can be expressed as **Equation**[2.6].

$$\Delta_h = (\psi_1 - \psi_2) \times \mathrm{H} \qquad [2.6]$$

Δ_h – Amount of subsidence in a period time, m.

ψ_1 – Coefficient of bulk at the begin.

ψ_2 – Coefficient of bulk at the end.

H – Height of bench, m.

For example, the height of bench of South external dumping area is 15 m height. After dumping, the coefficient of bulk is 1.25. One year later, the coefficient of bulk is 1.15. The amount of subsidence Δ_h in one year can be calculated as follows.

$$\Delta_h = (1.25 - 1.15) \times 15 = 1.5 \text{ m}$$

The floor seam is compacted as the total height of dumping area increases. It results in subsidence deformation in the floor. Pressure on the floor increases with increasing the total height of dumping area. The structural strength of loess in floor decrases as dumping area is higher than 78.4 m. It is assume that the bulk coefficient of floor seam at the begin is 1.18 after dumping. After one year, the coefficient of bulk of floor seam is 1.05. The amount of subsidence in this period Δ_h can be calculated as follows.

$$\Delta_h = (1.18 - 1.05) \times 34 = 4.4\text{m}$$

On the other hand, the collasible of loess results in subsidence. The cause is some contents materials of loess dissolve in water. For instance, $MgSO_4$, Na_2SO_4, Na_2CO_3, NaCl, and $CaSO_4$. Rainfall flows into ground or rainwater accumulated results in occurrence of subsidence in the dumping area.

2.4.2 Rise of groundwater level

The groundwater level rises due to freezing of the water at the toe of dumping area. **Figure 2.12** shows the Schemat of the groundwater level rises because of water freeze. The segment of EFG is water freeze area. Water freeze area prevents the water in the waste loess to flow out from the toe of dumping area. It results in the groundwater level increased.

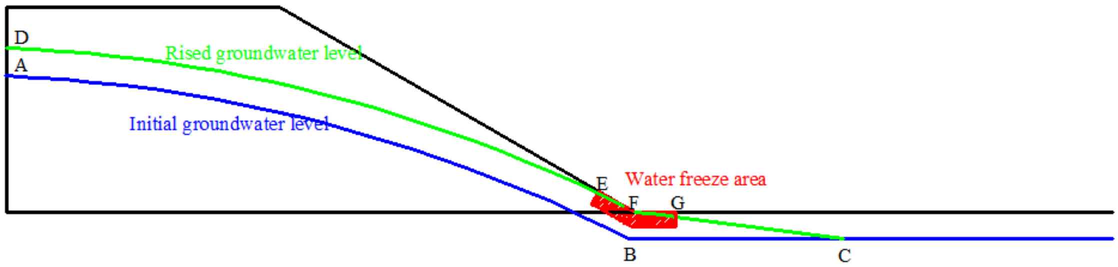


Figure 2.12 Schemat of groundwater level rose due to water freeze

The groundwater level rised due to the rainwater flowing into the ground. **Figure 2.13** shows the Schemat of the groundwater level rises due to rainwater flowing. Rainwater flows into dumping area and ground. Volume of underground water increases as a consequence of increasing the rise of groundwater level.

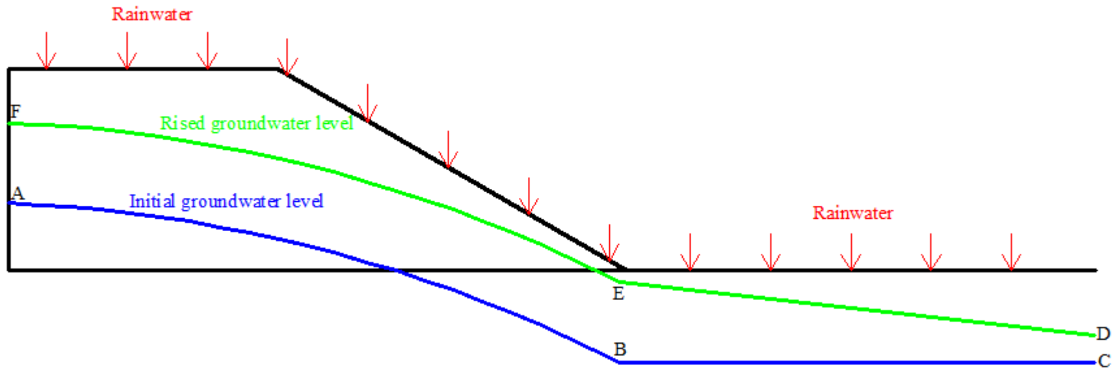


Figure2.13 Schemat of water rose due to rainwater seeps

The groundwater level rises due to the height of dumping area increases. **Figure 2.14** shows the schemat of groundwater level rise due to suction of waste loess on water. Bench was formed on the floor. Suction of waste loess on water results in the rise of groundwater level.

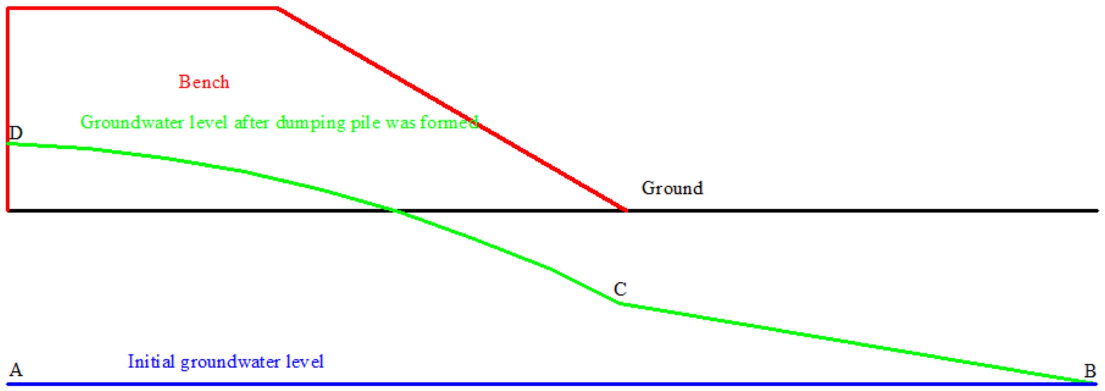


Fig 2.14 Schemat of groundwater level rise due to suction of waste loess on water

2.4.3 Formation of sliding surface

After the rise of groundwater level, the properties of waste loess and floor loess are changed. As the time elapsed a weak seam was formed due to high water content. **Figure 2.15** shows the Schemat of sliding surface before sliding. The segment of AB is a crack. The crack increases as the time elapsed. Part of BC is driving block. Part of CD is resisting block. The segment of BC and CD is shear resistant. Shear stress was acted on the planes of BC and CD. Finally, the potential sliding surface was formed.

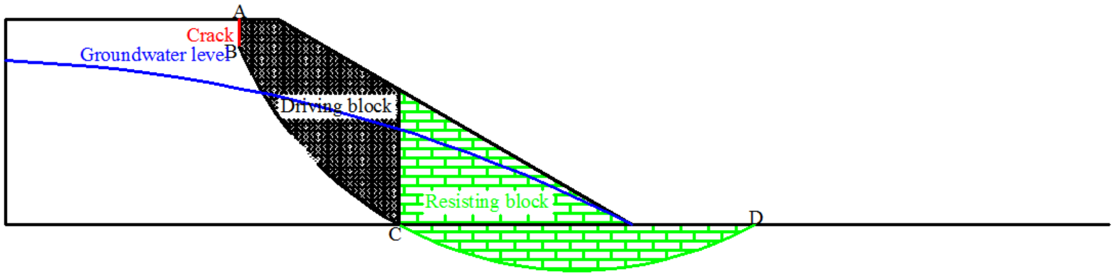


Figure 2.15 Schemat of sliding surface before sliding

2.4.4 Floor deformation

Figure 2.16 shows the Schemat of floor deformation. As the potential sliding surface was formed, the segment of AB subsided, and the segment of BC could be risen due to the pressure on the sliding mass. The distance between the toe of dumping area and starting point of shear deformation depends on the total height of the dumping area. In South external dumping area, the distance is from 65 m to 70 m.

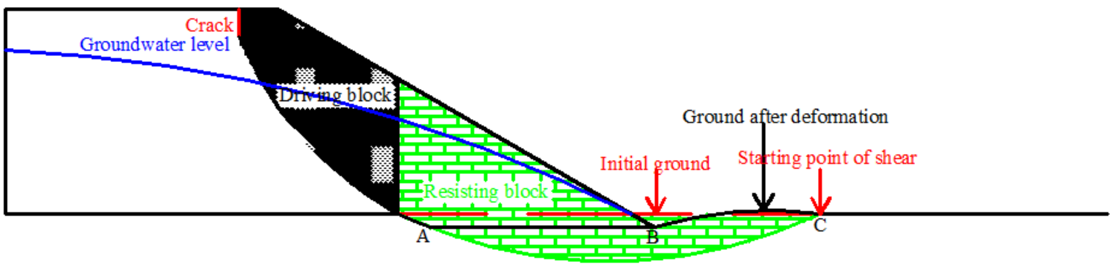


Figure 2.16 Schemat of floor deformation

2.4.5 Occurance of sliding

After the floor deform to a certain value, the sliding occurred. **Figure 2.17** shows the schemat of sliding occurred step by step. After sliding of mass Ⅰ occurred. This sliding resulted in formation of a steep slope in the mass Ⅱ. As a result, sliding Ⅱ occurred sliding due to the sliding Ⅰ. Sliding Ⅲ occurred due to sliding Ⅱ. The sliding will continued until to the top of the slope. Finally, a huge dumping area sliding was formed. The sliding type was circular failure.

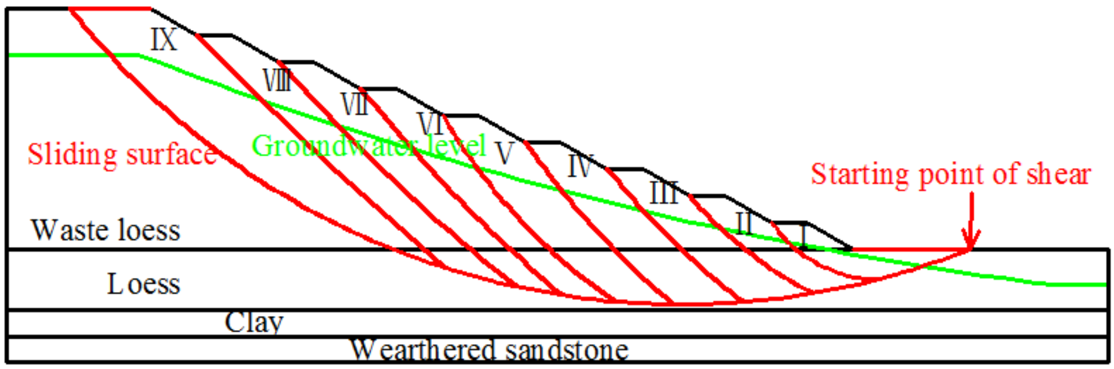


Figure 2.17 Schemat of sliding step by step

2.5 Summary

The South external dumping area had a security risk to industrial area. It was dangerous period from October 15th to November 1th for the stability of dumping area because of high groundwater level. The saturated clay seam and loess that below groundwater level were weak and easy to slide. Loess is aeolian deposit which is generally composed of homogeneous and angular particles. Loess is rich in soluble salt. Especially, the content of $CaCO_3$ accounts for 6-14%. The high content of $CaCO_3$ means that the high structure strength and collapsible property of loess. Due to chemical corrosion of iron minerals, loess is observed in yellow or brown color. The void ratio of loess is up to 50%. Most dominant loess dumping areas are located in Loess Plateau, and it is cold region. The climate belongs to semi-arid or arid types. Generally, the dip of coal seam is gentle, the dip angle from 3 to 8 degrees. Soil erosion by rain and wind is a serious problem here.

The width of each sliding mass was from 45 to 55 m. The bench sliding is constituted by multi-stages. The safety factor of dumping area decreases dramatically from 1.74 to 1.01 with increasing the piezometric line of dumping area from 50 m to 5 m below the surface. The safety factor of dumping area decreases obviously as the total height of dumping area increases. The primary cause of sliding was the rise of groundwater level due to freezing of water at the toe of the dumping area and much rain water, and the suction of waste loess on water. High water content of loess decreases the strength of floor layer. The structural strength of floor loess would be dispeared as the height of dumping area is higher than 78.4 m.

Based on site investigation and accident analysis, the sliding process can be concluded as follows. a) In the dumping area, the waste loess was compacted under overburden pressure. The amount of subsidence increased as the total height of dumping area increases and the time elapsed. b) The groundwater level rose because the water at the toe of the dumping area was frozen, rainwater seeps into the ground, and the suction of waste loess on water. c) After the rise of groundwater level, the properties of waste loess and loess of floor were changed to be weak. d) As the potential sliding surface was formed, the surface of floor under bench subsided. Meanwhile, the surface of floor between the toe of bench and the starting point of shear deformation is rose due to the stress of the sliding mass. e) After the amount of floor deformation reached to a certain value, the sliding occurred. The sliding made a steep slope that is formed in the next sliding mass. Then the next mass sliding, until to the top of the slope. Finally, a huge dumping area sliding was formed. The sliding type was circular failure.

From these results, the changes in the mechanical properties of loess by the elevation of the groundwater level associated with rainfall and a weak loess floor layer may lead to this large slope failure at dumping areas. These two main factors must be considered for the construction of dumping areas in order to develop specific guidelines for the appropriate designs of stable dumping areas in areas where loess is dominant near the surface, along with countermeasures to improve the stability of these dumping areas. Therefore, the next Chapter focuses on the effect of water content on stability of dominant loess dumping area.

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CHAPTER 3

STABILITY EFFECT OF WATER CONTENT OF LOESS ON DOMINANT LOESS DUMPING AREAS

From the results of Chapter 2, it is known that hydrological condition is the most important influential factor on stability of dumping area. It was discussed that the rise of groundwater level was the primary cause for loess dumping area sliding. Compared with other soil, loess is rich in carbonates and with obvious structural strength, collapsible deformation, and osmotic deformation (Yuan, 2003; Derbyshire et al., 1988). These properties make loess is sensitive to water content. By considering this background, this Chapter focuses on the effect of water content of loess on stability of dominant loess dumping area. In the initial stage of formation bench, the water content of waste loess is unsteady. In the long term, due to the groundwater level, climate, and suction of loess on water, the water content of waste loess in some place will be steady. Thus, it could be said that the water content of loess can be controled by controlling groundwater level.

The study was done at East open pit coal mine which address a problem of stability of loess dumping. In an attempt to achieve the subject of the research, geological information, hydrological condition, floor conditions, and stable problems were investigated. In the laboratory tests, a series of experiments were conducted to measure loess properties under the conditons of different water contents. Based on field investigations and laboratory tests, the results of laboratory tests were discussed and some treatments were proposed. In this study, a geological model is constructed to find out the relationship between water content of waste loess and safety factor, total slope angle, and volume capacity of dumping area.

3.1 Field investigation at East open pit coal mine

Field investigations are useful to govern dumping areas (Siegel et al., 1990; Xie & Pang, 2003; Costa & Schuster, 1988; Machado & Karimpour, 2010). This study was carried out at East open pit coal mine which is located in Shuozhou city, Shanxi Province.

The location of East open pit coal mine from google map was shown in **Figure 3.1**. The recoverable reserve at East open pit coal mine is 1,459 Mt. In 2012, the production of raw coal at East open pit coal mine was 8 Mt/Y. The East open pit coal mine has two dumping areas i.e. East and North external dumping area.

Figure 3.1 Location of East open pit coal mine from google map

3.1.1 Geological overview

East open pit coal mine belongs to low mountains and hills of the Loess Plateau that its mine area are covered by loess. This area is characterized by sparse vegetation, high erosion of land, and gullies. The depths of gullies vary from 30 to 50 m. **Figure 3.2** shows the overview of the East open pit coal mine. The mining area is situated on elevation of 1,214 m to 1,538 m. The length of the mine is about 6.5 to 10.3 km from south to north. Whereas, the width of the mine is about 4.4 to 5.5 km from east to west. While, the exploration area is about 48.7 km^2.

Figure 3.2 Overview of East open pit coal mine

3.1.2 Hydrological condition

Rainfall has an important effect on stability of dumping area at East open pit coal mine. The annual precipitation of East open pit coal mine is about 428 to 449 mm. Meanwhile, the annual evaporation is about 1,787 to 2,598 mm. The East open pit coal mine is situated near to the Yellow River. The elevation of coal seam floor is higher than the groundwater level of the Yellow River. Unfortunatelly, there are two small rivers that crossing the mining area of East open pit coal mine, i.e. the Maguan and the Maying river. In order to maintain the water in pit, the East open pit coal mine has been adopting two methods for drainage. One drainage method is natural infiltration and natural evaporation. Another drainage method is making the rainwater flow into the bottom of pit, then collecting water for daily activity. There is water outflow at the toe of external dumping area. The aquifer stratigraphy of East coal mine area from bottom to top is as follows:

a) Zone of weathering of bed stone. It has weak watery, unconfined aquifer or micro-confined aquifer.

b) Loess. It has strong watery, distributed in large valley or river bed nearby.

The watertight layer is clay with wide distribution. The main intake sources of water are rainfall and surface water.

3.1.3 Water content of waste loess

The samples were taken from East and North external dumping area at East open pit coal mine. Water content of waste loess tests were conducted in the laboratory. **Table 3.1** shows the water content of waste loess sample in the dumping areas at East open pit coal mine. Based on **Table 3.1**, the water content of waste loess was found in the range of 2.21% to 20.6%. The total average value of water content of waste loess sample was about 8.63%. It also can be seen at **Table 3.1** that the water contents of number 2 sample that was taken at the toe of East external dumping area was in high level.

Table 3.1 Water contents of waste loess sample in dumping areas at East open pit coal mine

	Water content	Average value		Water content	Average value
	12.95%			3.92%	3.78%
Number 1 sample	12.68%	12.78%	Number 6 sample	3.72%	
	12.72%			3.70%	
	21.16%			2.15%	2.21%
Number 2 sample	20.64%	20.60%	Number 7 sample	2.26%	
	20.00%			2.21%	
	15.14%			7.35%	7.39%
Number 3 sample	9.38%	9.32%	Number 8 sample	7.22%	
	9.26%			7.61%	
	3.90%			7.69%	
Number 4 sample	7.63%	7.51%	Number 9 sample	7.32%	7.32%
	7.39%			6.94%	
	6.74%				
Number 5 sample	7.05%	6.74%			
	6.43%				
Total average value			8.63%		

3.1.4 Floor condition of external dumping areas

The stratigraphy of external dumping area consists of four strata. The first stratum is diluvium. It is constituted by loess, sand, and gravel. The thickness of this stratum varies from 0 to 40 m. The average thickness is about 10 m. It is unconformable contact with underlying stratum. The second stratum is loess whose thickness ranges from 3 m to 47 m. The average thickness is about 24 m. It is regional unconformity contact with underlying stratum. The third stratum is clay. The thickness of this stratum varies from 0 to 77 m.

The average thickness is about 15 m. It is unconformable contact with underlying stratum. The fourth stratum is weathered sandstone. The average thickness of this stratum is about 14 m. The saturated clay seam and loess that are below groundwater level were weak seam and easy to become a weak seam. The dip of floor is in the range of 5 degrees to 7 degrees.

3.1.5 Stable problem statements

Due to the characteristic of loess, the stable problems at East open pit coal mine were dominated by:

a) There are many gullies in the loess bench due to rainfall. The width of the gully is approximately 10 m. The interval distance is approximately 80 m. **Figure 3.3** shows a gully in bench at East open pit coal mine in 2012.

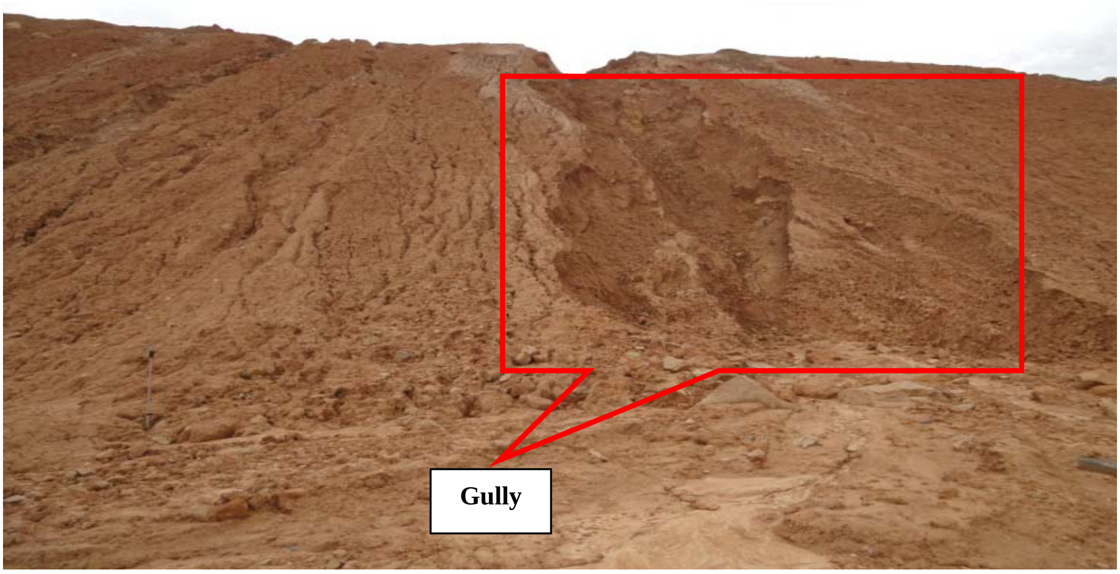

Figure 3.3 A gully in bench at East open pit coal mine

b) Water accumulates in dumping area. **Figure 3.4** shows the water accumulates in dumping area and in the top of bench in 2012.

Figure 3.4 Water accumulates in dumping area and in the top of bench

c) The roads were destroyed frequently due to flowing rainwater along the roads in the dumping area, especially for temporary roads. In most places of dumping area, there is no drainage channel. Due to this situation, the truck cannot work during rainy day at East open pit coal mine.

3.2 Laboratory tests with loess

A series of experiments was carried out to clarify the relationship between water content and properties of loess. The density, Young's modulus, cohesion, and internal friction angle of loess were measured under the conditions of different water contents for the sample of External dumping area at East open pit coal mine.

3.2.1 Process of laboratory tests

Figure 3.5 shows the overview of the shear apparatus in the laboratory. The process of testing is as follows:

Figure 3.5 Overview of the shear apparatus

a) Dried the sample thus the water content was 0 by putting the loess sample into the oven at 105^{o}C for more than 24 hours. **Figure 3.6** shows the loess sample and the oven.

Figure 3.6 Overview of loess sample and the oven

b) Mixed the the 500 g loess and 75 g, 100 g, and 125 g of water thus the content of water were 15%, 20%, 25%, respectively. Divide the mixture into four samples. Wrapped the samples by using plastic to fix water content. **Figure 3.7** shows the sample for test.

Figure 3.7 Sample for test

c) Impacted the sample twice with the compactor to make the compaction coefficient keep in a constant value. And then, cut off excess soil from cutting ring with a soil cut knife, weighted and recorded the cutting ring and the soil sample. **Figure 3.8** shows the compactor, sample, and soil cut knife.

Figure 3.8 Compactor, sample, and soil cut knife

d) Put the sample into shear apparatus. Set the pressure of 10 kg, 20 kg, 30 kg, and 40 kg. Compressed the sample and recorded the compression strain over time until the compression strains less than 1μm/min.

e) Started the shear process when the compression process finished. Recorded the shear force as the shear strain diminished. The shear process was finished as the shear force began reducing or the shear deformation up to 7 mm.

f) Repeated step c) to step e) four times, and then repeated step a) to step e).

3.2.2 Results and discussions

Figure 3.9 shows the density of waste loess under the conditions of different water contents. It was shown that the density of waste loess increases with increasing the water content. Owing to the density is proportional to the weight, thus it could be said that the weight of waste loess will also be increased with increasing the water content. In regards to transportation cost, the cost of weighter material should be more costly than that of lighter material. Based on this background, a graphic of relationship between unit transport cost and water constent was built with assumption 3 $/t of unit transport cost. The correlation is given in **Figure 3.10**. It is seen at **Figure 3.10** that the unit transport cost of waste loess increases with increasing the water content of waste loess.

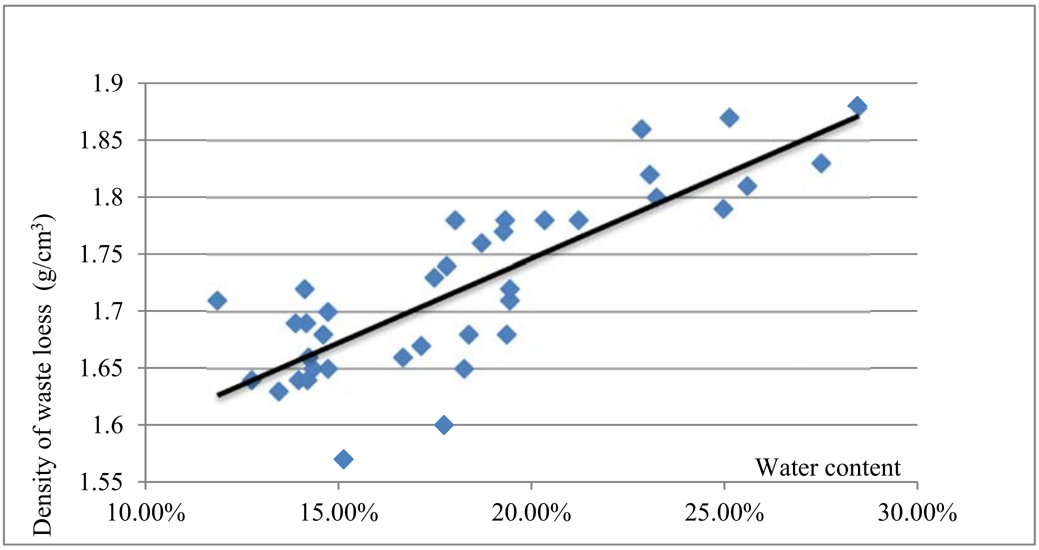

Figure 3.9 Density of waste loess under the conditions of different water contents

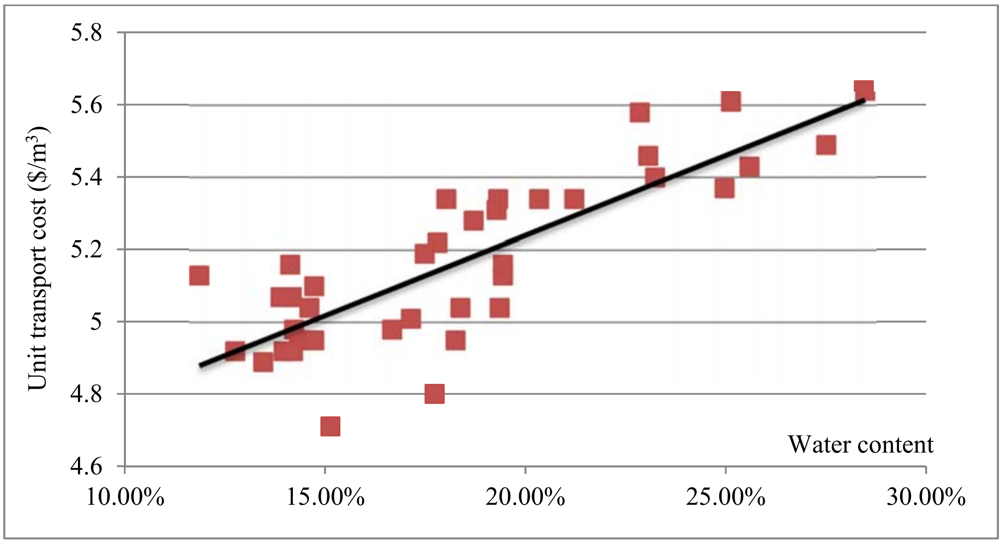

Figure 3.10 Unit transport cost of waste loess under different water contents

Based on **Figure 3.10**, it could be stated that the transportation cost will increases in rainy day. Therefore, some measures should be done to decrease the water content of transported waste loess in order to reduce the transportation cost such as optimize drainage operation to make the rainwater outflow quickly and not easy into the surface in the working face.

Moreover, according to Peng (2010), maximum dumping area height in inversely proportional to the water content of waste loess because the pressure on the floor cannot higher than the ultimate bearing capacity of the floor. The maximum total height of dumping area H_m can be expressed as **Equation** [3.1].

$$H_m = \frac{P_m}{\gamma} \qquad [3.1]$$

H_m – Maximum total height of dumping area, m.

P_m – Ultimate bearing capacity, kPa.

γ – Density of waste loess, kN/m^3.

In order to find out the maximum total height of dumping area at East open pit coal mine, the maximum total height of dumping area was calculated by applying Equation [3.1]. The density was put from the experimental, while the ultimate bearing capacity of loess in floor was assummed 2,320 kPa. The result of calculation can be seen at **Figure**

3.11. It was shown that the maximum total height of dumping area was from 126 m to 151 m as the water content of waste loess is from 25% to 15%.

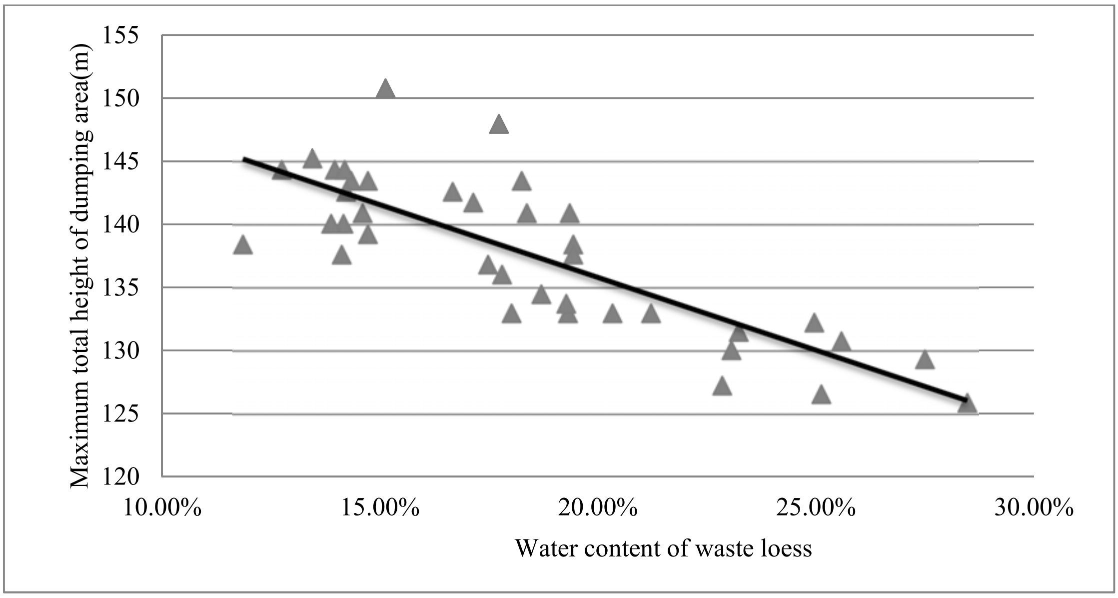

Figure 3.11 Maximum total height of dumping area under different water contents of waste loess

Furthermore, in order to mitigate the slope failure, the correlation between physical rock property (density) and mechanical rock property (Young's modulus, cohesive strength and internal strength) was investigated. The Young's modulus, cohesive strength and internal strength of rock is well known plays important role on stability of slope. The correlation is given at **Table 3.2**. It was shown that the Young's modulus and internal friction angle of loess decrease with increasing the water content from 15% to 25%. The cohesive strength of loess decreases dramatically with increasing the water content from 15% to 25%. Thus, it could be said that the failure potency of slope increases with increasing the water content of waste loess.

Table 3.2 Relationship of water contents of loess and Young's modulus, cohesion, and internal friction angle

Water content of loess	15%	20%	25%
Number of samples	11	15	8
Density (g/cm^3)	1.66	1.72	1.86
Young's modulus (MPa)	1.81	1.62	1.43
Cohesion (kPa)	109	96	41.5
Internal friction angle (degree)	42.1	34.5	32.7

Based on the results of laboratory tests, we can concluded that the shear strength decrease with increasing the water content of waste loess from 15% to 25%. Meanwhile, the shear strength of waste loess were low at the water content 0%. Therefore, there is an optimum moisture content of waste loess. The waste loess has good density, compressive strength, and shear strength as the water content is optimum water content.

In the field investigation, the roads were destroyed frequently because of rainwater flowing along roads in the dumping area, especially for temporary roads. In the surface of the temporary roads of dumping area is a loose loess seam. The thickness was from 5 cm to 40 cm. The road is built simply conditions that the truck was few and service life was short time. All the materials of the road was loess. Meanwhile, East open pit coal mine in a semi-arid area, the water content of loess was low. Damage of loose loess seam is as follows.

a) It was easy erosion in the rainy day, make the road destroyed.

b) Made the truck transport difficultly

c) Caused a big dusting when truck transport

The key point was low water content causing low cohesion of waste loess. East open pit coal mine is located in a semi-arid area. Low cohesion of waste loess is resulting from the fact that the waste loess is loose. Meanwhile, the transport of truck causes the waste loess more loose. The treatment measure is water spray to increases the water content of waste loess. **Figure 3.12** shows water spray in the road of the dumping area. The water spray rate Wa can be expressed as **Equation** [3.2]:

$$W_a = L \times W_r \times E_r \qquad [3.2]$$

W_a - Water spray rate, m^3/hour.

L - Length of road, m.

W_r - Width of road, m.

E_r - Evaporation rate, m/hour.

Figure 3.12 Water spray in the road of the dumping area

For instance, in the external dumping area at East open pit coal mine. The length of road is 1,000 m. The width of road is 30 m. The evaporation rate is 0.4 mm / hour.

The water spray rate = $1,000 \times 30 \times 0.4 \times 10^{-3} = 12\ m^3$/hour

After water spray in the road of the dumping area, the water content increases. The waste loess has good cohesion, compressive strength, and shear strength. The loess is not loose. The transport of truck has a compaction effect on road of waste loess. The road compacted as time went by, the road become to have good density, compressive strength, and shear strength. And then, the road is not easy to be destroyed frequently by rainwater flowing along roads. The truck transport easily and decrease the dusting when truck transport.

3.3 Numerical simulation for East open pit coal mine

In this section, the effect of water content of loess on the stability of dumping area was analysed by Phase^{2D} software. In this numerical simulation, shear strength reduction technique was used to analyze the stability of dumping area.

3.3.1 Build a geological model based on East open pit coal mine

A loess dumping model was built by Phase^{2D} software. **Table 3.3** shows the parameters of external dumping area. The physical and mechanical properties of coal and rock of external dumping area at East open pit coal mine were shown in **Table 3.4**.

Table 3.3 Parameters of external dumping area

Bench height	15 m	Total height of dumping area	150 m
Angle of bench	30 degrees	Total slope angle of dumping area	19 degrees
Length of safety bench	20 m	Angle of floor	0 degrees
Piezometric line	20 m depth below the		

Table 3.4 Physical and mechanical properties of coal and rock of external dumping area

Lithology	Depth (m)	Average thickness (m)	Unit weight (KN/m^3)	Young's modulus (MPa)	Poisson's ratio	Cohesion (MPa)	Friction angle (°)	Tensile strength (MPa)
Waster loess	135		17.6	15	0.42	0.04	25	0.006
Loess	34	34	19.6	15	0.42	0.085	28	0.013
Clay	49	15	19.8	10.5	0.36	0.131	20	0.18
Weathered sandstone	63	14	23.0	2,000	0.36	2.5	38	0.75
bedrock	405	342	23.8	2,900	0.28	5.0	41	1.2

Figure 3.13 shows the geological model of external dumping area at East open pit coal mine that built based on data given by **Table 3.3** and **Table 3.4**. The simulation result as seen in **Figure 3.14** shows that the safety factor of geological model is 1.29, meeting the Code for Design of Open Pit Coal Mine of Coal Industry in China (China National Coal Construction Association, 2005). Moreover, it was found that, on the simulation condition, a circular failure can happen. The maximum shear strains centralized in clay seam and waste loess seam.

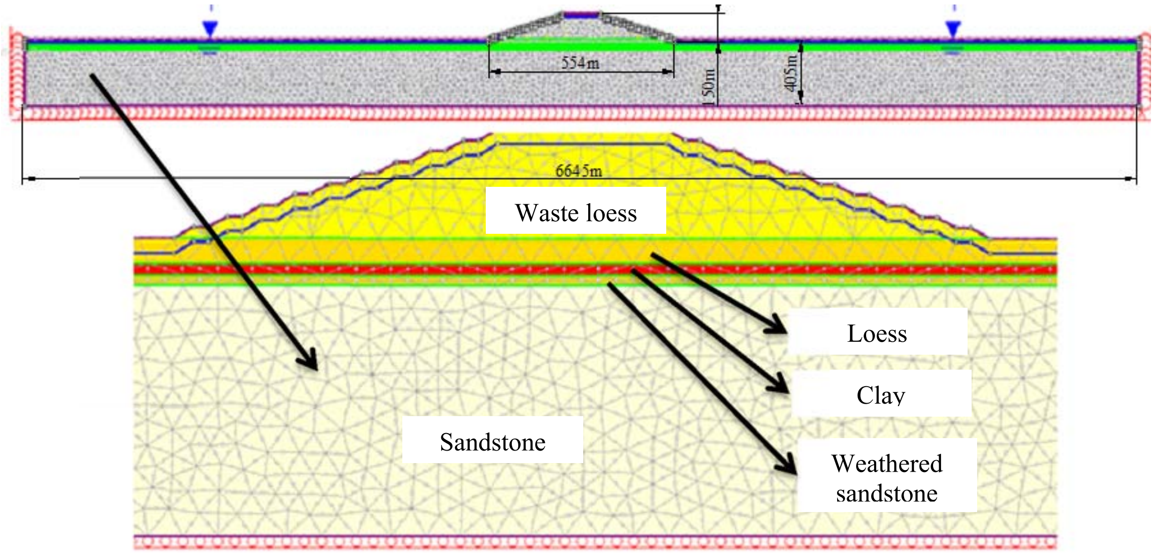

Figure 3.13 Geological model of external dumping area at East open pit coal mine

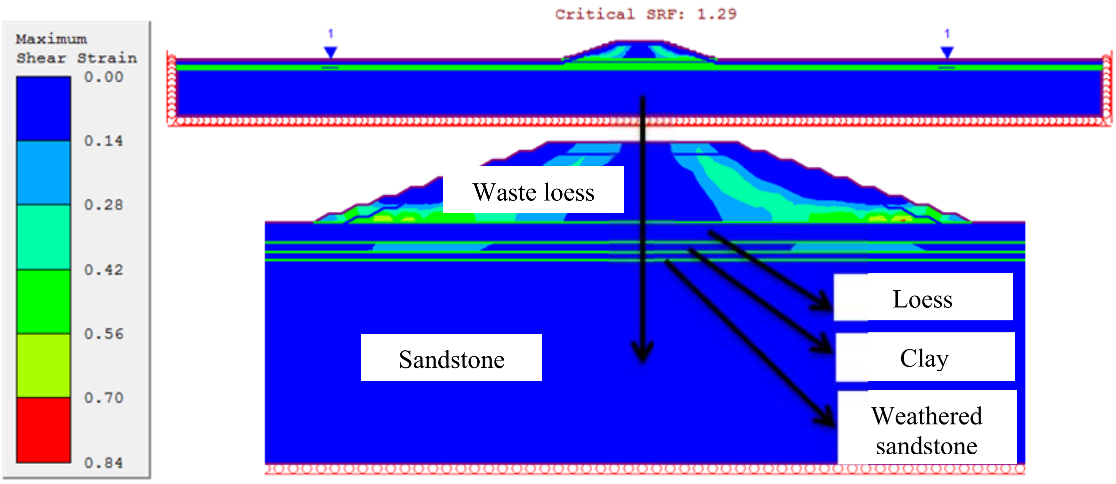

Figure 3.14 Safety factor and maximum shear strain of geological model

3.3.2 Results and discussions

In this simulation, the laboratory results of **Table 3.2** were used in the geological model, meanwhile other parameters were constant. As a result, **Figure 3.15** shows safety factor of dumping area under different water contents of loess. It was shown that the safety factor of dumping area decreases with increasing the water content of loess from 15% to 25%.

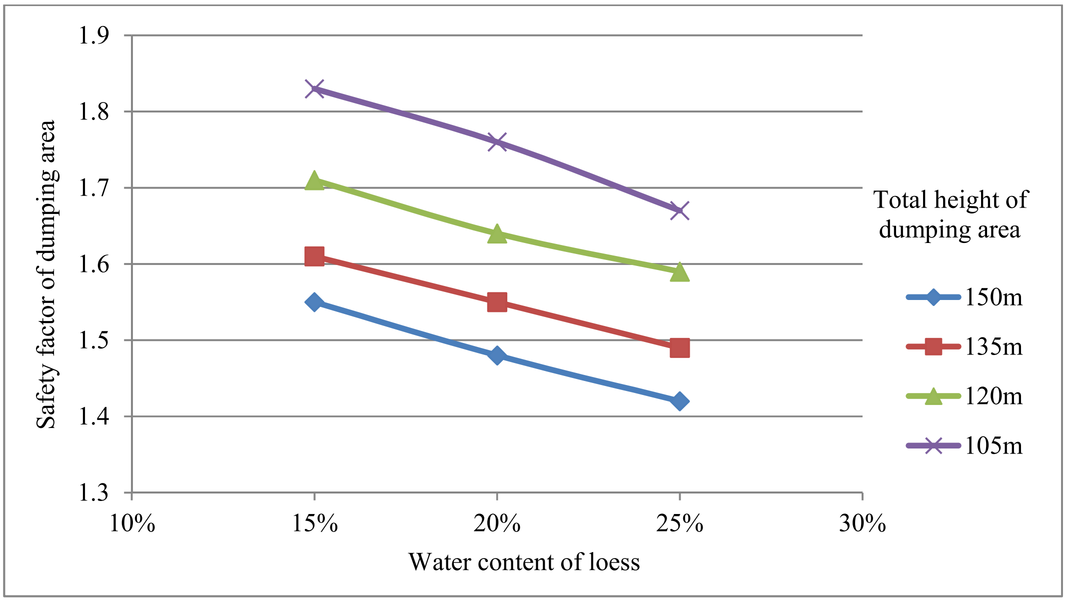

Figure 3.15 Safety factor of dumping area under different water contents of loess

Based on the simulation result, it was also found that the total slope angle of the dumping area will change as the water content of waste loess changes. We assume that the safety factor of dumping area is maintained constant value as 1.42 and the area of dumping area is maintained constant value. The total slope angle of the dumping area is deformed by changing the width of safety bench. **Figure 3.16** shows the total slope angle of the dumping area under different water contents of loess. It was shown that the total slope angle of dumping area decreases with increasing the water content of loess from 15% to 25%.

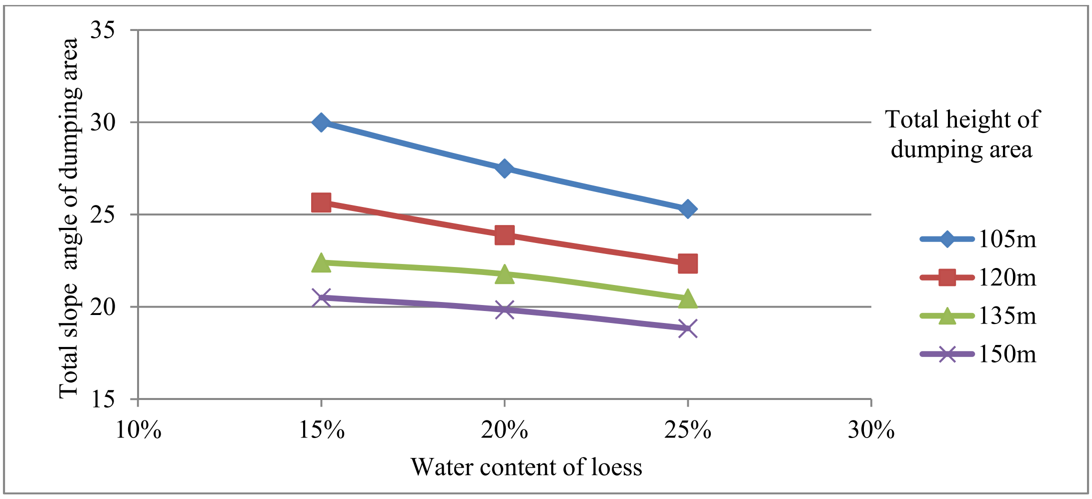

Figure 3.16 Total slope angle of the dumping area under different water contents of loess

The volume capacity of the dumping area was calculated in the geological model under the conditons of different water contents. At first, the maximum total height of dumping area was calculated by the ultimate bearing capacity of the floor based on the density of waste loess. Second, the total slope angle of dumping area was calculated based on the conditions of total height, safety factor, area of dumping area and properties of waste loess. We assume that the volume capacity of dumping area is equal to the cross-sectional area of the dumping area times 1.5 km. **Figure 3.17** shows that the volume capacity of the dumping area under different water contents of loess. It was shown that the volume capacity of dumping area decreases with increasing the water content of loess.

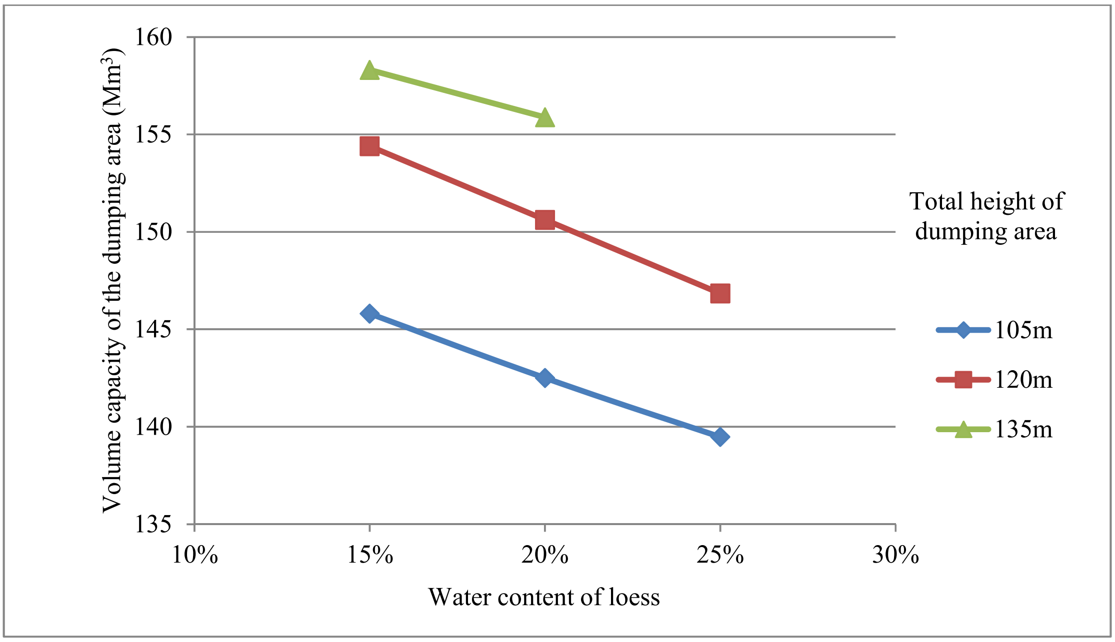

Figure 3.17 Volume capacity of the dumping area under different water contents of loess

Based on the simulation, it could be stated that in the dumping area, the water content of waste loess should be as low as possible to improve the safety factor and increase the total slope angle and volume capacity of the dumping area. Furthermore, the water content of waste loess must meet the request of environmental protection and land reclaiming. Thus, the water content of waste loess should be as low as possible from the view of stability of dumping area under the conditions of meeting environmental protection and land reclaiming.

3.4 Summary

Based on the field investigation at East open pit coal mine, rainfall has an important effect on stability of dumping area. The water content of waste loess at East open pit coal mine were around 2.21% to 20.60% based on the laboratory test. The saturated clay seam and loess that situated at below of groundwater level were weak seam and/or easy to become a weak seam. In this dumping area, the stable problems due to gullies were formed in the edge of bench due to soil erosion by rain, water accumulate resulted from cracks formation and subsidence occurrence. According to mechanical and physical rock properties test, it was found that the density of waste loess increases as the water content increases, the Young's modulus and internal friction angle of loess decrease with increasing the water content from 15% to 25%, and the cohesive strength of loess decreases dramatically with increasing the water content from 15% to 25%. Based on these characteristics, it was found by numerical calculation that the maximum total height of dumping area increases from 118 m to 132 m with decreasing the water content of loess from 25% to 15%.

In the working face, the water content of loess should be as low as possible to decrease transport cost. The transport cost will increase in rainy day. Some measures should do to decrease the water content of waste loess that needs to be transported. In roads of dominant loess dumping area, the waste loess should be maintained to achieve the optimum moisture content to promote the quality of roads. The treatment measure could be done by spraying the water based on local evaporation.

In the dumping area, the water content of waste loess should be as low as possible from the view of stability of dumping area under the conditions of meeting environmental protection and land reclaiming based on the simulation the safety factor, total slope angle, and volume capacity of dumping area increase with decreasing the water content of waste loess.

From these guidelines for the improvement of stability are suggested, indicating the importance of drainage systems to decrease the groundwater level and water content of loess dumping areas in order to maintain the stability of the predominant loess dumping area and its dumping capacity. If we only consider hydrological condition, the stability of dumping area is not enough stable. Floor condition as an important influential factor on stability of dumping area must be researched. Therefore, the next Chapter focuses on improvement of stability of dumping area by compaction floor.

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CHAPTER 4

IMPROVEMENT OF STABILITY OF DUMPING AREA BY COMPACTION OF FLOOR

In the previous Chapter, the effect of water content on stability of dominant loess dumping area has been discussed. As a result, it can be seen clearly that the stability significantly decreases with increasing the water content of loess and then the available height of dumping pile decreases dramatically. Therefore, this Chapter focuses on improvment of stability of dumping area by compaction of floor to overcome water effect on stability of dumping. This Chapter discusses the effect of weak floor layer on the stability of dumping area when the thickness and dip of floor are changed, and the effect of a compacted layer built using heavy equipment on the stability of dumping area.

A site investigation was conducted at an open pit coal mine in Indonesia. The floor layer of the dumping area consists of mudstone and clay. At first, the basic properties of the samples were tested in a laboratory, and then a geological model was built based on geological properties and rock properties of mine site. Different initial conditons were adopted to simulate the effect of thickness and dip of weak floor on the stability of dumping area. After that, the permeability coefficient of samples were tested under the different pressures and different water contents. From the results of tests, the minimum loading and minimum thickness of the compacted layer are discussed in regard to the civil engineering standard of Japan. Meanwhile, the effect of the thickness of compacted layer on the stability of dumping area is simulated. After that, the applications of drainage system and compacted layer to the dominant loess dumping area are discussed. Finally, the results are discussed and some conclusions were constructed.

4.1 Effect of the thickness of weak floor on the stability of dumping area

The computational method of bearing capacity of weak floor in high dumping area was summarized (Zhou, 2002). There are also many researches about the bearing capacity of floor and the effect of weak floor in specific open pit coal mines (He et al., 1999; Kan et al., 2010; Sun et al., 2010; Wang, 2007; Wang, 2014; Yang, 2005; Zhang, 2006; Zhao, 2011; Zhao, 2011; Zhou, 2002).

In the external dumping area of mine site which investigates in this research, the floor layer of the dumping area consists of loess. Therefore, the effect of the thickness of weak floor on the stability of dumping area have to be considered because the strength of loess is weak. Geological conditions of mine site are simplified to conduct numerical simulation. **Table 4.1** shows the parameters of external dumping area at an open pit coal mine in Indonesia. The average thickness of weak floor is about 20 m. In order to conduct numerical analysis, the basic properties of compacted layer were tested by constant direct shear test. The water content of the samples was arranged to 12.5% as the optimum moisture content. The processes of laboratory tests are shown in Chapter 3. The basic properties of bedrock, weak floor, and waste come from Indonesia open pit coal mine. **Table 4.2** indicates the basic properties of materials. **Figure 4.1** shows the geological model of external dumping area at an open pit coal mine in Indonesia.

Table 4.1 Parameters of external dumping area

Bench height	10 m	Total height of dumping area	30 m
Angle of bench	40 degrees	Total slope angle of dumping	28 degrees
Length of safety bench	10 m	Dip of floor	0 degrees
Piezometric line	underground 6 m	Thickness of weak floor	20 m

Table 4.2 Basic properties of materials

	Bed rock	Weak floor	Compacted layer	Waste
Density (g/cm^3)	2.0	1.5	1.5	1.5
Young's modulus (MPa)	1,000	50	50	50
Poisson ratio	0.4	0.4	0.4	0.4
Tensile strength(MPa)	0.15	0.02	0.12	0.07
Internal friction angle (Degree)	30	20	43.8	25
Cohesion(MPa)	0.15	0.02	0.106	0.07

Figure 4.2 shows the safety factor and the maximum shear strain of geological model under the thickness of weak floor is 20 m, and the dip of floor is 0 degree. It shows that the safety factor of dumping area is 1.38. The safety factor of dumping area meets

the standard of Indonesia. Furthermore, the circular failure along the floor can be suspected because the shear strains concentrate in the toe of dumping area.

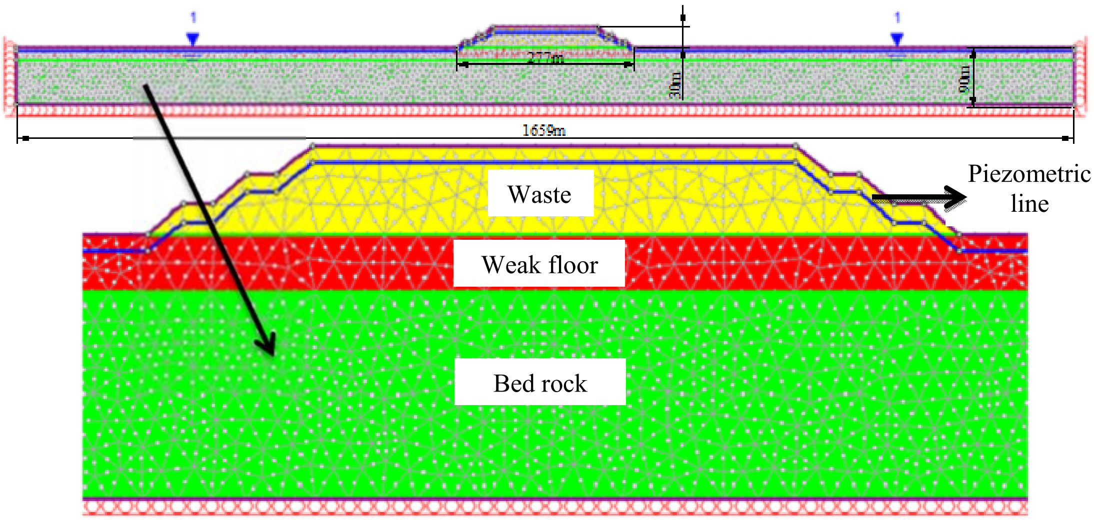

Figure 4.1 Geological model of external dumping area

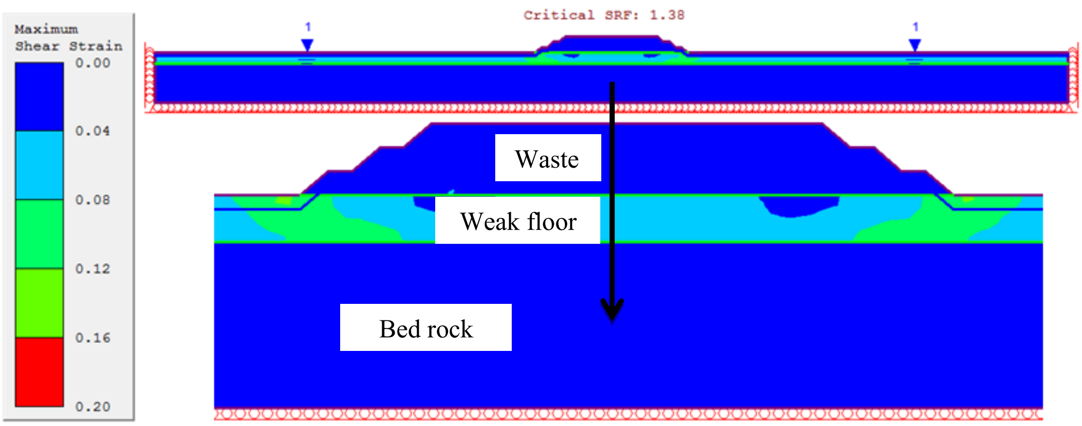

Figure 4.2 Safety factor and the maximum shear strain of geological model when the thickness of weak floor is 20 m and the dip of floor is 0 degree

Figure 4.3 shows the absolute vertical displacement of geological model. It shows that the vertical displacement concentrated on the crest and toe of the dumping area. In the crest of dumping area, the risk of forming cracks is higher due to large displacement to a downward direction. In the toe of dumping area, the vertical displacement is upwards.

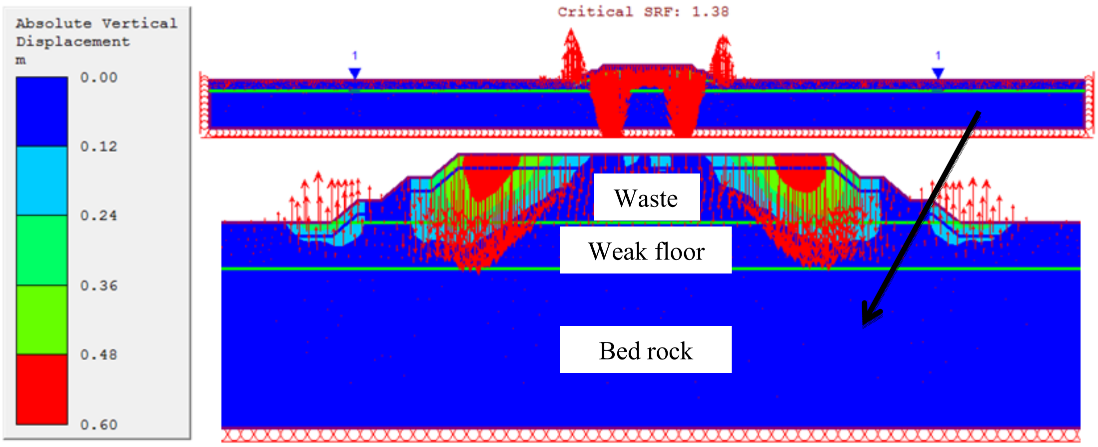

Figure 4.3 Absolute vertical displacement of geological model

In this simulation, the thickness of weak floor is set up as 0 m, 5 m, 10 m, 15 m, 20 m, 25 m, 30 m, 35 m, 40 m, 45 m, and 50 m. **Figures 4.2**, **4.4-4.13** show the maximum shear strain distributions under the different thickness of weak floor. These results show that the dominant maximum shear strain is concentrated in the weak floor. The highest shear strain is concentrated in the toe of the dumping area and weak floor. High shear strain is found at near to the toe of dumping area. Maximum shear strain is found more than 0.04 in most of the weak floor. In other layers, maximum shear strain is mostly less than 0.04. On the whole, maximum shear strain increases with increasing the thickness of weak floor. Moreover, the highest maximum shear strain is found when the thickness of weak floor is 35 m.

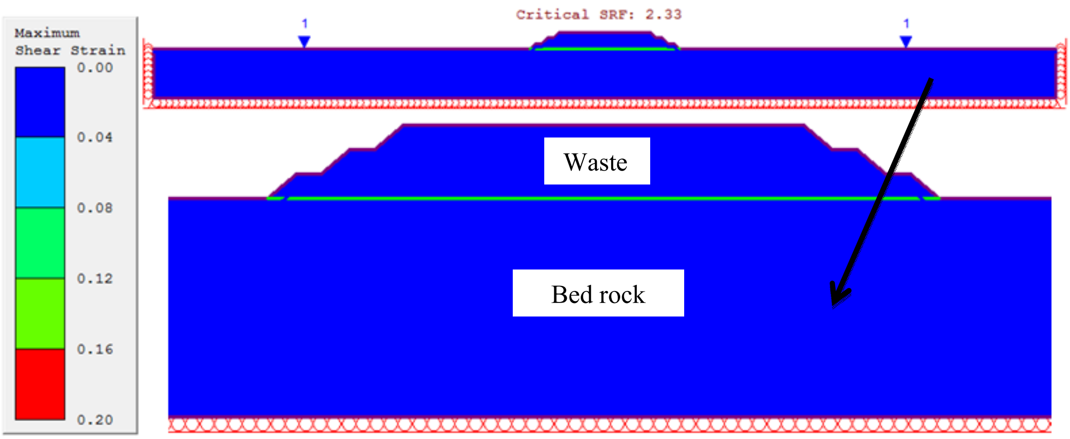

Figure 4.4 Maximum shear strains when the thickness of weak floor is 0 m

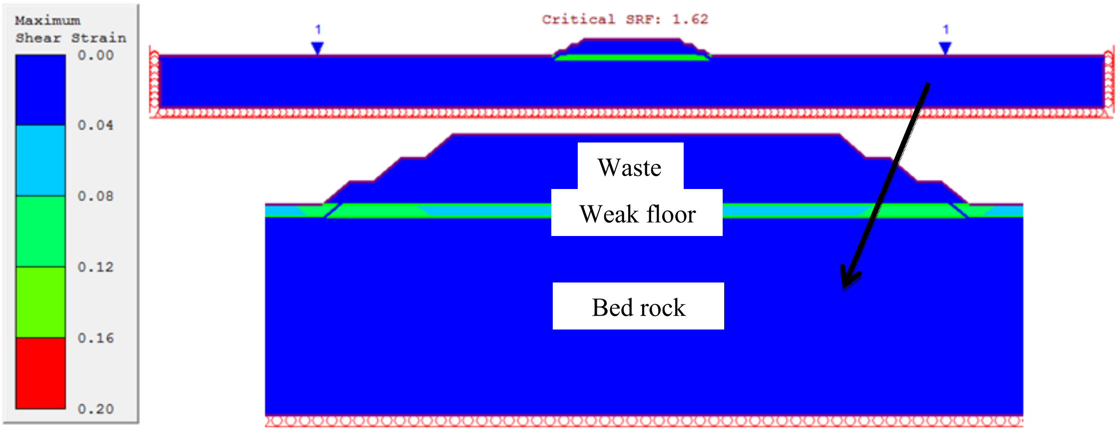

Figure 4.5 Maximum shear strains when the thickness of weak floor is 5 m

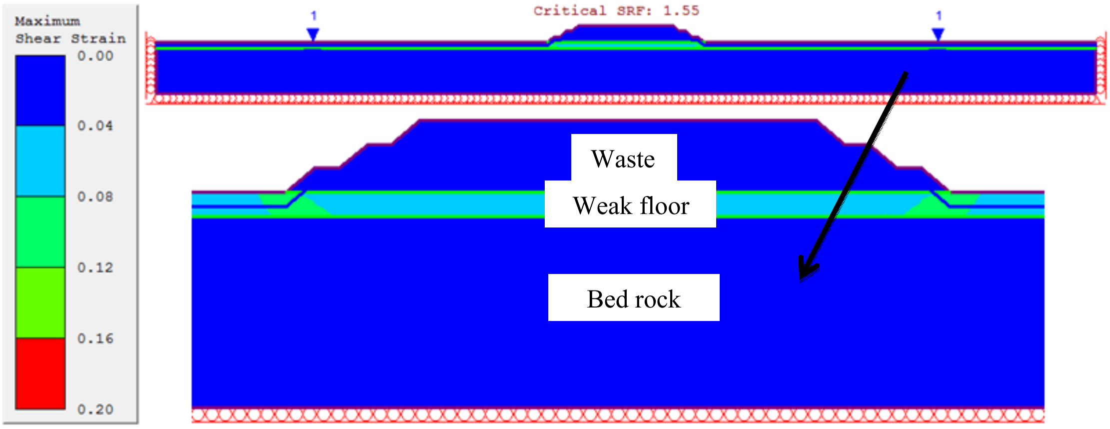

Figure 4.6 Maximum shear strains when the thickness of weak floor is 10 m

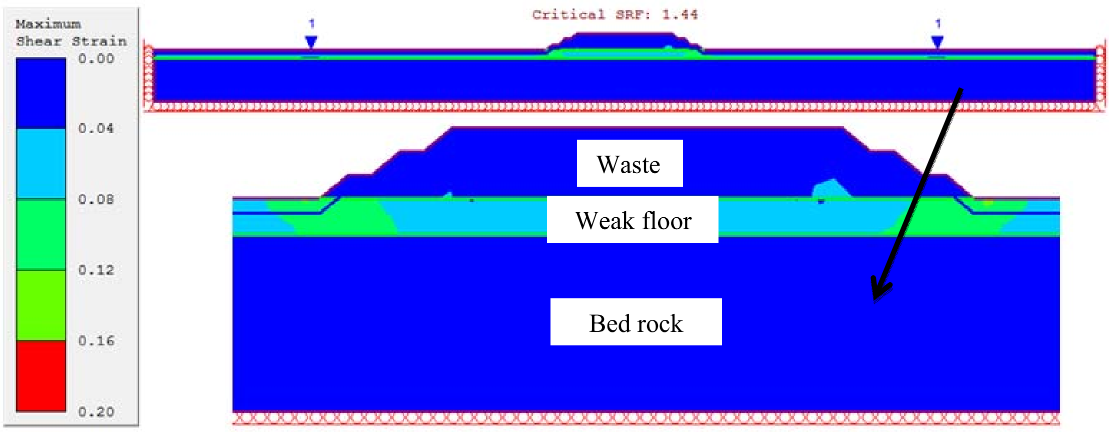

Figure 4.7 Maximum shear strains when the thickness of weak floor is 15 m

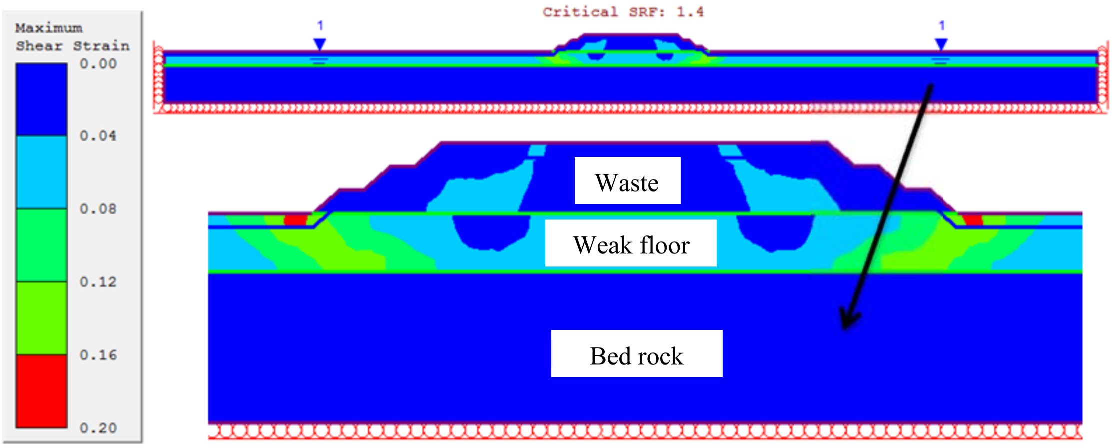

Figure 4.8 Maximum shear strains when the thickness of weak floor is 25 m

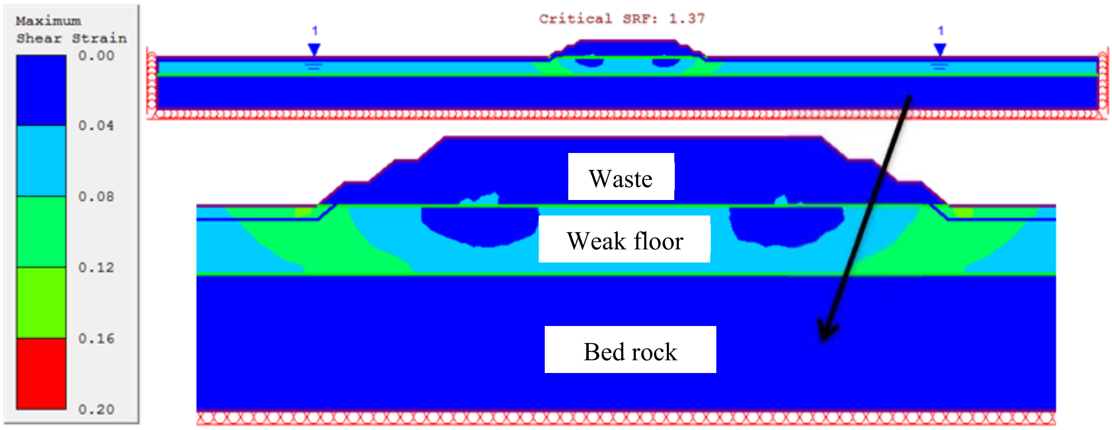

Figure 4.9 Maximum shear strains when the thickness of weak floor is 30 m

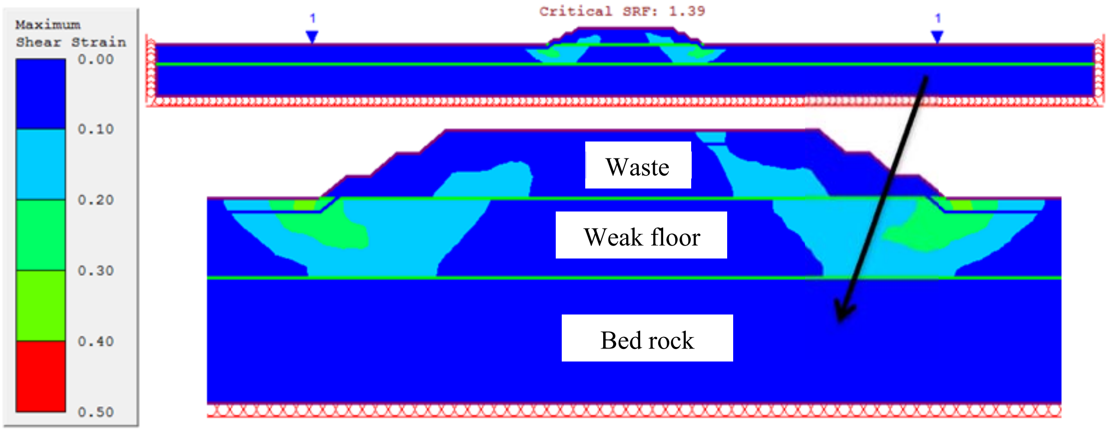

Figure 4.10 Maximum shear strains when the thickness of weak floor is 35 m

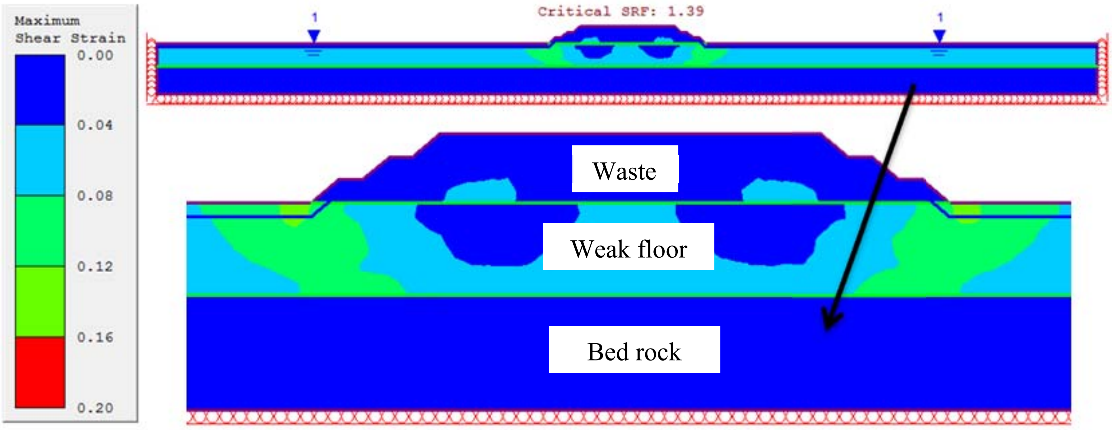

Figure 4.11 Maximum shear strains when the thickness of weak floor is 40 m

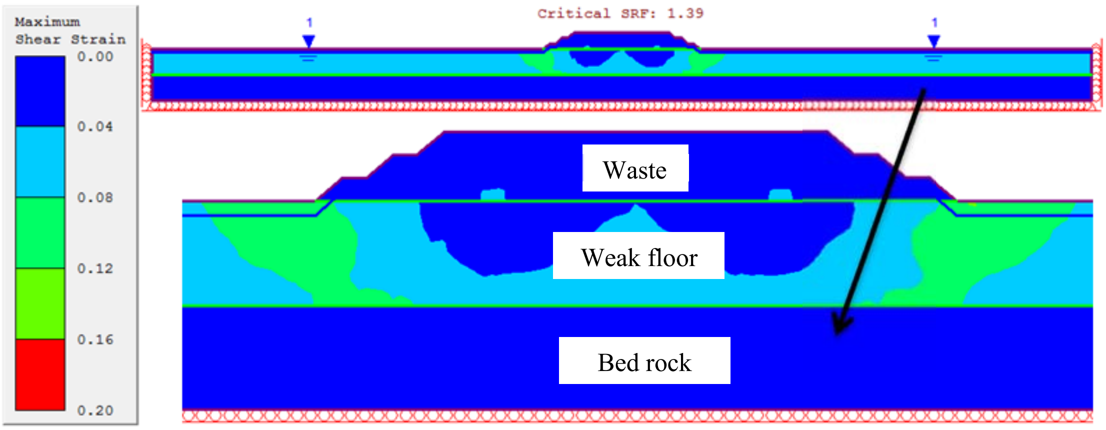

Figure 4.12 Maximum shear strains when the thickness of weak floor is 45 m

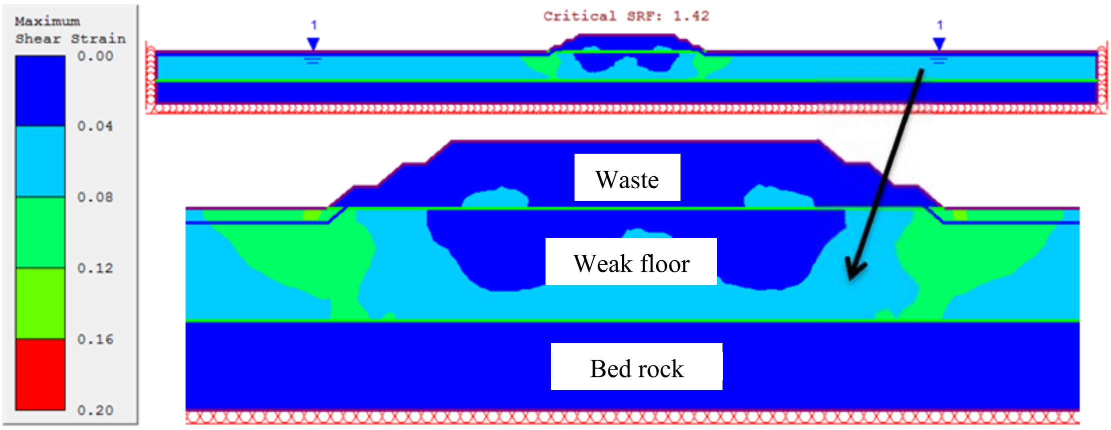

Figure 4.13 Maximum shear strains when the thickness of weak floor is 50 m

Figure 4.14 shows the safety factor of dumping area under the different thickness of weak floor. It shows that the safety factor decreases dramatically with increasing the thickness of weak floor, especially from 0 m to 20 m. The safety factor of dumping area does not have an obvious change from 20 m to 50 m. The thickness of weak floor has an important effect on stability of dumping area. Meanwhile, the thickness of weak floor has a big change as topographic relief. As a result, in the process of selecting dumping area, thin weak floor is better than thick weak floor when the thickness of weak floor is less than 20 m. On the other hand, the stability of dumping area can be improved through decreasing the thickness of weak floor when the thickness of weak floor is less than 20 m.

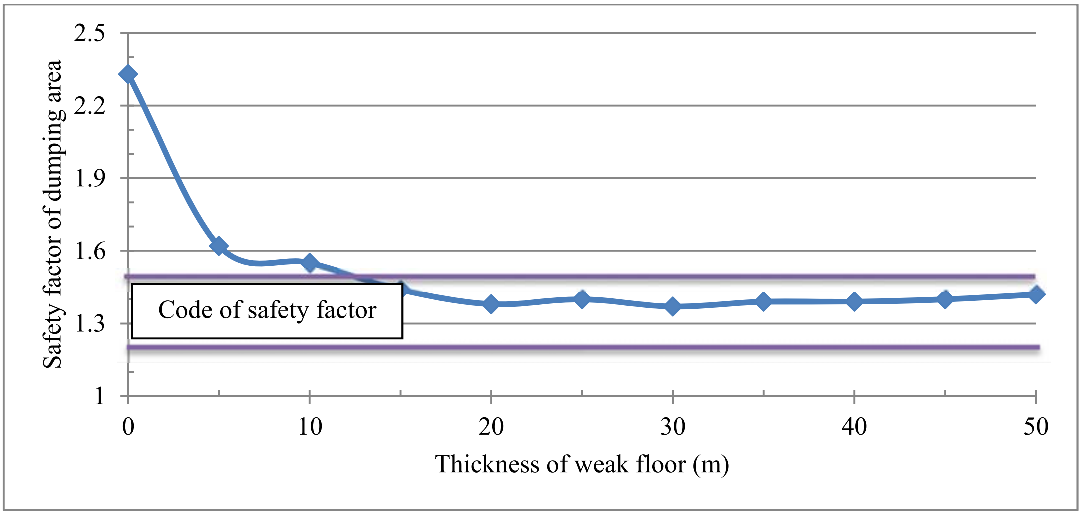

Figure 4.14 Safety factor of dumping area under the different thickness of weak floor

4.2 Dip of weak floor on the stability of dumping area

The dip of floor has an important effect on volume capacity and stability of dumping area. The failure mechanism of the inclined floor dumping area was analyzed (Su et al., 1997; Wang et al., 2009). In this section, the dips of floor are modified gradually to analyze the effect on the stability of dumping area. The dips of floor are set up as 0-6 degrees. The floor length of dumping area and X axis length of geological model keeps a constant value. **Figure 4.15** shows the the geological model when the dip of the floor is 3 degrees.

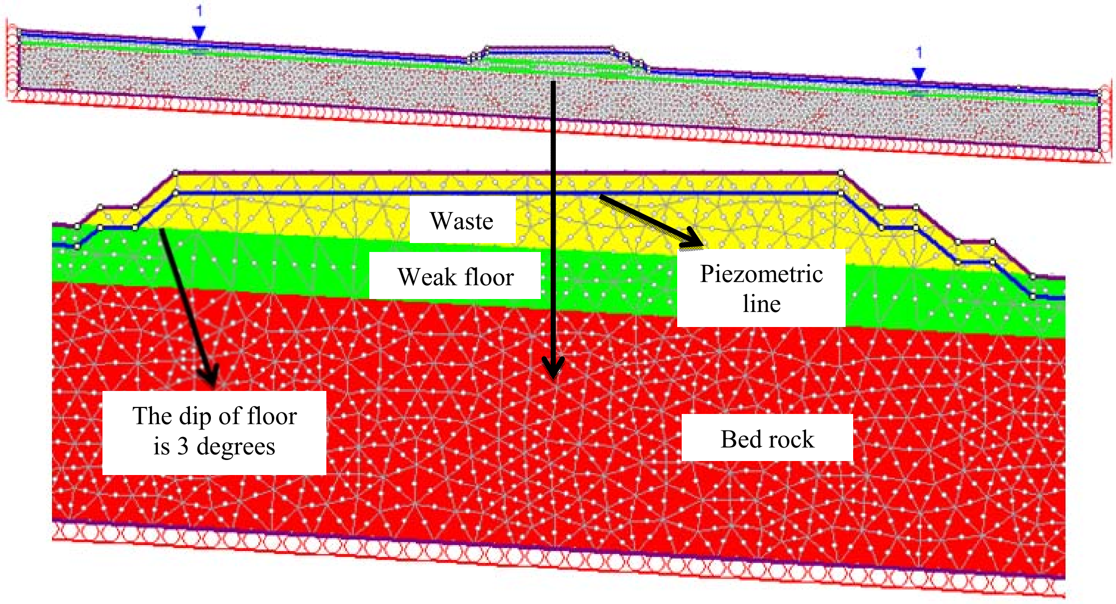

Figure 4.15 Geological model when the dip of floor is 3 degrees

Figures 4.2, 4.16-4.21 shows the maximum shear strain of geological model under the different dips of floor. These show that the maximum shear strain is from 0 to 0.15. The maximum shear strain is concentrated in the toe of the dumping area, especially in the right toe of the dumping area. Maximum shear strain is not stable as increasing the dip of floor.

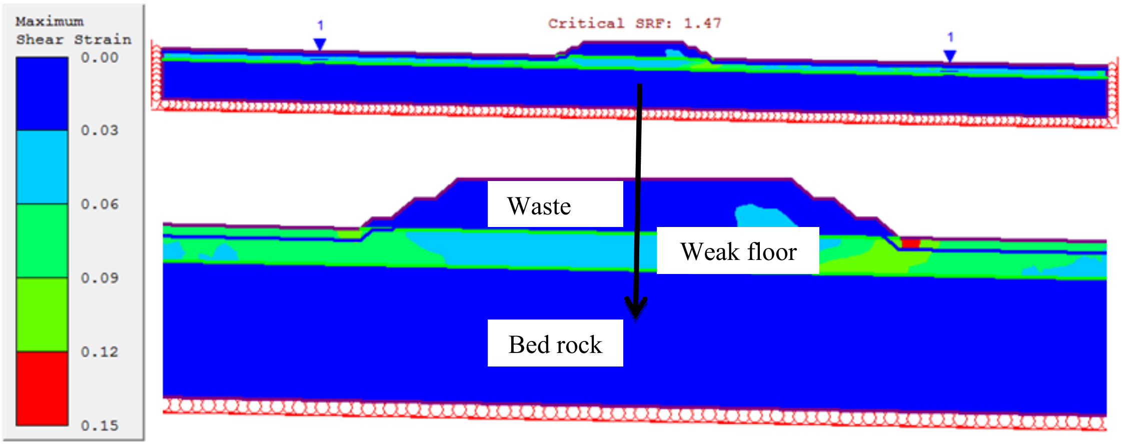

Figure 4.16 Maximum shear strains when the dip of floor is 1 degree

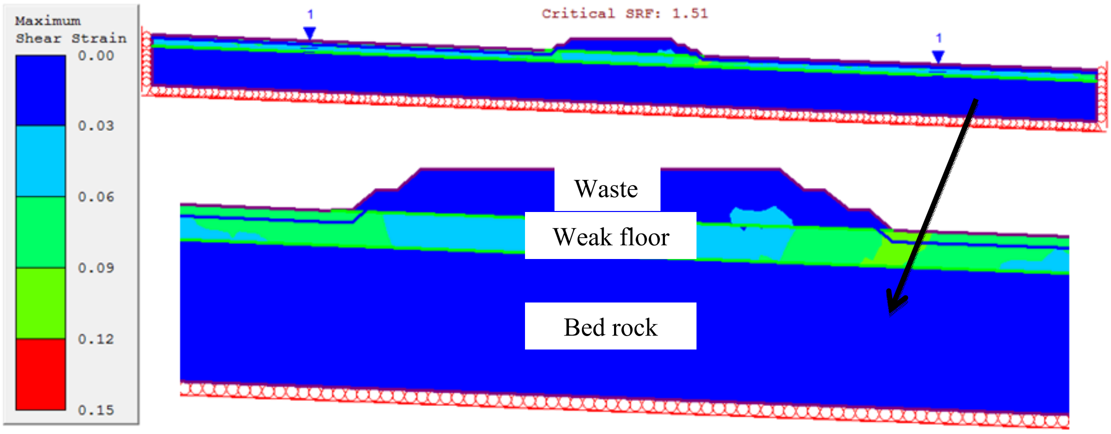

Figure 4.17 Maximum shear strains when the dip of floor is 2 degrees

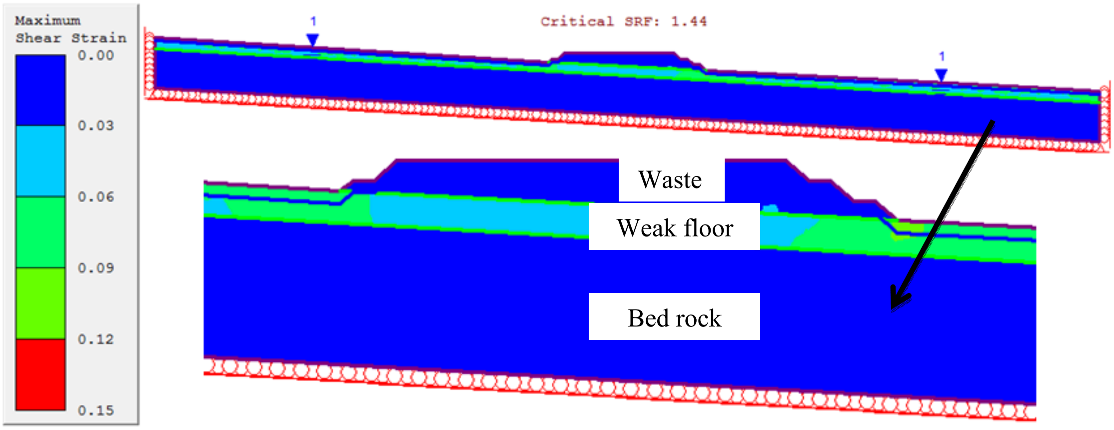

Figure 4.18 Maximum shear strains when the dip of floor is 3 degrees

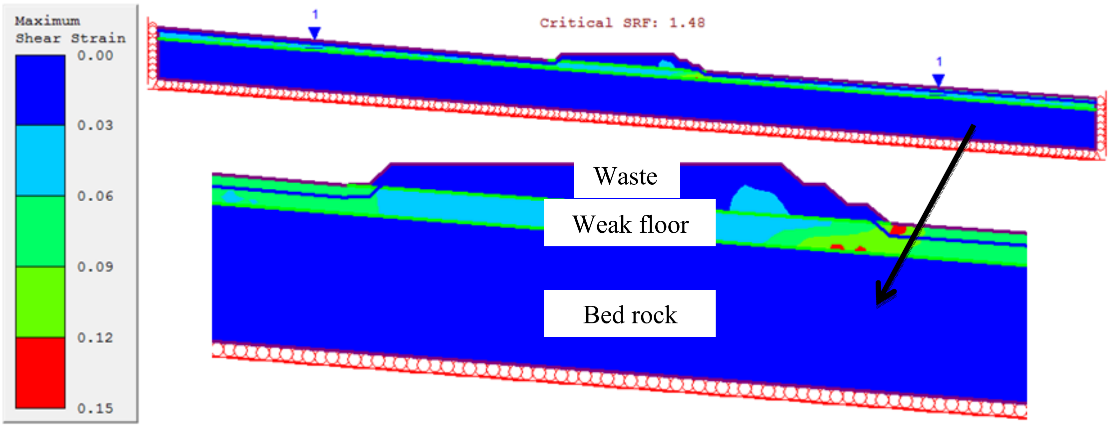

Figure 4.19 Maximum shear strains when the dip of floor is 4 degrees

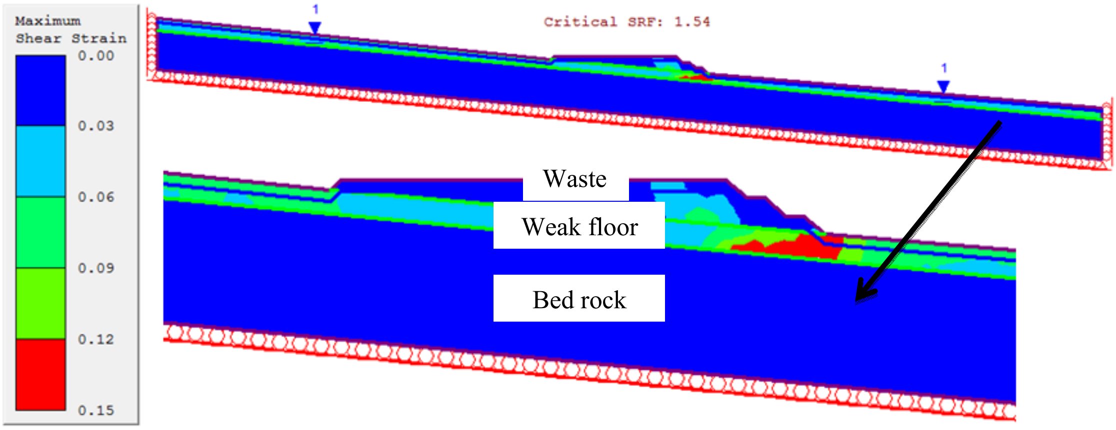

Figure 4.20 Maximum shear strains when the dip of floor is 5 degrees

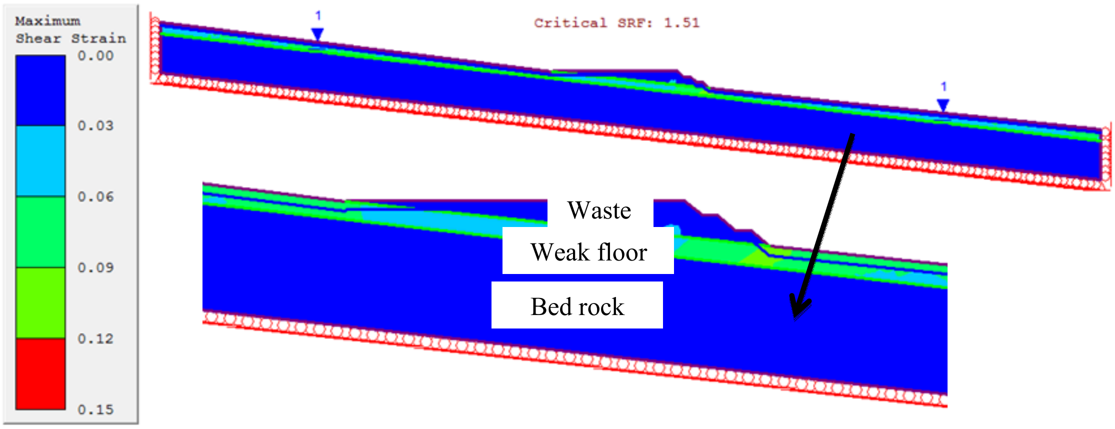

Figure 4.21 Maximum shear strains when the dip of floor is 6 degrees

Figure 4.22 shows the relationship between the dip of floor and safety factor, and volume capacity of the dumping area. It shows that the volume capacity of the dumping area decreases dramatically with increasing the dip of floor. The cause is that the cross section area of dumping area decreases dramatically with increasing the dip of floor. Meanwhile, the figure shows the safety factors of dumping area do not have big differences with increasing the dip of floor. On the other hand, the stability of dumping area is improved due to decreasing the volume of dumping area. Therefore, it can be expected that the stability of dumping area decreases with increasing of the dip of floor under the constant volume capacity of dumping area. As a result, the dip of floor should be as low as possible to improve the volume capacity of the dumping area.

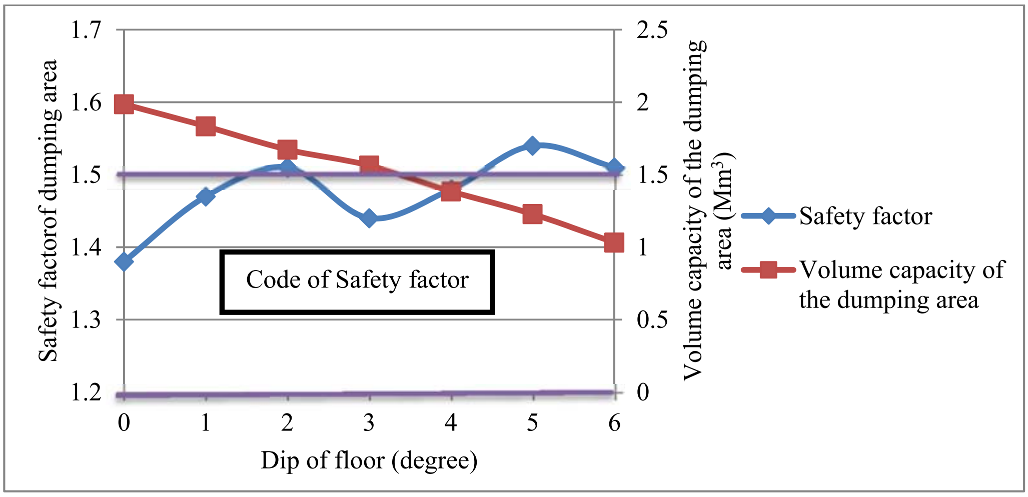

Figure 4.22 Relationship between dip of floor and safety factor, and volume capacity of the dumping area

4.3 Thickness of the compacted layer on the stability of dumping area

The engineering treatments of slope and landslide are consisted of various control methods and drainage system (Wang & Xiang, 2011). There are a lot of researches about the stability control of dumping areas (Guan, 2013; Yang et al., 2007; Zhang, 2013). The thickness of weak floor gives an obvious effect on the stability of dumping area. Meanwhile, application of a compacted layer is a common control measure to improve the stability of dumping area. Therefore, application of compacted layer to improve the stability of dumping area is discussed in this section.

Before the thickness of compacted layer on stability of dumping area is discussed, the minimum thickness of compacted layer for the environment protection is researched. The minimum thickness of compacted layer cannot be ignored due to government's request because the coal mine has water pollution. Clay and iron components are associated with deposits at an open pit coal mine in Indonesia. Iron components results in acid water. Therefore, an appropriate thickness of compacted layer have to be determined in order to prevent the infiltration of acid water to the underground. Meanwhile, the effect of water contents of waste and compressive pressures on the permeability must be examined because the permeability of the sample is affected by these factors. From these reasons, the permeability of the sample which obtained from the mine site is investigated under the different pressures and the different water contents.

The samples are from Q10 of dumping area of the mine, Indonesia. It consists of sample 1, sample 2, and sample 3. At first, optimum moisture content, plastic limit, and natural water content were measured. **Table 4.3** shows the test results of optimum moisture content, plastic limit, and natural water content. After that, the consolidation test was conducted under the different pressures and the different water contents. **Figures 4.23**, **4.24**, and **4.25** show the relationship between coefficient of permeability and pressure under the optimum moisture content, the plastic limit, and the natural water content.

Table 4.3 Test results of optimum moisture content, plastic limit, and natural water content

	Sample1	Sample 2	Sample 3
Optimum moisture content	11%	12.5%	14%
Plastic limit	23%	25.8%	29%
Natural water content	17.5%	13.8%	18.3%

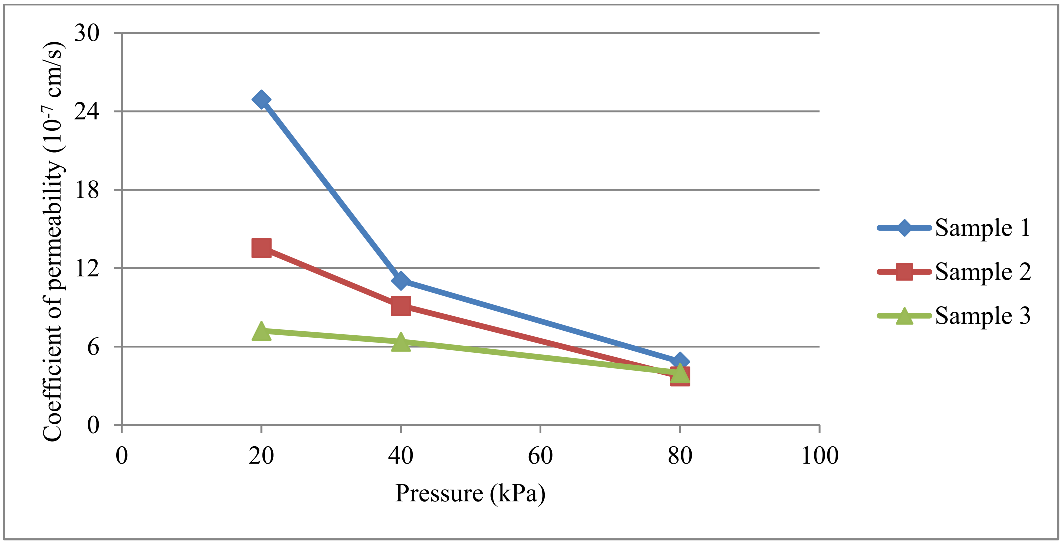

Figure 4.23 Relationship between coefficient of permeability and pressure under the optimum moisture content

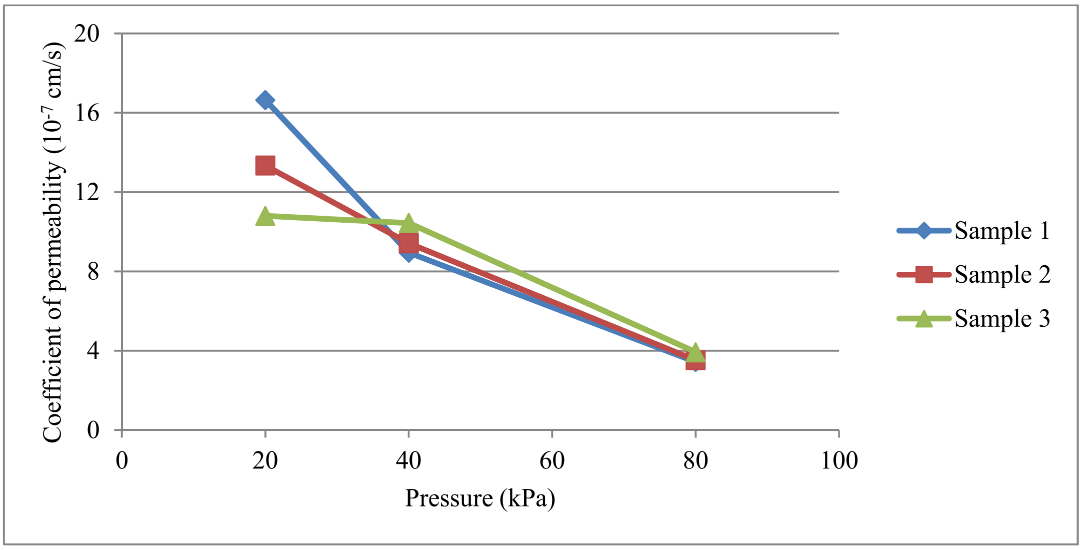

Figure 4.24 Relationship between coefficient of permeability and pressure under the plastic limit

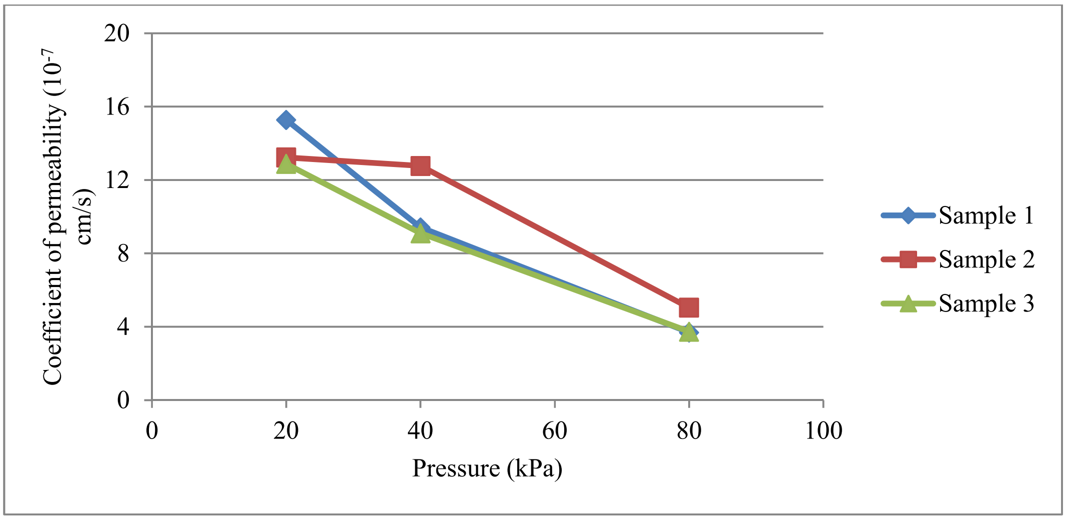

Figure 4.25 Relationship between coefficient of permeability and pressure under the nature water content

Figures 4.23-4.25 indicate that the coefficient of permeability of samples decreases with increasing the pressure. This is reason why the void ratio decreases with increasing the pressure. However, the coefficient of permeability converges on a constant value as loading increases. It indicates that the type of samples which used in this test has less effect on consolidation behavior. The coefficient of permeability of all samples is approximately 4.0×10^{-7} cm/sec when the pressure is 80 kPa. According to civil engineering standard of Japan, the layer which the permeability is less than 1.0×10^{-6} cm/sec is classified as low-permeability layer. This indicates that all of samples can be formed a low-permeability layer when the pressure is 60 kPa regardless of water contents. To form low-permeability layer in the floor, a compact machinery with pressure more than 60 kPa should be selected. Considering the pressure from overburden, the pressure of 60 kPa can be achieved when the density of the compacted layer is 1.8 g/cm^3 and the thickness of the compacted layer is 3.3 m. When the thickness of layer is more than 3.3 m, the layer can be consolidated more due to increasing the weight of overburden. It is effective not only for minimizing the strength reduction in the bottom part of the floor layer due to infiltrating rain water, but also for controlling the drainage of the dumping pile.

Next, the effect of the thickness of the compacted layer on the stability of dumping area is discussed. The thickness of compacted layer is set up as 1.5 m, 3.0 m, 4.5 m, and 6.0 m. The thickness of weak floor is 10 m, 15 m, 20 m, 25 m, 30 m, 35 m, 40 m, 45 m, and 50 m. **Figure 4.26** shows a geological model when the thickness of the compacted layer and weak floor are 3 m and 15 m, respectively.

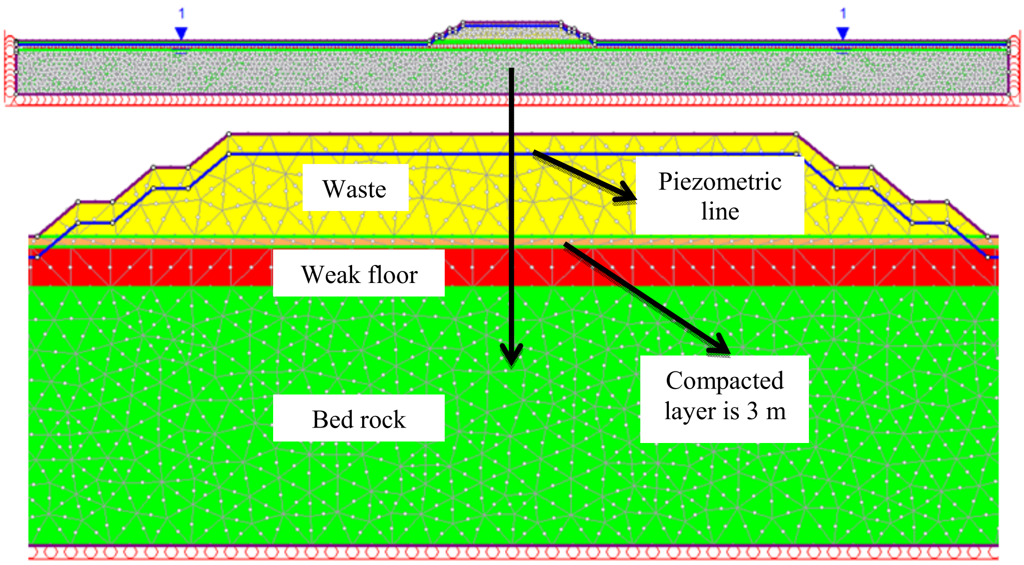

Figure 4.26 Geological model when the thickness of the compacted layer and weak floor are 3 m and 15 m, respectively

Figures 4.27-4.30 show the maximum shear strain under the different thickness of compacted layer when the thicknesses of weak floor is 15 m. It shows that the maximum shear strain concentrated in toe of the dumping area. The maximum shear strain shows higher value in weak floor, compacted layer, and internal of dumping area. Furthermore, the maximum shear strain in the compacted layer decreases with increasing the thickness of compacted layer. The maximum shear stain in the weak floor increases with increasing the thickness of compacted layer.

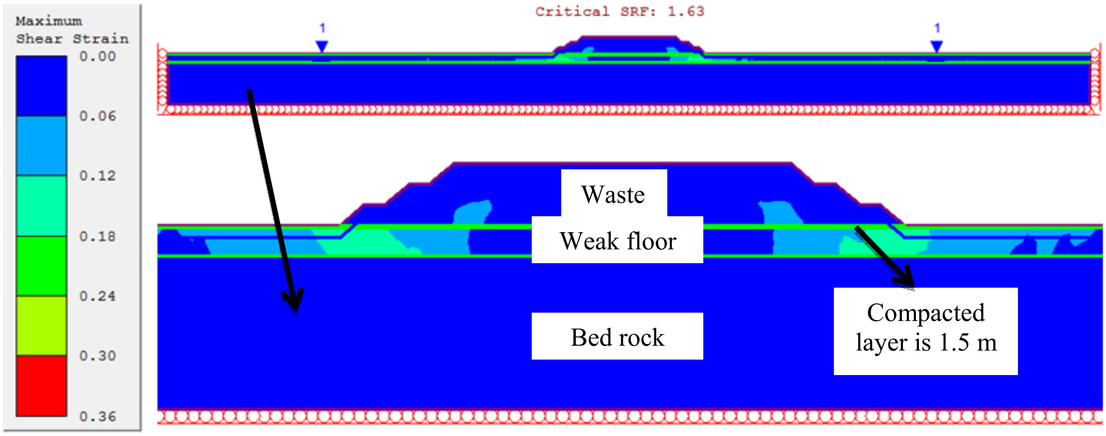

Figure 4.27 Maximum shear strains when the thickness of the compacted layer and weak floor are 1.5 m and 15 m, respectively

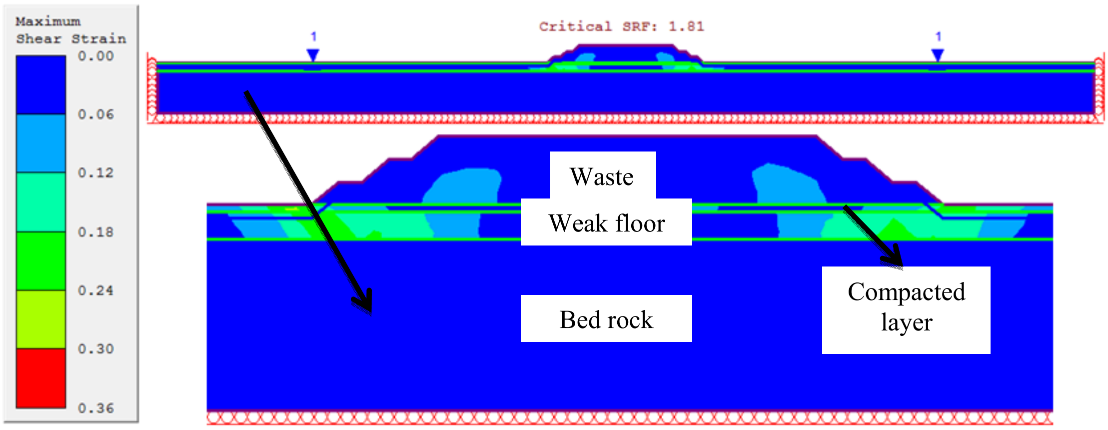

Figure 4.28 Maximum shear strains when the thickness of the compacted layer and weak floor are 3.0 m and 15 m, respectively

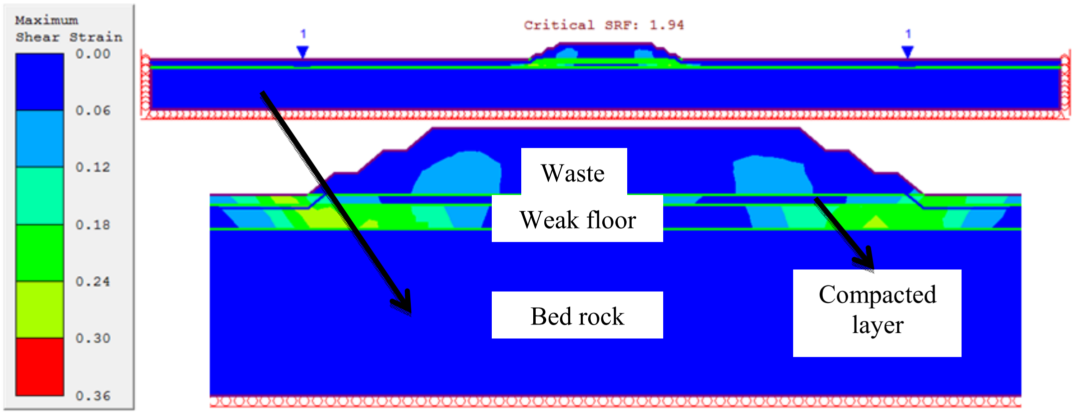

Figure 4.29 Maximum shear strains when the thickness of the compacted layer and weak floor are 4.5 m and 15 m, respectively

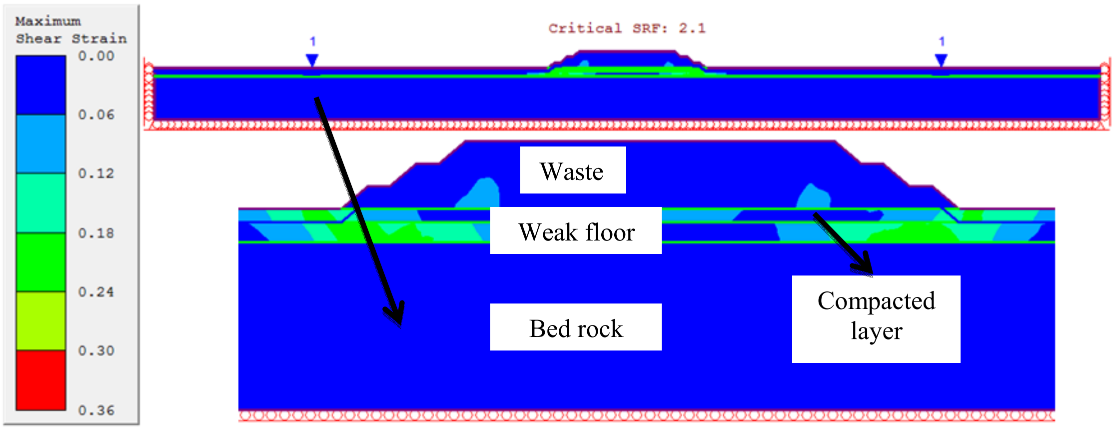

Figure 4.30 Maximum shear strains when the thickness of the compacted layer and weak floor are 6.0 m and 15 m, respectively

Figure 4.31 shows the safety factor of dumping area under the different thickness of compacted layer and weak floor. It shows that the safety factor of dumping area increases with increasing the thickness of compacted layer when the thickness of weak floor is from 0 m to 20 m. The safety factor of dumping area increases smoothly with increasing the thickness of compacted layer when the thickness of weak floor is from 20 m to 50 m. According to these results, it can be said that the much more thickness of compacted layer is required with increasing the thickness of weak floor when the safety factor of dumping area is maintained in a constant value and the thickness of weak floor is from 0 m to 20 m. In addition, compacted layer of floor can control rainwater seeping into ground on rainy days. Regarding the risk of decreasing the stability of dumping area on rainy days, application of compacted layer is necessary. Improvement of the stability of dumping area can be achieved by compaction of floor when the thickness of weak floor is from 0 m to 20 m. Regarding the open pit in Indonesia, the safety factor is 1.62 when the thickness of compacted layer and weak floor are 3 m and 20 m, respectively. Therefore, the safety factor of dumping area can be achieved more than 1.62 because the minimum thickness of the compacted layer is 3.3 m for environmental protection. In this case, the height of dumping area can be increased from the stability point of view at the mine.

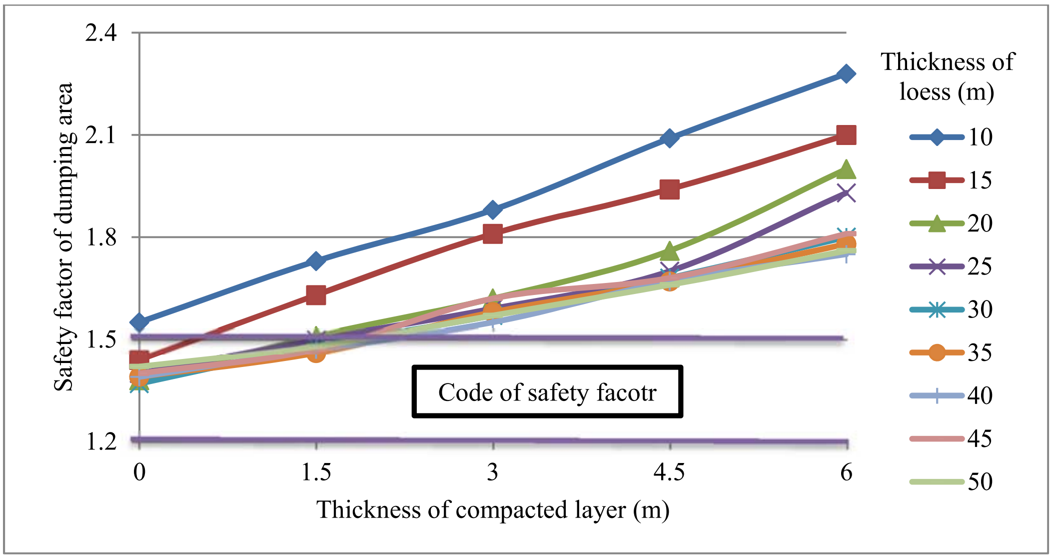

Figure 4.31 Safety factor of dumping area under the different thickness of compacted layer

4.4 Applications of drainage system and compacted layer on dominant loess dumping area

Previous researches have pointed out the failure mechanism, the stability effect of water content of loess, and the improvement of stability of dumping area by compaction of floor in dumping area which has weak floor. This section discusses these researches together, and then apply these researches to dominant loess dumping area by Phase^{2D} software.

In the geological model of Chapter 4, the piezometric line is assumed as 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, and 8 m below the surface, and the thickness of compacted layer is 0 m, 1.5 m, 3.0 m, 4.5 m, and 6.0 m. Other parameters keep in constant value. **Figure 4.32** shows a geological model when the thickness of the compacted layer is 6 m and the piezometric line is 8 m.

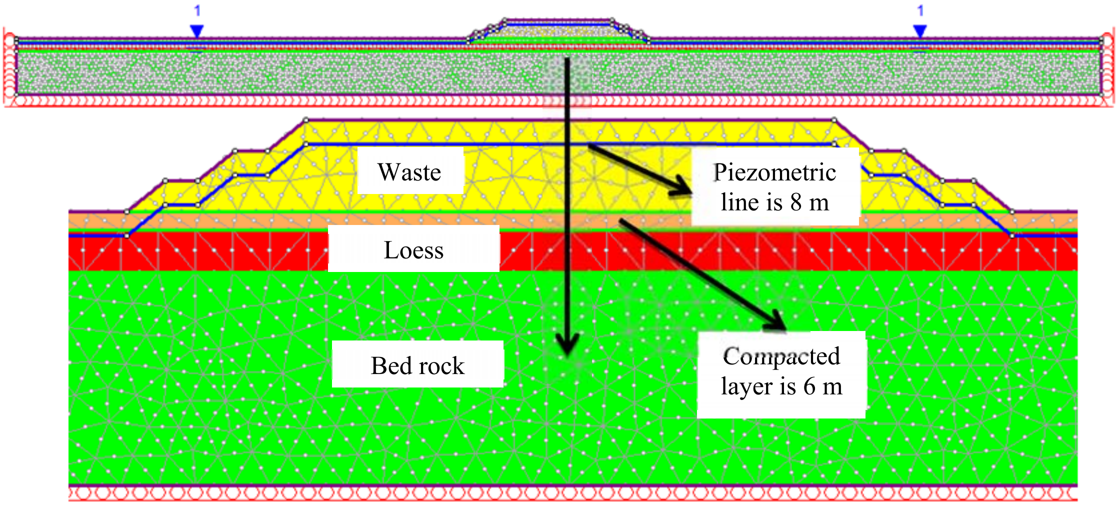

Figure 4.32 Geological model when the thickness of the compacted layer is 6 m and the piezometric line is 8 m

Figure 4.33 shows the safety factor of dumping area under the different thickness of compacted layer and different piezometric line. In the initial condition, the piezometric line is 6 m below the surface; the thickness of compacted layer is 0 m. The safety factor of dumping area increases from 1.03 to 1.50 with increasing the piezometric line from 1 m to 8 m below the surface when the thickness of compacted layer is 0 m. The safety factor increases from 1.38 to 2.00 with increasing the thickness of compacted layer from 0 m to 6 m when the piezometric line is 6 m below the surface. From these results, it can be said that the safety factor of dumping area can be improved obviously by designing the proper thickness of compacted layer though the safety factor is affected by the piezometric line.

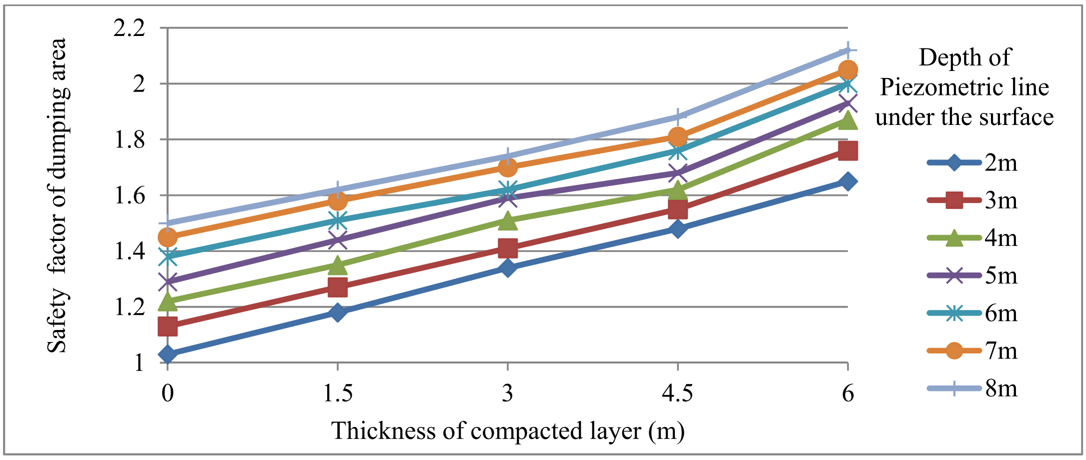

Figure 4.33 Safety factor of dumping area under the different thickness of compacted layer and thicknesses under different piezometric line

Next, the effect of water content on the stability of dumping area is discussed. The water content of loess is 15%, 20%, and 25%, and the thickness of compacted layer is 0 m, 1.5 m, 3.0 m, 4.5 m, and 6.0 m. The piezometric line is 6 m below the surface. Other parameters keep in constant value. The properties of waste loess under the different water contents come from Chapter 3. **Figure 4.34** shows a geological model when the water content of waste loess is 20% and the thickness of compacted layer is 6 m.

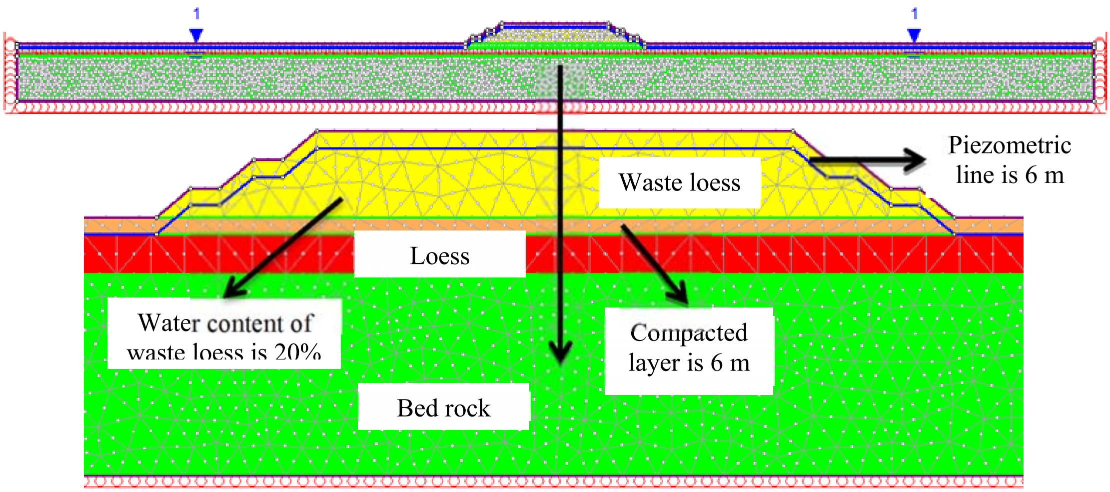

Figure 4.34 Geological model when the water content of waste loess is 20% and the thickness of compacted layer is 6 m

Figure 4.35 shows the safety factor of dumping area under the different thickness of compacted layer and the different water content of waste loess. The safety factor of dumping area increases from 1.31 to 1.40 with increasing the water content of waste loess from 15% to 25% when the thickness of compacted layer is 0 m. The safety factor of dumping area increases from 1.41 to 2.04 with increasing the thickness of compacted layer from 0 m to 6 m when the water content of waste loess is 20%. The stability of dumping area can be improved by decreasing of water content of waste loess, and the effect is not more obvious than compacted layer.

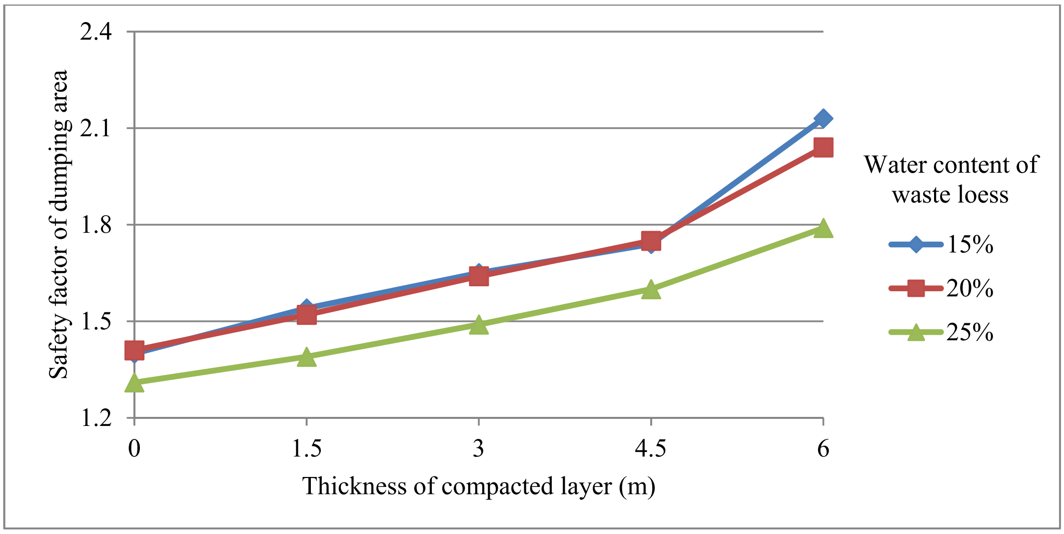

Figure 4.35 Safety factor of dumping area under the different thickness of compacted layer and the different water content of waste loess

To conclude, the primary factor of the stability of dumping area is groundwater level. Meanwhile, the water content of waste loess is also important to discuss the stability of dumping area. Therefore, the design of good drainage system has an important role to improve the stability of dumping area. **Figure 4.36** shows the proposed for drainage system. Horizontal drainage channels are set up in the bottom of bench to descend the groundwater level in the dumping area. In South external dumping area at Antaibao open pit coal mine, the distance between the toe of dumping area and the starting point of shear deformation is from 65 m to 70 m. In this range, the floor is easy to be a weak. **Figure 4.37** shows the drainage system that the dewatering wells are set up in the floor close to toe of the dumping area and a compacted layer is formed in the floor. The purpose is to descend the groundwater level in the toe of dumping area and prevent the rainwater seeping into the ground. Moreover, the bear capacity of weak loess and the stability of dumping area can be also improved by compacted layer. Meanwhile, the frozen water cannot be occurred in the toe of dumping area due to descending the groundwater level. Furthermore, as the water content of floor in this area is maintained at a low level, the floor has a good strength. The length of horizontal drainage channel and depth of dewatering well depend on the state of stability of dumping area and code of mining development. For instance, in the Indonesian open pit coal mine, the code of mining development requests that safety factor is more than 1.2 in dumping area. The piezometric line should not be higher than 4 m below the surface based on the results of **Figure 4.33**. Therefore, the depth of dewatering well should be more than 4 m and the length of horizontal drainage channel should be more than 4.8 m when the slope angle is 40 degree. Moreover, the drainage system must make rainwater run out dumping area easily on rainy days.

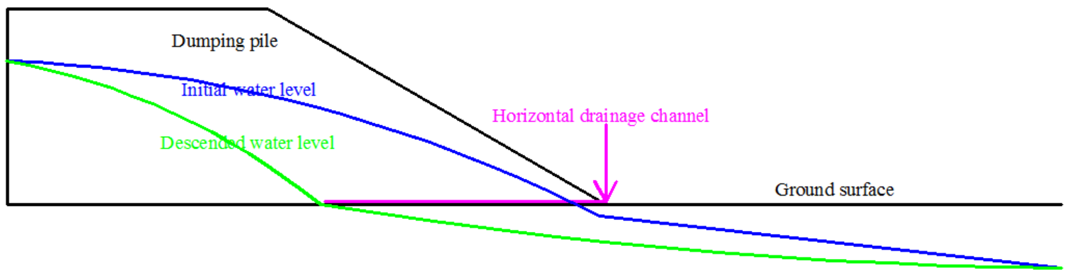

Figure 4.36 Proposed for drainage system

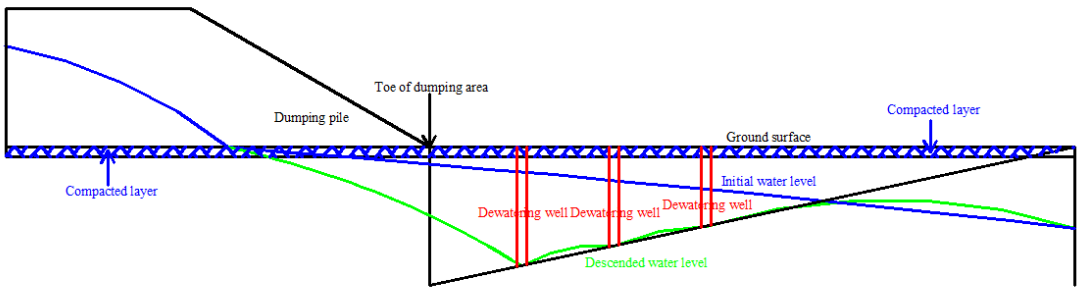

Figure 4.37 Dewatering well in the floor close to toe of dumping area and a compacted layer is formed in the floor

The compacted layer should be set up on the top of layers of weak floor to prevent the infiltration of acid water to the underground, to prevent the rainwater seeping into the ground on rainy days, and to improve the stability of dumping area. At first, the thickness of compacted layer have to be considered to prevent the infiltration of acid water to the underground. The minimum thickness of compacted layer has to be determined by the permeability coefficient test and the standard of civil engineering to prevent the infiltration of acid water to theunderground. For instance, in the Indonesia open pit coal mine, this minimum thickness of compacted layer should be 3.3 m to prevent the infiltration of acid water to the underground. And then, the thickness of compacted layer should be determined in order to prevent the rainwater seeping into the ground on rainy days. This thickness depends on climate and properties of loess. After that, the thickness of compacted layer should be determined in order to improve the stability of dumping area under the various groundwater levels. For instance, in the Indonesia open pit coal mine, this thickness should be more than 1.5 m based on the results of **Figure 4.33**.

4.5 Summary

In this Chapter, the effects of the thickness and dip of weak floor on the stability of dumping area, and the thickness of the compacted layer to improve the stability of dumping area were analyzed. After that, the applications of dominant loess dumping area based on these researches were discussed. From the results of site investigation, a series of laboratory tests, and numerical analyses, some main conclusions can be summarized as follows.

a) For the weak floor, the results of numerical simulation show that the possible failure model is circular failure along the floor. Furthermore, in the crest of dumping area, the risk of forming cracks is higher due to vertical large displacement to a downward direction. The subsidence results in formation of numerous cracks. In the toe of dumping area, the vertical displacement increases. The results of numerical simulation show that the safety factor of dumping area decreases dramatically with increasing the thickness of weak floor when the thickness of weak floor is from 0 m to 20 m. When the thickness of weak floor is from 20 m to 50 m, the safety factor of dumping area does not have an obvious change. The thickness of weak floor has an important effect on the stability of dumping area. Meanwhile, the thickness of weak floor has a big change as topographic relief. As a result, in the process of selecting dumping area, thin weak floor is better than thick weak floor when the thickness of weak floor is less than 20 m. On the other hand, the stability of dumping area can be improved through decreasing the thickness of weak floor when the thickness of weak floor is less than 20 m.

b) The volume capacity of the dumping area decreases dramatically with increasing the dip of floor. The cause is that the cross section area of dumping area decreases dramatically with increasing the dip of floor. Meanwhile, the results show that the safety factor of dumping area does not have a big difference with increasing the dip of floor. On the other hand, the stability of dumping area can be improved by decreasing the volume of dumping area. Therefore, it can be expected that the stability of dumping area decreases with increasing of the dip of floor under the constant volume capacity of dumping area. As a result, the dip of floor should be as low as possible to improve the volume capacity of dumping area.

c) Improvement of the stability of dumping area can be achieved by compaction of floor. The results of numerical simulation show that the safety factor of dumping area increases with increasing the thickness of compacted layer when the thickness of weak floor is from 0 m to 20 m. The safety factor of dumping area increases smoothly with increasing the thickness of compacted layer when the thickness of weak floor is from 20 m to 50 m. The thickness of compacted layer increases with increasing the thickness of weak floor when the safety factor of dumping area is maintained in a constant value and the thickness of weak floor is from 0 m to 20 m. In addition, compacted layer of floor can control rainwater seeping into ground on rainy days. For example, in the Indonesia open pit coal mine, the minimum thickness of the compacted layer is 3.3 m and the loading pressure should be more than 60 kPa. Furthermore, the safety factor is 1.62 when the thickness of compacted layer is 3 m. Therefore, the safety factor of dumping area can be achieved more than 1.62 because the minimum thickness of the compacted layer is 3.3 m for environmental protection. In this case, the height of dumping area can be increased from the stability point of view at the mine.

d) The primary stability factor of dumping area was piezometric line. Meanwhile, the water content of waste loess is also important to discuss the stability of dumping area. The safety factor of dumping area increases from 1.03 to 1.50 with increasing the piezometric line from 1 m to 8 m below the surface when the thickness of compacted layer is 0 m. The safety factor of dumping area increases from 1.38 to 2.00 with increasing the thickness of compacted layer from 0 m to 6 m when the piezometric line is 6 m below the surface. The stability of dumping area can be improved by decreasing of water content of waste loess, and the effect is not more obvious than the compacted layer. The safety factor of dumping area increases from 1.31 to 1.40 with increasing the water content of waste loess from 15% to 25% when the thickness of compacted layer is 0 m. The safety factor of dumping area increases from 1.41 to 2.04 with increasing the thickness of compacted layer from 0 m to 6 m when the water content of waste loess is 20%.

Horizontal drainage channels are set up in the bottom of bench and dewatering wells are set up in the floor close to toe of the dumping area to descend the groundwater level. The length of horizontal drainage channel and depth of dewatering well depend on the state of the stability of dumping area and code of mining development. For instance, in the Indonesia open pit coal mine, the depth of dewatering well should be more than 4 m and the length of horizontal drainage channel should be more than 4.8 m when the slope angle is 40 degree because the piezometric line should not be higher than 4 m below the surface in order to improve the stability of dumping area. Moreover, the drainage system must make rainwater run out dumping area easily on rainy days. The compacted layer of floor should be set up to prevent the infiltration of acid water to theunderground, to prevent the rainwater seeping into the ground on rainy days, and to improve the stability of dumping area. The minimum thickness of compacted layer should be determined by the permeability coefficient test and the standard of civil engineering to prevent the infiltration of acid water to the underground. And then, the thickness of compacted layer should be determined in order to prevent the rainwater seeping into the ground on rainy days. This thickness depends on climate and properties of loess. After that, the thickness of compacted layer should be determined in order to improve the stability of dumping area under the various groundwater levels. For instance, in the Indonesia open pit coal mine, this thickness should be more than 1.5 m. As a result of numerical analysis, it was concluded that the application of this countermeasure improves the safety factor of a dumping area from 1.38 to 1.51.

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CHAPTER 5

FORMATION MECHANISM OF BENCHES ON STABILITY OF DUMPING AREA

After discussing the factors which influence hydrological condition and floor on stability of dumping area, the formation mechanism of benches on stability of dumping area to design optimum dumping areas will be discussed in this Chapter. At the Heidaigou open pit coal mine, the geological overview, dumping operation, waste particle distribution, and stable problems were investigated. Then, a series of the experiments was conducted in the laboratory to simulate the formation process of single bench, multiple benches, and the efficiency of dumping operation's design. Finally, the relationship between safety factor of dumping area and bench height, bench angle, bulk factor of waste loess, and truck transport were simulated by using numerical simulation.

5.1 Field investigations at Heidaigou open pit coal mine

The Heidaigou open pit coal mine was located in the Inner Mongolia Autonomous Region, China (see **Figure 5.1)**. In 2011, raw coal production was 31 Mt. The recoverable reserve was 1,093 Mt. This open pit coal mine has one internal dumping area and five external dumping areas.

Figure 5.1 Location of the Heidaigou open pit coal mine from Google map

5.1.1 Overview of geology at Heidaigou open pit coal mine

The studied open pit coal mine on the Erdos Plateau is relatively high in the northwest area and low in the southeast area; the maximum and minimum elevations are 1366 and 870 m, respectively. Generally, the elevation ranges from 1,100 to 1,300 m. **Figure 5.2** provides an overview of the Heidaigou open pit coal mine.

Figure 5.2 Overview of the Heidaigou open pit coal mine

The annual precipitation of Heidaigou open pit coal mine is from 231 to 635 mm. The average of annual precipitation is 408 mm; the annual evaporation ranges between 1,324.7 and 2,896.1 mm, with average of approximately 2,100 mm. The climate around the open pit coal mine is arid. The coal seam floor elevation is higher than the Yellow River groundwater level elevation. There are two primary drainage mechanisms i.e. natural infiltration and natural evaporation. The length of mining area is 7.8 km. The average mine width at the bottom is 5.09 km; the area is 40.25 km^2, and the average depth is 150 m.

5.1.2 Dumping operation at Heidaigou open pit coal mine

The Heidaigou open pit coal mine utilizes three dumping operation types. These operations consist of bucket wheel excavator-belt-stacker dumping, shovel-truck-bulldozer dumping, and dragline dumping operation.

a) The bucket wheel excavator-belt-stacker dumping operation

Loess is present at the top of the overburden. The bucket wheel excavator-belt-stacker dumping operation is used to remove the overburden. **Figure 5.3** shows bucket wheel excavator-belt-stacker dumping operation. **Figure 5.4** shows the dumping area which is a result of bucket wheel excavator-belt-stacker dumping operation. In these dumping benches, the waste is primarily loess and contains only small amounts of rock. The particle size distribution is very small and uniform. The waste soils are dumped from the stacker to the top of dumping pile, which then roll along the bench slope. Bulldozers adjust the bench top. **Table 5.1** shows the main parameters for bucket wheel excavator-belt-stacker dumping operation.

Figure 5.3 Bucket wheel excavator–belt-stacker dumping operation

Figure 5.4 Dumping area of bucket wheel excavator–belt–stacker dumping operation

Table 5.1Main parameters for bucket wheel excavator–belt–stacker dumping operation

Parameters	Unit	Value	Parameters	Unit	Value
Bench height	Meter	18	Minimum bench working width	Meter	120
Dumping height	Meter	20	Final slope angle of slope	Degree	20
Dumping width	Meter	40	Bulk factor		1.15

b) The shovel-truck-bulldozer dumping operation

Various rocks are found in the middle of the overburden. The shovel-truck-bulldozer dumping operation is used to remove the overburden. **Figure 5.5** shows shovel-truck-bulldozer dumping operation. **Figure 5.6** shows the dumping area of shovel-truck-bulldozer dumping operation. In these benches, the major wastes are sandstone, mudstone, and clay rock. The particle size distribution varies widely. Generally, small blocks are centralized in the top bench and large blocks are located in the bottom bench. The waste rocks are dumped from the truck to the ground surface and slope. Afterwards, waste materials roll from the slope top to bottom. Bulldozers push the remaining materials from the ground surface to the slope. **Table 5.2** shows the main parameters for shovel-truck dumping operation.

Figure 5.5 Shovel-truck-bulldozer dumping operation

Figure 5.6 Dumping area of shovel-truck-bulldozer dumping operation

Table 5.2 Parameters for shovel-truck-bulldozer dumping operation

Parameters	Unit	Value	Parameters	Unit	Value
Bench height	Meter	35	Final slope angle	Degree	20
Rock roll distance	Meter	18	Minimum working width	Meter	90～95
Repose angle	Degree	35～38	Bulk factor		1.2

c) The dragline dumping operation

At the overburden bottom, dragline dumping is used to remove the overburden. The particle size distribution is similar to the shovel-truck-bulldozer dumping operation. **Figure 5.7** shows dragline dumping operation. **Figure 5.8** shows the dumping area of dragline dumping operation. The waste rocks are dumped from dragline bucket to the slope top, which then roll along the slope. The dumping height is approximately 88 m. **Table 5.3** shows the main parameters for dragline dumping operation.

Figure 5.7 Dragline dumping operation

Figure 5.8 Dumping area of shovel-truck-bulldozer dumping operation

Table 5.3Main parameters for dragline dumping operation

Parameters	Unit	Value	Parameters	Unit	Value
Average bench height	Meter	60.8	Coal bench angle	Degree	75
Bench height	Meter	72.5	Bench angle	Degree	38
Bench width	Meter	80	Blasted stock pile settlement height	Meter	13.5
Average bench height	Meter	60.8	Blasted stockpile height	Meter	31.5
Bulk factor		1.35	Efficiency throwing coefficient	Percent	25
Coal bench height	Meter	30	Coal road width	Meter	30
Rock bench angle	Degree	65			

5.1.3 Waste particle size distributions

The size and shape are two major parameters in waste particle. In the blasting operation of open pit coal mine, the size of waste particle is easy to be controlled, while the shape of particle size is not easy to be controlled. Therefore, in this Chapter, the shape of waste particle was not considered in this research. We selected 7 pictures from separate benches in the shovel-truck-bulldozer and dragline dumping areas. The waste particle size distribution is analyzed with Spilt-Desktop Version 2.0 software. **Table 5.4** shows the analysis results of waste particle size distribution for the shovel-truck-bulldozer and dragline dumping areas. The table shows that the range of waste main particle sizes of is 126.5 to 391.3 mm.

Table 5.4 Analysis results of waste particle size distribution for the shovel-truck-bulldozer and dragline dumping areas

Material No.	P20 (mm)	P50 (mm)	P80 (mm)	Top size (mm)
1	88.7	177.1	362.1	642.4
2	109.9	199.2	300.0	524.4
3	151.4	264.7	393.9	577.9
4	91.4	146.7	293.2	565.5
5	143.1	274.0	539.8	845.4
6	186.0	302.9	482.1	800.6
7	114.7	215.0	368.0	664.7
Average	126.5	225.7	391.3	660.1

Note: P20 – Corresponds to the size in which 20% of the total mass is represented by smaller particles.

P50 – Corresponds to the size in which 50% of the total mass is represented by smaller particles.

P80 – Corresponds to the size in which 80% of the total mass is represented by smaller particles.

5.1.4 Stable problems statement at Heidaigou open pit coal mine

The dumping area problems at the Heidaigou open pit coal mine are as follows.

a) For excavator-belt-stacker dumping, the operation efficiency was low.

b) For shovel-truck-bulldozer dumping, the main waste material is loess in the Yinwan external dumping area. The dumping area is next to a reservoir as shown in **Figure 5.9**. It causes extensive subsidence in the dumping area. Therefore, large trucks cannot work in this area because there is a potential safety risk for both the workers and equipment.

c) For dragline dumping, the bench height is 75 m as shown in **Figure 5.10**. Small landslides occur frequently and affecting the safety of workers and equipment.

Figure 5.9 Yinwan external dumping area next to a reservoir

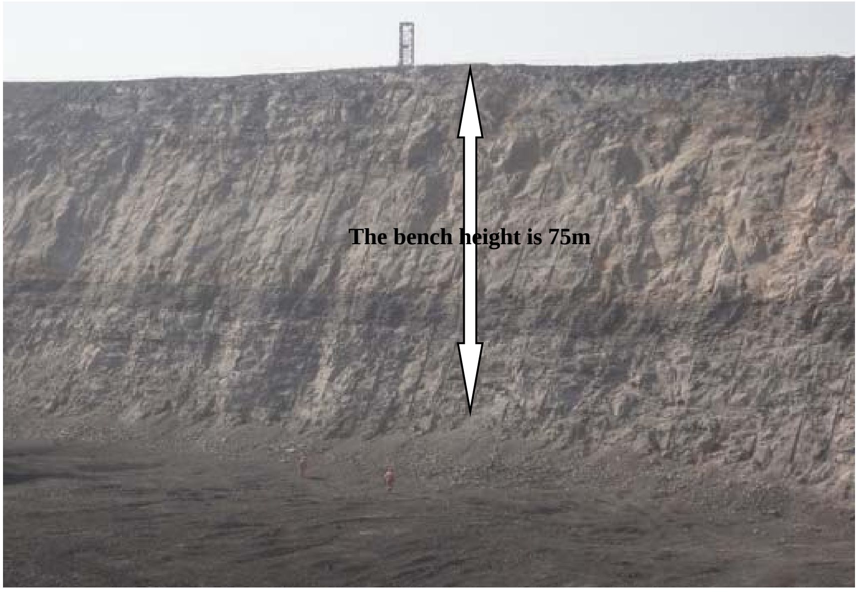

Figure 5.10 High working slope bench in dragline operation

d) Small sliding in loess, rock bench and destroyed road caused by rainfall. **Figure 5.11** shows a small sliding after rain in dominant loess dumping area in 2011.

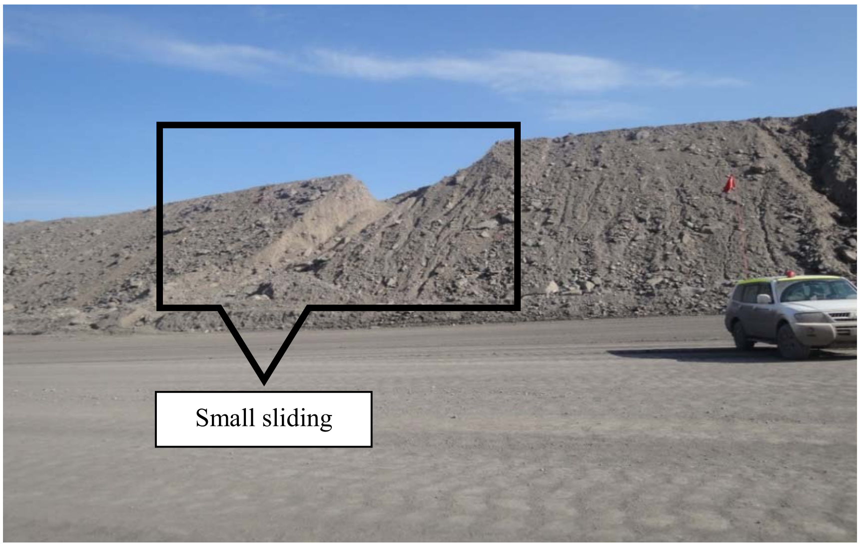

Figure 5.11 Small sliding after rained in dominant loess dumping area in 2011

5.1.5 Setting of tests

Experimental tests are useful to prove and verify theories (Bellaloui and Chtaini, 1999; Krahn et al., 1989; Pelkey et al., 2001). Experiments were conducted to clarify the mechanism of bench formation on stability of dumping area. **Figure 5.12** provides an overview of the experimental device. A certain volume sample is dumped from a specified height with a constant initial velocity. Then, the pile shape is measured. To maintain a constant frictional force at the floor surface, a felt mat is placed on the plate surface. The particle size distribution, dumping volume, dumping height, floor angle, and interval distance can be set in the device.

The experimental procedures are as follows:

a) Select a group of samples that correspond to a particle size range with a sieve.

b) Measure a constant volume sample with a graduated cylinder.

c) Place the constant volume samples into the bucket.

d) Set the dumping height and floor angle.

e) Start the crane and dump them on the floor with a constant initial velocity.

f) Measure the pile height, length, width, and angle.

g) Repeat b) through f) 5 times. Record data and calculate averages.

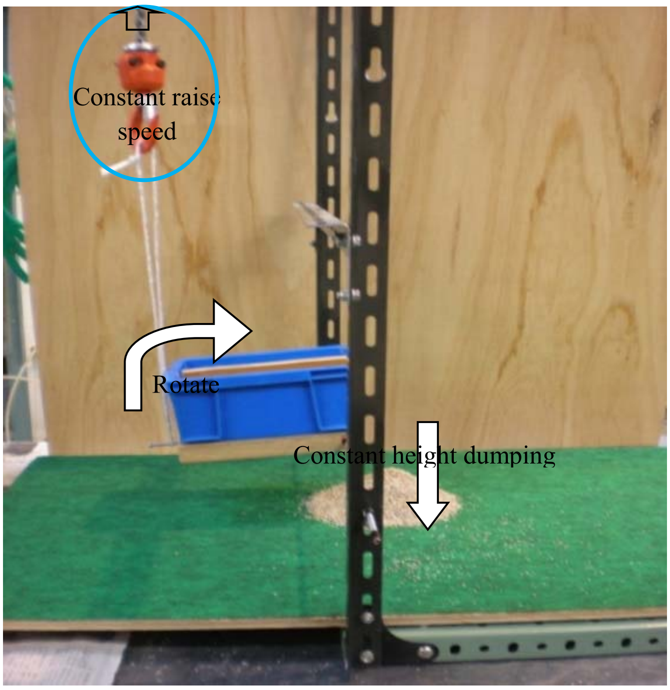

Figure 5.12 Overview of the experimental device

Figures 5.13 and **5.14** show the measurement process in the experimental tests. At first, the effects of particle size, dumping height and drop volume on the formation of single bench were discussed. Secondly, multiple benches are formed and then the interaction between adjacent benches was discussed under different interval distances. In order to eliminate the effect of water contents of samples, all samples are dried before the test. Gravel and coarse sand were used in this test as the waste materials. Scale factor was set as 80 based on the results of field investigations and the condition of laboratory test. The average values of P20, P50, and P80 are converted to 1.58 mm, 2.82 mm, and 4.89 mm, respectively. According to the opening of standard sieve, the particle sizes of samples are set from 1.00-1.68 mm, 1.68-2.83 mm and 2.83-4.75 mm. A certain volume of a sample was dropped from a certain height to the floor and then the dimension of the pile was measured. A felt mat was laid on the floor in order to maintain the frictional force between bench/waste materials and floor constant. In this device, drop volume, drop height, drop rate and floor angle can be controlled.

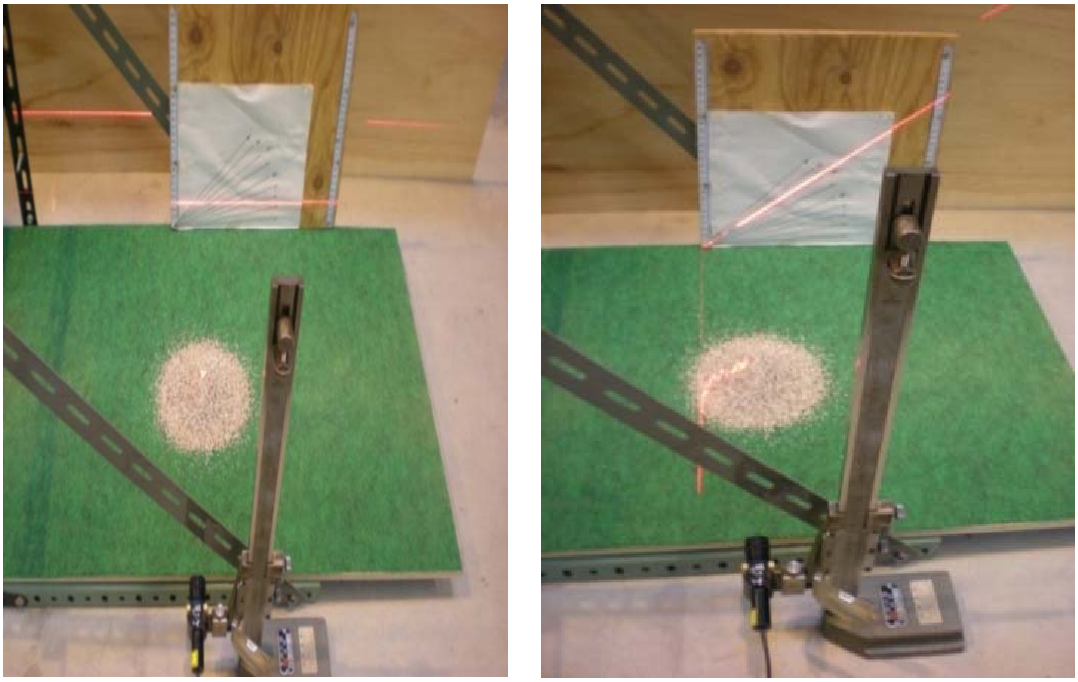

Figure 5.13 Process to measure the height and the repose angle

Figure 5.14 Process to measure the length and width

5.2 Experiment methods and results

5.2.1 Single bench

At first, effects of a particle size, a drop height, a drop volume, and a dip of floor on the formation of single bench are discussed.

(1) Effect of a particle size and a drop height on the shape of bench

The relationship between the pile height / slope angle of bench and the drop height under different particle sizes of waste materials are shown in **Figures 5.15** and **5.16**, respectively. Slope angle is angle of repose of the bench.

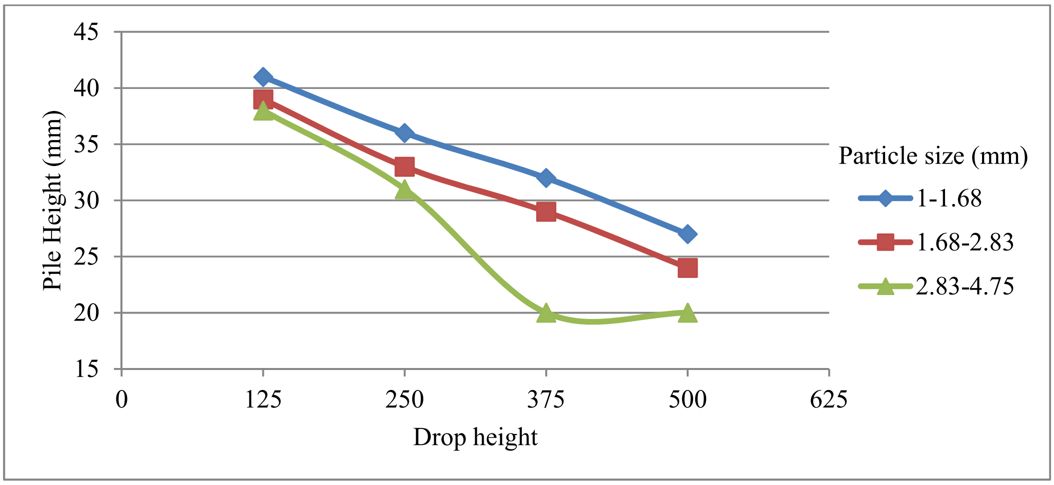

Figure 5.15 Relationship between pile height and drop height

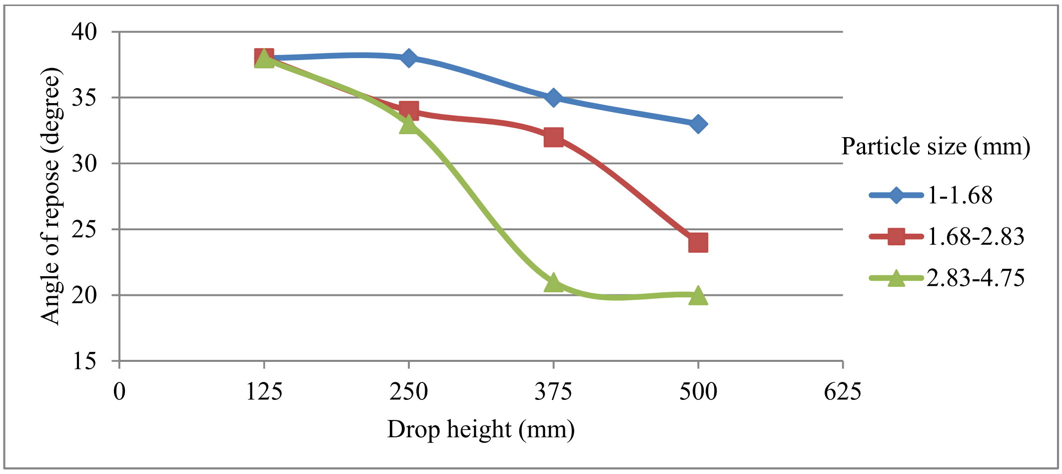

Figure 5.16 Relationship between slope angle and drop height

Figure 5.15 and **5.16** show the larger particle size is, the lower the bench height is and the smaller the slope angle is. It can be said that the larger the particle size, the more weight the dropping material and more inertia force they have, so the materials are well spread. The figures also show that the higher the drop height is, the lower the bench height is and the smaller the slope angle is. The velocity of dropping material when it reaches at the top of the pile increases with increasing the drop height. As a kinetic force of friction is fixed, dropping material rolled the slope faster and reached farther away. Moreover, as their impact force also increases with increasing of the drop height, waste material was compacted and the bench height was decreased. From the above results, it can be concluded that both particle size and dropping height have an obvious impact on the formation of bench.

Based on above laboratory tests and site investigation, the following conclusions were found:

a) The design of blasting need to be changed to make the waste particle size of smaller. In the dumping area, the bench repose angle decreases and the roll distance of rock increase with increasing the particle size of the waste. The volume capacity of bench and stability of the dumping area decreases with decreasing the bench repose angle. Moreover, the safety distance by rock roll increases with increasing the roll distance of rock.

b) The volume capacity of bench is maximized and the safety distance by rock roll is minimized in the bucket wheel excavator-belt-stacker dumping operation. The value of shovel-truck dumping operation is in the mid-level. The volume capacity of bench is minimized and the safety distance by rock roll is maximized in the dragline dumping operation.

(2) Effect of a drop volume on the shape of bench

The relationship between the pile height/slope angle and the drop volume of sample is given in **Figure 5.17**.

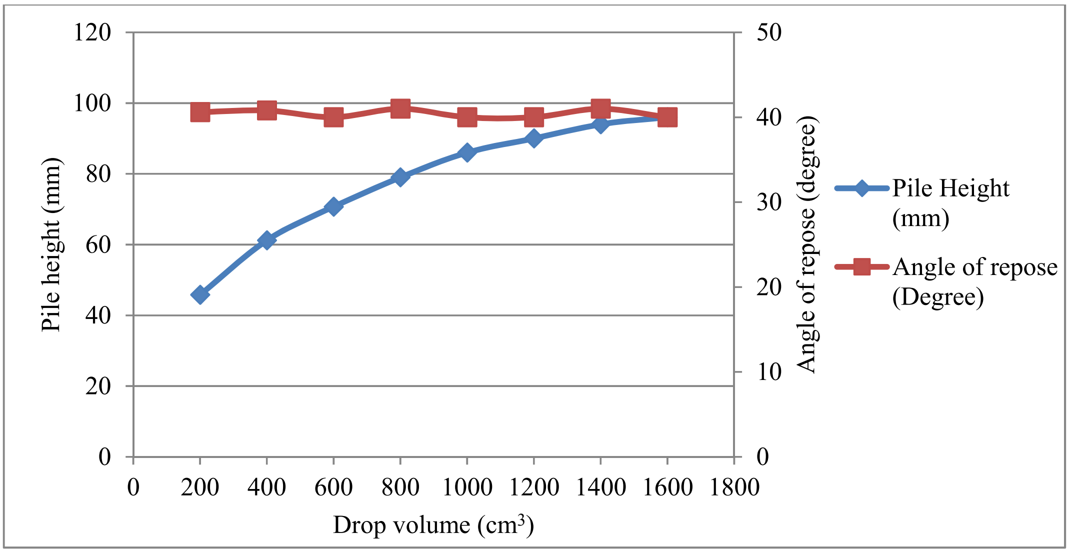

Figure 5.17 Relationship between pile height/slope angle and drop volume

It can be seen from this figure that the pile height increases with increasing the drop volume. However, there are no obvious changes on the slope angle and the bench shape due to the change of drop volume. Hence, it can be said that a drop volume do not have an obvious impact on the shape of bench.

(3) Effect of floor dip on the shape of bench

Figure 5.18 shows length, height and repose of angle of bench. **Table 5.5** shows the relationship between dips of floor and bench shape. Pile length is a length of tendency direction; pile width is a length of strike direction. It can be seen from **Table 5.5** that the pile height and angle of repose decreases with increasing dip of floor. However, obvious change of the shape cannot be seen in angle of repose. The larger the dip of floor is, the faster the waste material roll along the surface of the floor. As the results, the pile length increases and the pile height decreases with increasing the dip of floor.

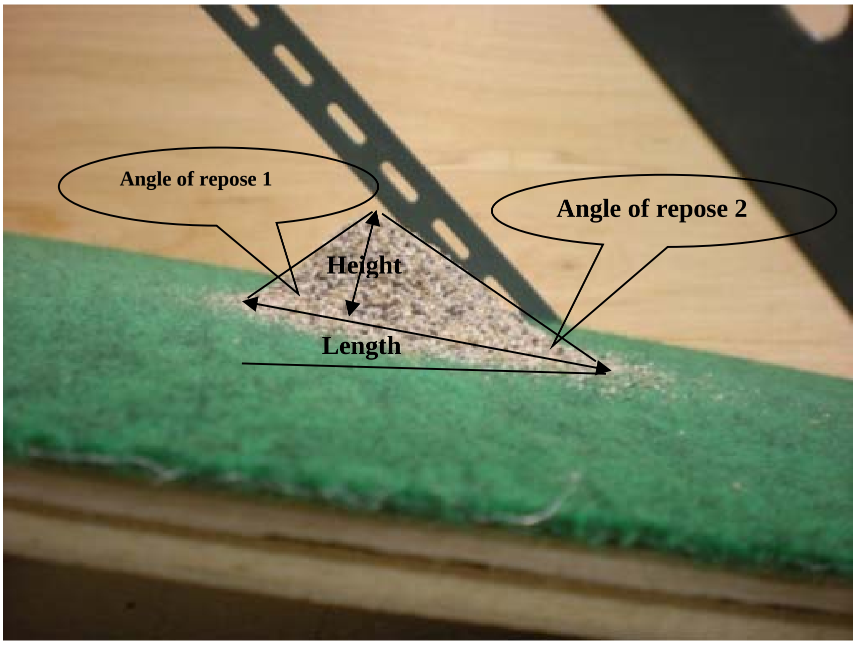

Figure 5.18 Diagram of length, height and repose of angle of bench

Table 5.5 Relationship between dips of floor and bench shape

Dip of foundation (degree)	Pile height (mm)	Angle of repose 1 (degree)	Angle of repose 2 (degree)	Pile length (mm)	Pile width (mm)
20	32	37	21	155	145
15	37	39	23	145	145
10	40	40	30	140	140
5	41	40	32	140	145
0	40.5	38	36	143	153

Based on the above laboratory tests and site investigation, the following measures were found:

a) In the selection process of dumping area, the smaller the floor inclination is better than that of higher inclination. The bench height decreases and bench length increase with increasing the floor inclination. Moreover, the capacity of bench decreases and the roll distance of rock increases with increasing the floor inclination.

b) Some measures should be taken to increase the kinetic force of friction between waste material and floor surface. The kinetic force of friction between waste material and floor surface is no more than the kinetic force of friction of waste material. It is easy to a weak seam. Generally the inclined floor is flat and an entirety surface thus it is easy to be a slide surface. For example, in the treatment process of floor, we can remove the loose earth and all vegetation to make the floor strong seam. Some pits can be formed in the floor's surface with blasting method to make the floor not easy to be a slide surface.

5.2.2 Multiple benches

Next, the formations of multiple benches were investigated under different conditions. **Figures 5.19** and **5.20** show the diagram of dumping order and drop interval distance and that of pile height and their difference, respectively.

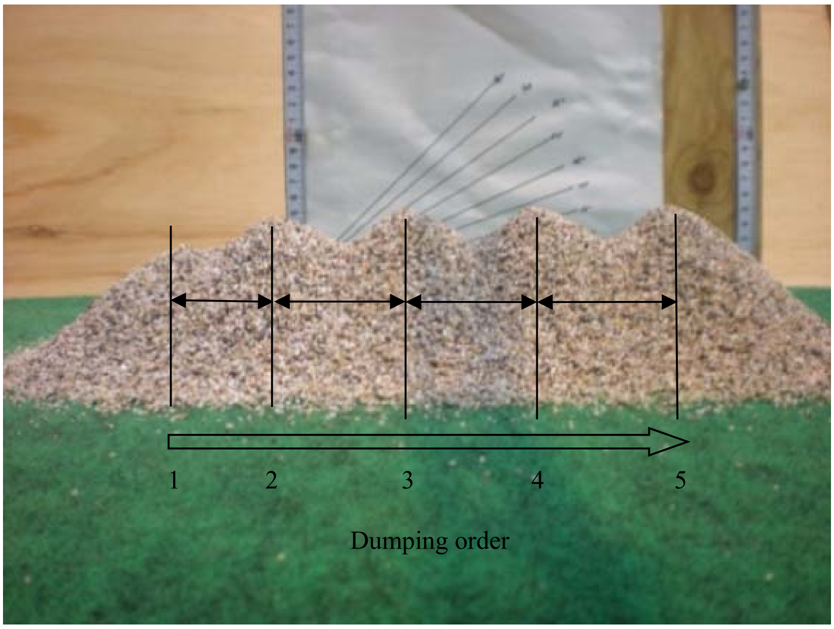

Figure 5.19 Diagram of dumping order and interval distance

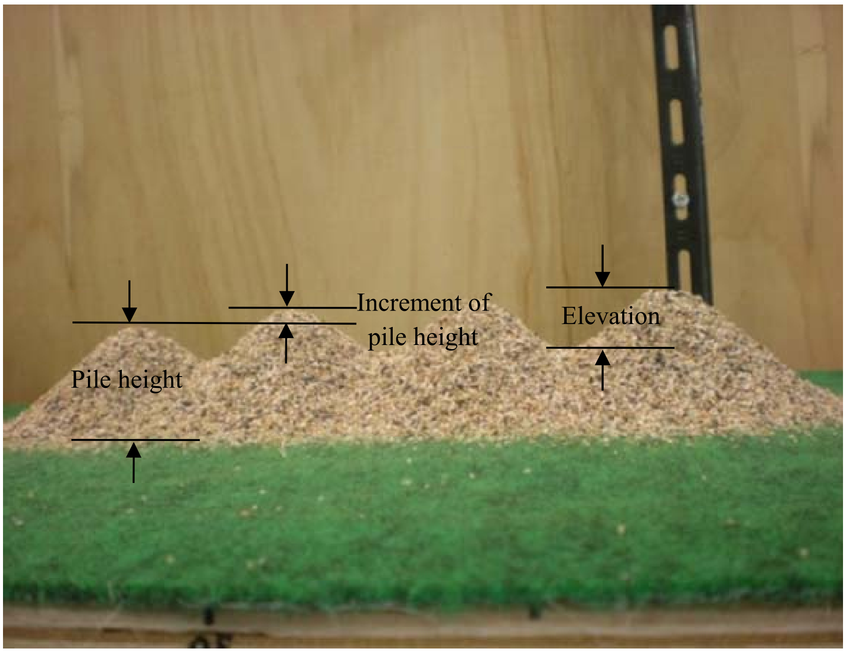

Figure 5.20 Diagram of elevation difference and pile height measurements

Figure 5.21 shows the relationship between the pile height and the pile number under different drop intervals. Pile numbers indicates the first, second, third, fourth and fifth bench. Here, the increasing of the pile height means the difference between the height of each bench and that of first one. It represents that the height of bench increases with the increasing pile number. The height of bench increases gradually and then becoming constant. Moreover, the shorter the drop interval is, the higher the bench is.

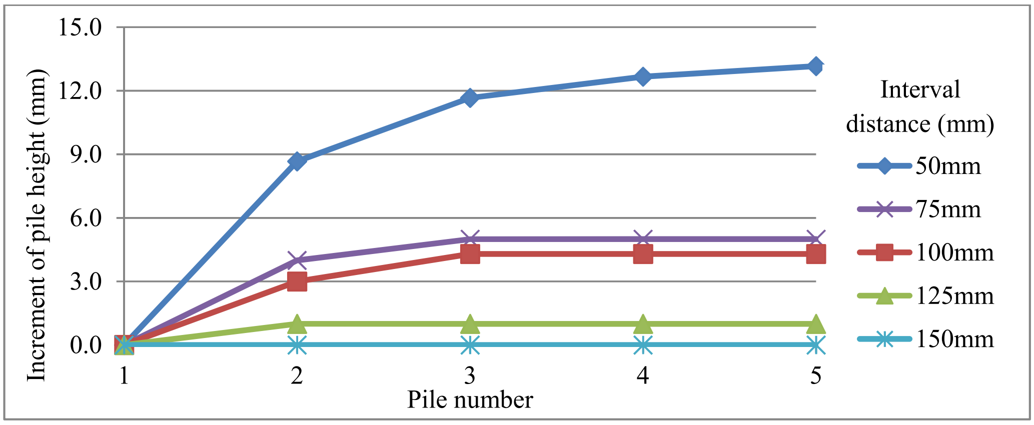

Figure 5.21Relationship between the increase of pile height and the pile number

Based on the above laboratory tests and site investigation, the following conclusions were found. In bucket wheel excavator-belt-stacker dumping operation and dragline dumping operation, the dumping width should be decided through optimization efficiency of bulldozer and dumping device. The interaction decreases with increasing width of the dumping. In bucket wheel excavator-belt-stacker dumping operation and dragline dumping operation, the work amount of bulldozer increases with decreasing the interaction. Efficiency of dumping device decreases with decreasing the width of dumping.

Figure 5.22 shows the relationship between the increase of fifth pile height and drop intervals under different drop volumes. It shows that the height of bench increases with decreasing intervals under all drop volumes. When interval distance reaches to a specific one at each drop volume, no interaction between neighboring piles are observed. This is because of the interference between two adjacent piles. As the drop interval decreases, the interference of previous bench on the next one appears and becoming large.

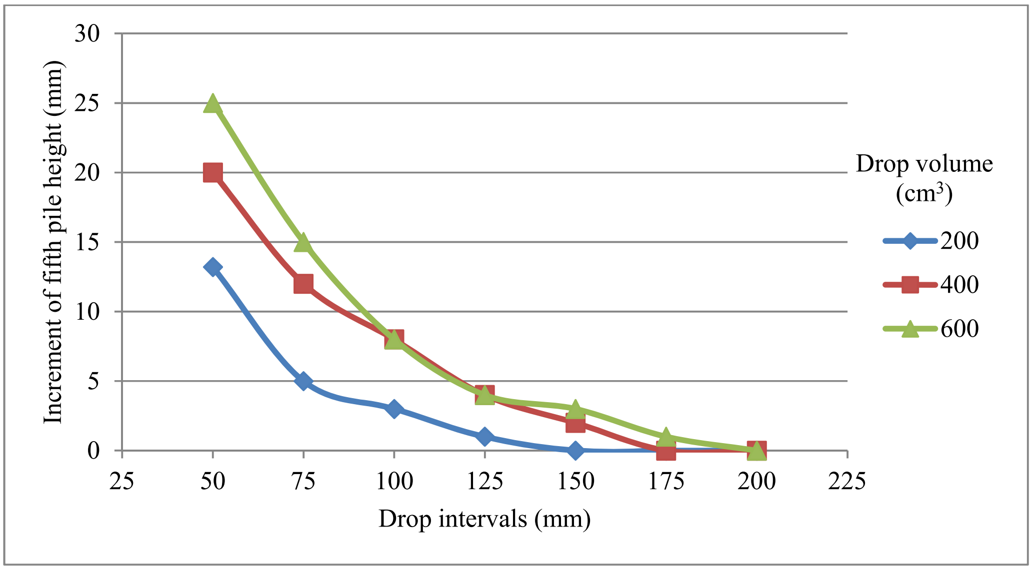

Figure 5.22 Relationship between the increase of the fifth pile height and drop interval

In the dumping operation, the volume of bucket does not have a pronounced interaction effect on dumping operation. The pile height and the minimum interval distance increases with increasing volume of the dumping. Meanwhile, the ratio of dumping volume to bench volume is too small.

Figure 5.23 represents the relationship between the ratio of the height increment and the ratio of the interval of drop point to volume. Here, the ratio of the height increment represents the increasing of fifth pile height divided by the height of the first pile. The ratio of the dropping interval is dropping interval (I) divided by the cubic root of volume ($V^{1/3}$). **Figure 5.23** shows the similar tendencies of height increment despite of drop volume. Thus, the pile height can be estimated by the following **Equation** [5-1].

$$\Delta H / H_o = -0.260 \ln (I / V^{1/3}) + 0.800 \qquad [5\text{-}1]$$

ΔH–Increasing of fifth pile height, m.

H_o–Height of the first pile, m.

I–Drop interval, m.

V–Volume, m^3.

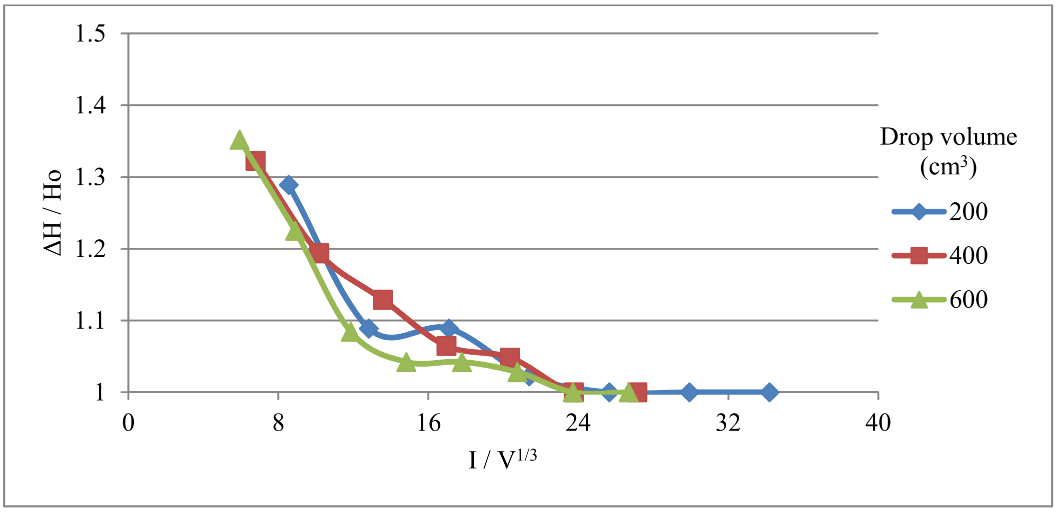

Figure 5.23 Ratio of increase height – ratio of interval of drop point to volume

From the above discussions, it can be concluded that in the dumping operation, the work amount of bulldozer decreases with increasing size of bench. The pile height decreases while interaction effect increases with increasing height of the dumping. Meanwhile, the work amount of bulldozer decreases with increasing the interaction effect.

5.2.3 Efficiency of dumping operation design

Land reclaiming must be carried out after dumping work. **Figure 5.24** shows the process of ground leveling operation work. It is necessary to level the benches with bulldozer. Therefore, the elevation difference and pile numbers are measured to examine the amount of grading work needed under different dumping conditions.

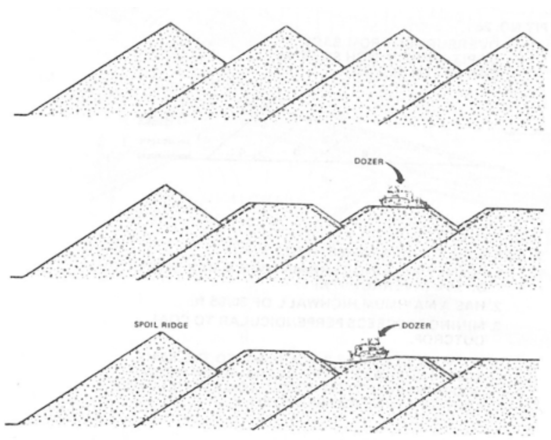

Figure 5.24 Process of ground leveling operation work

At first, we measure the elevation difference of the fifth bench. **Figure 5.25** shows the relationship between elevation difference and interval distance. It shows that the elevation difference increases with increasing interval distance. Therefore, it is believed that the elevation difference of bench decreases with decreasing interval distance. The amount of grading work decreases with decreasing elevation difference of bench. Therefore, cost reduction of the ground leveling operation is possible.

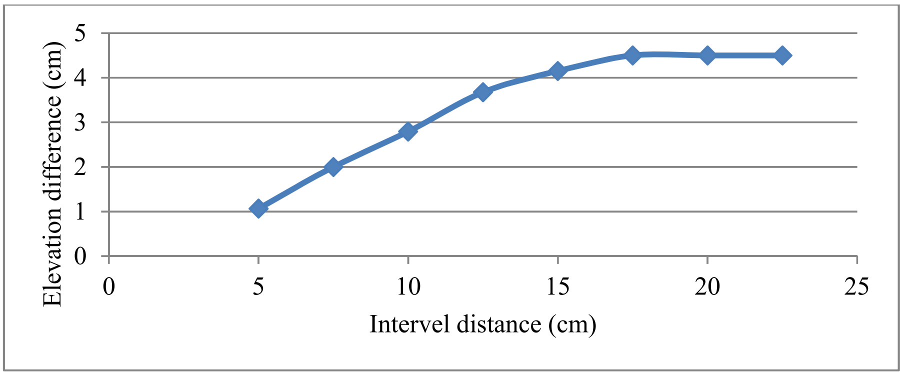

Figure 5.25 Relationship between the elevation difference and interval distance (200cm^3)

Second, the volume of each pile was changed to examine the relationship between pile numbers and amount of grading needed under the condition of constant total volume and constant floor area. An example of the results is shown in **Table 5.6**. It shows that the amount of grading increases with increasing the pile numbers. The result shows that the work amount of grading operation decreases with decreasing dumping volume of equipment.

Table 5.6 Relationship between the amount of grading work and pile numbers

Total volume V_0 (cm^3)		1,200		
Pile numbers	6	4	2	1
Floor area A (cm^2)		570		
Amount of grading ΔV (cm^3)	81.5	160.8	197.6	461.1

However, different equipment has different efficiency, different flexibility, and bucket volume. Equipment capability will decide the dumping volume, cost, the work time of building the bench and stripping work. Therefore, the design of the dumping operation must consider the total efficiency of ground leveling operation and formation of dumping area.

5.3 Simulation for the effect of dumping operation on stability of dumping area

The site investigation shows different operation results in different shapes of dumping area, and have effect on bulk of factor. In this section, the height of bench, the angle of bench, the bulk factor, and the transporting truck were changed to analyze the effect of dumping operation on stability of dumping area.

The Heidaigou open pit coal mine and East open pit coal mine are located in Loess Plateau. Meanwhile, as the crow flies, the distance between Heidaigou open pit coal mine and East open pit coal mine is about 120 km from google maps. The geological conditions between these open pit coal mine is similar. Therefore, the geological model of Chapter 3 was applied. The height of bench was changed to simulate the relationship between height of bench and safety factor of dumping area. The length of safety bench was changed to keep the total slope angle of slope constant value. Other parameters keep in constant value. **Figure 5.26** shows the geological model under the height of bench is 30m. **Figure 5.27** shows the relationship between height of bench and safety factor of dumping area. It shows that the safety factor of dumping area slightly increases with increasing height of bench. In the dumping area, the efficiency of working and subsidence of bench increases with increasing the bench height. The subsidence of bench was a dangerous factor to workers and equipements. The height of bench can be as high as possible, up to the allowed safety values of workers and working equipment.

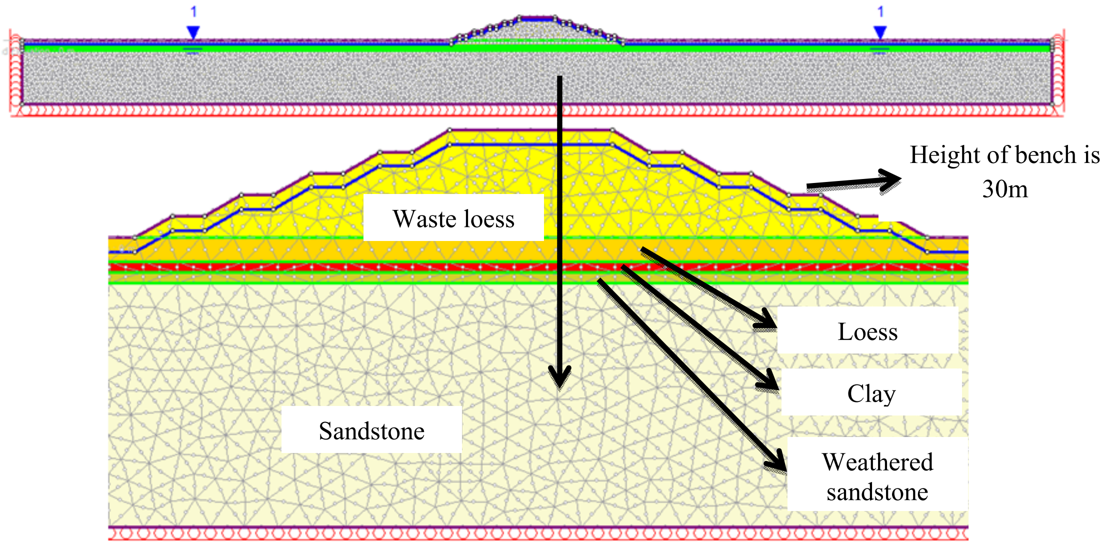

Figure 5.26 Geological model under the height of bench is 30 m

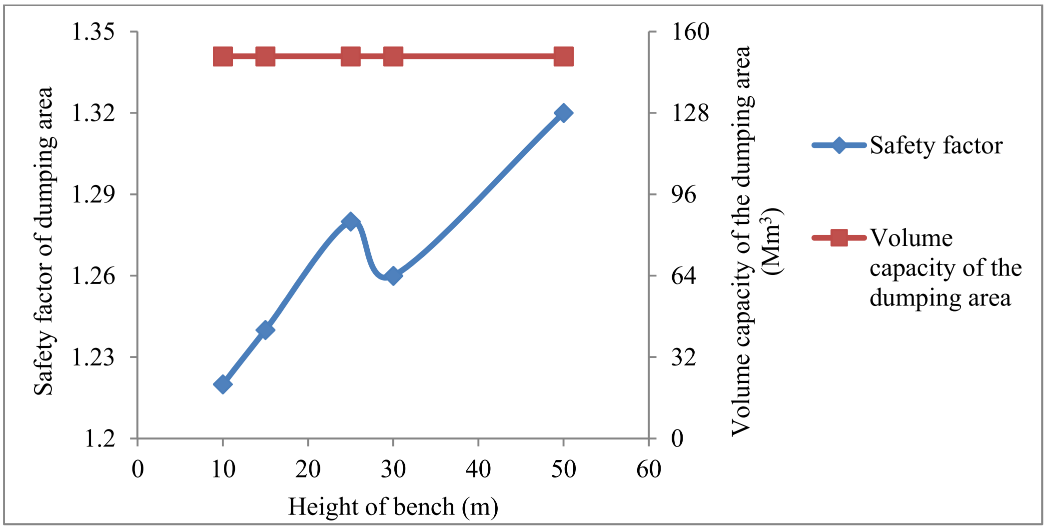

Table 5.27 Relationship between bench height and safety factor of dumping area

The length of safety bench was changed to keep the total slope angle of slope in a constant value. Other parameters keep in constant value. **Figure 5.28** shows the geological model under the angle of bench is 40 degrees. **Figure 5.29** shows the relationship between angle of bench and safety factor of dumping area, volume capacity of the dumping area. It shows that the safety factor of dumping area decreases with increasing the angle of bench. Meanwhile, the volume capacity of dumping area has a small increment as the angel of bench increases. Therefore, the angle of bench is not important to dumping operation.

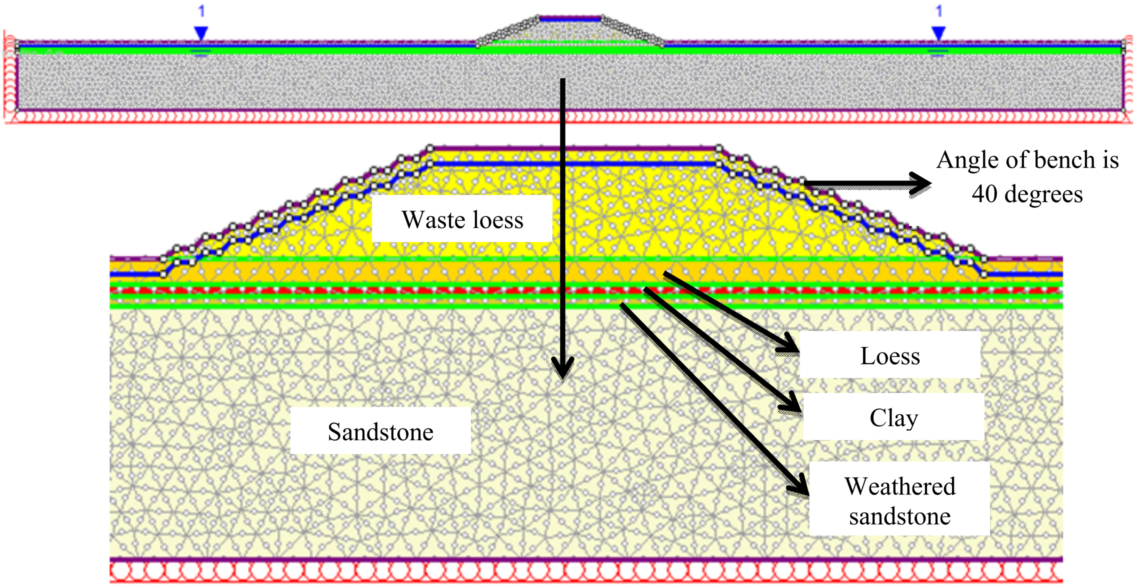

Figure 5.28 Geological model under the angle of bench is 40 degrees

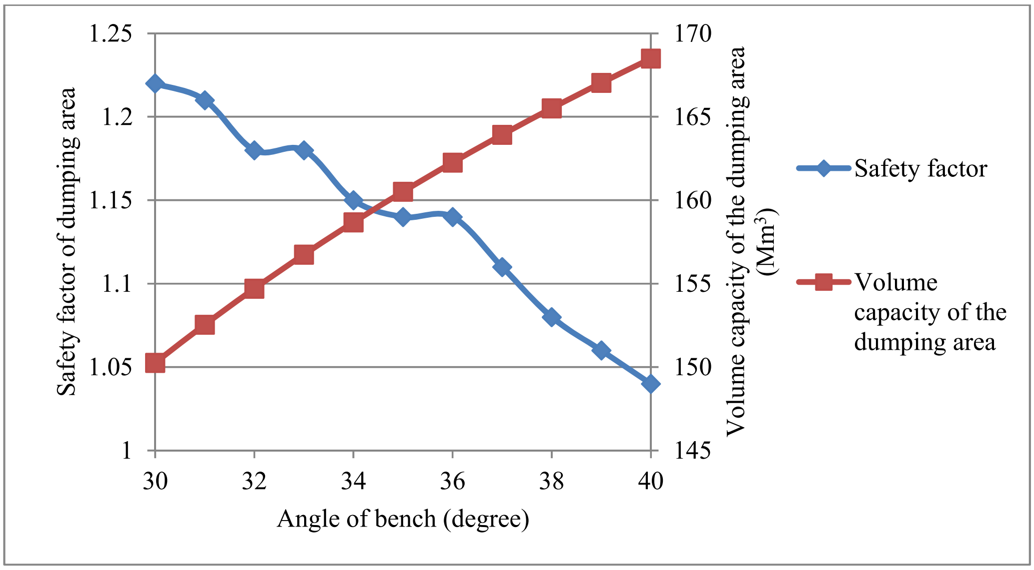

Figure 5.29 Relationship between angle of bench and safety factor of dumping area, volume capacity of the dumping area

The bulk factor of waste loess represents the ratio between volume after stripped to initial volume. The bulk factor of waste loess was changed to clarify the relationship between bulk factor of waste loess and stability of dumping area. The density of waste loess will be changed with changing the bulk factor. Other parameters keep in a constant value. **Figure 5.30** shows the relationship between bulk factor of waste loess and volume capacity increase, safety factor of dumping area. It shows that the volume capacity increment increases with decreasing bulk factor of waste loess. Furthermore, the bulk factor of waste loess has a beneficial and small effect on safety factor of dumping area. The bulk factor of waste should be as small as possible to improve stability of dumping area.

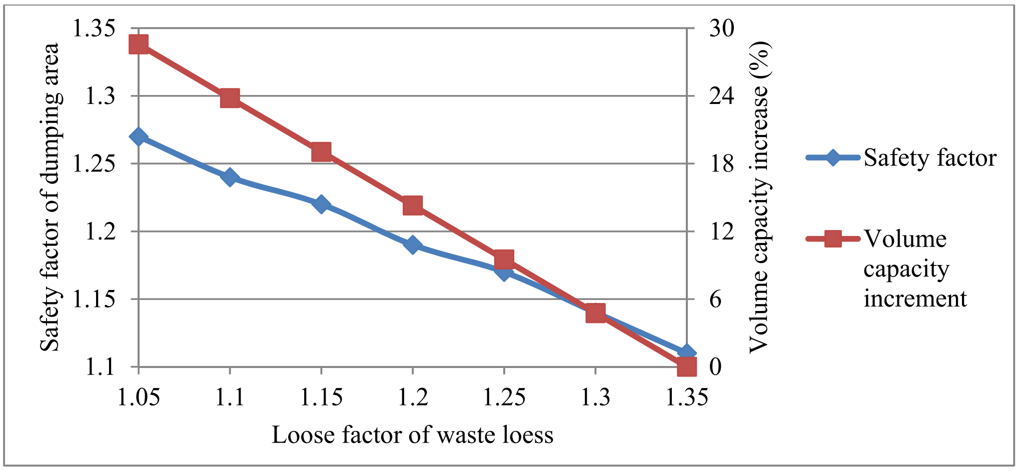

Figure 5.30 Relationship between bulk factor of waste loess and volume capacity increase, safety factor of dumping area

The stability effect of transport truck in roads on dumping area was analyzed. We assume that the weight of truck is 100 tonnes, 200 tonnes, 300 tonnes, 400 tonnes, the length of truck is 10 m. Therefore, the force is 0.1 MN/m, 0.2 MN/m, 0.3 MN/m, 0.4 MN/m, respectively. **Figure 5.31** shows the geological model as the truck load force is 0.2 MN/m. **Figure 5.32** shows the relationship between truck load and safety factor of dumping area. It shows that the truck load does not have effect on safety factor of dumping area. Meanwhile, the activity of truck transport can give compaction effect to dumping area. The activity of transport truck in dumping area has a beneficial effect on stability of dumping area.

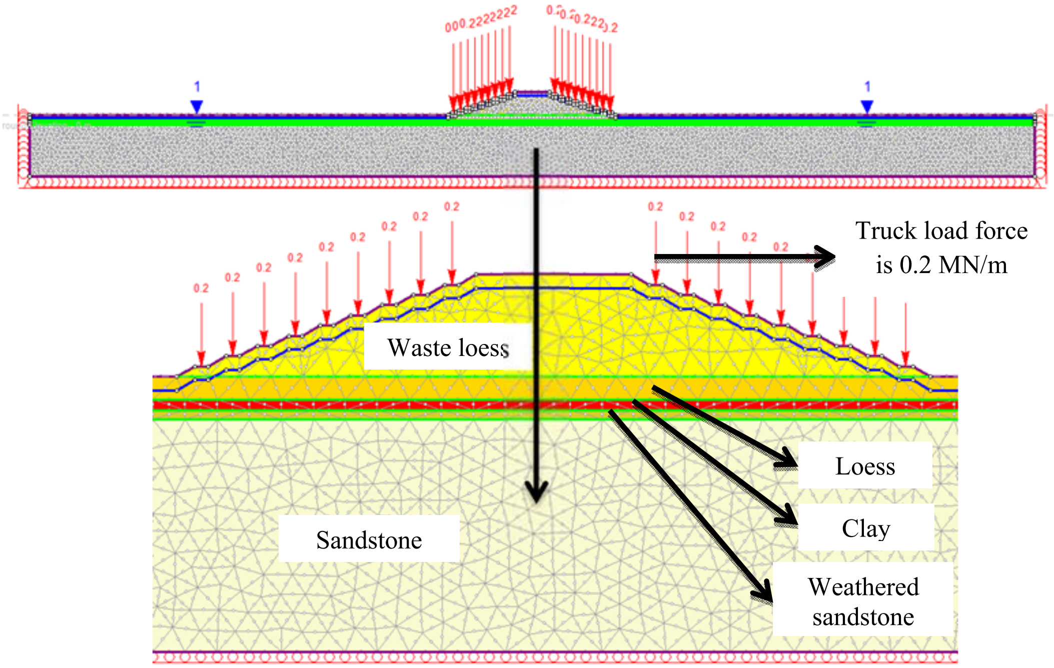

Figure 5.31 Geological model as the truck load force is 0.2 MN/m

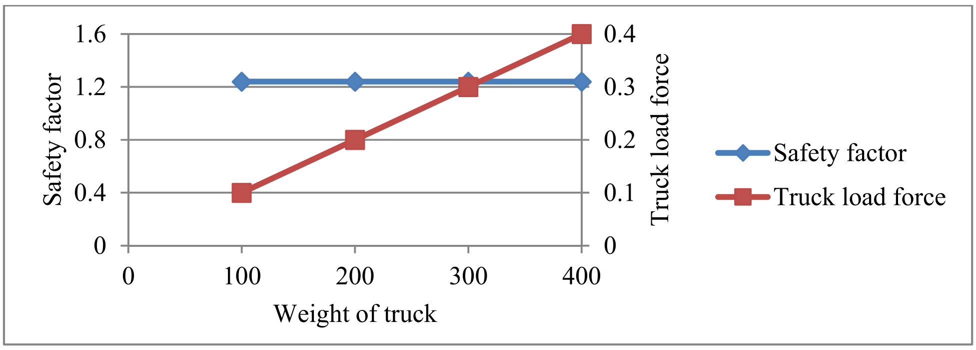

Figure 5.32 Relationship of truck load and safety factor of dumping area

5.4 Summary

In this study, a site investigation, a series of experiments, and a series of numerical simulations were performed to determine the formation mechanisms of benches on stability of dumping area. Some main conclusions can be summarized as follows.

Based on site investigations at the Heidaigou open pit coal mine, different dumping operations have different operational and geotechnical issues. In the bucket wheel excavator-belt-stacker dumping area, the operation efficiency is low. Moreover, in the shovel-truck-bulldozer dominant loess dumping area, substantial subsidence were exists. It causes large trucks cannot work in this dumping area. In the dragline dumping area, small landslides occur frequently due to the high bench height. It was a safety risk to staffs and equipment.

The design of blasting is modified to make the particle size of waste smaller. In the dumping area, the capacity of bench decreases while safety distance by rock roll increase with increasing particle size of the waste. In the bucket wheel excavator-belt-stacker dumping operation, the volume capacity of bench was maximized and the safety distance by rock roll was minimized. The value of shovel-truck dumping operation is in the mid-level. In the dragline dumping operation, the volume capacity of bench was minimized and the safety distance by rock roll was maximized. The volume of bucket does not have a pronounced effect on bench repose angle, volume capacity of bench, and stability of dumping area. In the selection process of dumping area, smaller floor inclination is better than that of higher inclination. Two methods are proposed to increase the stability of dumping areas. First, the loose earth and all vegetation need to be removed to make the floor strong seam. Second, floor surface of dumping area becomes rough by blasting, which can prevent the floor to be slide surface.

In bucket wheel excavator-belt-stacker dumping operation and dragline dumping operation, dumping width should be decided through optimization efficiency of bulldozer and dumping device. Volume of bucket does not have a pronounced interaction effect on dumping operation. The work amount of bulldozer decreases with increasing bench. Design of the dumping operation must consider the total efficiency of ground leveling operation work and forming dumping area work.

Height of bench can be as high as possible, up to the allowed safety values of workers and equipment working. Angle of bench is not important to dumping operation. Bulk factor of waste loess should be as small as possible to improve dumping operation stability. The activity of transport truck in dumping area has a beneficial effect on stability of dumping area.

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CHAPTER 6

CONCLUSIONS

In China, the excavation depth of coal seams becomes deeper and the production of open pit coal mine becomes larger with the increasing the national economic. Since 1987, open pit coal mines focused on excavating flat-dipping coal seam that situated at the depth of 200 m to 600 m. In 1987, Antaibao open pit coal mine was established in Shuozhou city, Shanxi province as the first large scale open pit coal mine with production more than 10 Mt/y. The increase of excavation depth resulted in new open pit mining areas were formed. In these areas, the loess distributed in 6 major open pit mining areas of total 9 major open pit mining areas. At present, numerous dominant loess dumping areas were formed and will be formed. Meanwhile, in the first large scale dominant loess dumping area in China, South external dumping area of Antaibao open pit coal mine occurred failure on October 29th, 1991. On the other hand, systematic studies on stability of dominant loess dumping area is still limited. Therefore, research on appropriate design of loess dominant dumping area at open pit coal mine in China is valuable and urgent. Main conclusions of this study are revealed as the following four aspects, which are interlinking with one another.

Failure mechanism of dominant loess dumping areas

By results of investigation at Antaibao open pit coal mine, from October 15 to November 1 was in a dangerous period for the stability of dumping area because of the appearance of maximum value of the groundwater level. Saturated clay seam and loess that below groundwater level were weak seam and easy to slide. Loess has high structure strength, collapsible property, and big void ratio. Loess Plateau located in cold region. The climate belongs to semi-arid or arid types. Soil erosion by rain and wind is a serious problem in Loess Plateau. The width of each sliding mass was from 45 to 55 m. The dumping area sliding constituted by multi-stage. The safety factor of dumping area decreases dramatically from 1.74 to 1.01 with increasing the piezometric line from 50 m to 5 m below the surface. The structural strength of floor loess would be disappeared as the height of dumping area reaches 78.4 m. From these results, the changes in the mechanical properties of loess by the elevation of the groundwater level associated with rainfall and a weak loess floor layer may lead to this large slope failure at dumping areas. Based on above investigation and accident analysis, the sliding process was summarized. It consists of compression stage, rise of groundwater level, formation of sliding surface, floor deformation, and sliding occurrence.

Stability effect of water content of loess on dominant loess dumping areas

Based on the field investigation at East open pit coal mine, rainfall has an important effect on stability of dumping area. Gullies formed in the edge of bench due to erosion. Water accumulates result in cracks formation and subsidence occurrence. The water content of waste loess at East open pit coal mine were around 2.21% to 20.60% based on the laboratory test. The density of waste loess increases as the water content increases, the Young's modulus and internal friction angle of loess decrease with increasing the water content from 15% to 25%, and the cohesive strength of loess decreases dramatically with increasing the water content from 15% to 25%.

The maximum total height of dumping area increases from 118 m to 132 m with decreasing the water content of loess from 25% to 15%. The safety factor, total slope angle, and volume capacity of dumping area increase with decreasing the water content of loess. In the working face, the water content of loess should be as low as possible to decrease transport cost. In roads of dominant loess dumping area, the water content of waste loess should be maintained with a suitable value to promote the quality of roads. In the dumping area, the water content of waste loess should be as low as possible from the view of stability under the conditions of meeting environmental protection and land reclaiming. From these results, guidelines for the improvement of stability were suggested, indicating the importance of drainage systems to decrease the groundwater level and water content of loess dumping areas, in order to maintain the stability of the predominant loess dumping area and its dumping capacity.

Improvement of stability of dumping area by compaction of floor

The safety factor of dumping area decreases dramatically with increasing the thickness of weak floor when the thickness of weak floor is from 0 m to 20 m. When the thickness of weak floor is from 20 m to 50 m, the safety factor of dumping area does not have an obvious change. Therefore, in the process of selecting dumping area, thin weak floor is better than thick weak floor when the thickness of weak floor is less than 20 m. On the other hand, the stability of dumping area can be improved through decreasing the thickness of weak floor when the thickness of weak floor is less than 20 m. The volume capacity of the dumping area decreases dramatically with increasing the dip of floor. Meanwhile, the safety factor of dumping area does not have a big difference with increasing the dip of floor. Therefore, dip of floor should be as low as possible to improve the volume capacity of the dumping area. The safety factor of dumping area increases with increasing the thickness of compacted layer when the thickness of weak floor is from 0 m to 20 m. The safety factor of dumping area increases smoothly with increasing the thickness of compacted layer when the thickness of weak floor is from 20 m to 50 m. The thickness of compacted layer increases with increasing the thickness of weak floor when the safety factor of dumping area is maintained in a constant value and the thickness of weak floor is from 0 m to 20 m. It is effective in not only minimizing the strength reduction in the bottom part of the floor layer due to infiltrating rain water, but also in controlling the drainage of the dumping pile. The safety factor of dumping area can be achieved more than 1.62 because the minimum thickness of the compacted layer is 3.3 m for environmental protection. In this case, the height of dumping area can be increased from the stability point of view at the mine.

Horizontal drainage channels are set up in the bottom of bench and dewatering wells are set up in the floor close to toe of the dumping area to descend the groundwater level. The length of horizontal drainage channel and depth of dewatering well depend on the state of the stability of dumping area and code of mining development. For instance, in the Indonesia open pit coal mine, the depth of dewatering well should be more than 4 m and the length of horizontal drainage channel should be more than 4.8 m. The compacted layer of floor should be set up to prevent the infiltration of acid water to theunderground, to prevent the rainwater seeping into the ground on rainy days, and to improve the stability of dumping area. The minimum thickness of compacted layer should be determined by the permeability coefficient test and the standard of civil engineering to prevent the infiltration of acid water to the underground. And then, the thickness of compacted layer should be determined in order to prevent the rainwater seeping into the ground on rainy days. This thickness depends on climate and properties of loess. After that, the thickness of compacted layer should be determined in order to improve the stability of dumping area under the various groundwater levels. For instance, in the Indonesia open pit coal mine, this thickness should be more than 1.5 m. As a result of numerical analysis, it was concluded that the application of this countermeasure improves the safety factor of a dumping area from 1.38 to 1.51.

Formation mechanism of benches on stability of dumping area

Based on site investigations at the Heidaigou open pit coal mine, different dumping operations have different operational and geotechnical issues. In the bucket wheel excavator-belt-stacker dumping area, the operational efficiency was low. Moreover, in the shovel-truck-bulldozer dominant loess dumping area, substantial subsidence existed. It caused large trucks could not work in this dumping area. In the dragline dumping area, the bench height was high. Small landslides occur frequently, affecting the safety of staff and equipment.

The design of blasting can was modified to make the particle size of waste smaller. The volume of bucket does not have a pronounced effect on bench repose angle, volume capacity of bench, and stability of dumping area. Two methods are proposed to increase the stability of dumping areas. First, the loose earth and all vegetation can be removed to make the floor strong seam. Second, floor surface of dumping area becomes rough by blasting, which can prevent the floor to be slide surface. Height of bench can be as high as possible, up to the allowed safety values of workers and equipment working. Angle of bench is not important to dumping operation. Bulk factor of waste loess should be as small as good to dumping operation stability. The activity of truck transport in dumping area has a beneficial effect on stability of dumping area. In bucket wheel excavator-belt-stacker dumping operation and dragline dumping operation, dumping width should be decided through optimization efficiency of bulldozer and dumping device. Design of the dumping operation must consider the total efficiency of ground leveling operation work and forming dumping area work.

It must be noted that achievements of this research were concluded from the view of stability of dumping area. In site, manage dumping area must take into consideration of economy, safety, land reclaiming, and environment. Further studies will be undertaken in the view of economy, land reclaiming, and environment.