Study of Slope Instability of Nablus – Al-Bathan Road

Stations 2+100

Part Two

Submitted to:

Nablus Public Works and Housing Directorate

Nablus - Palestine

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Stations 2+100

1. Introduction

The Nablus – Al-Bathan Road was widened, reconstruction and rehabilitated in 2009 by Nablus Public Works and Housing Directorate (PWHD - Nablus). In 2010 based on observations by PWHD - Nablus, there were some road defects at this road in several places and especially at Station 2+100. Some minor remediations were carried out to fix these defects. In 2011 road defects reappeared at several locations and especially at Station 2+100. These defects can be described as longitudinal cracks along the eastern side of the road, in addition to initial sliding of this part of the road. In March 2012, PWHD - Nablus attempted to fix these defects at station 2+100 by replacing the soil and using big boulders to support the road. Unfortunately, large settlement occurred in the part of the road under maintenance and more sliding and slope instability in the road at station 2+100 occurred. PWHD - Nablus requested the Construction and Transportation Research Unit (CTRU) of An-Najah National University (NNU) to evaluate these defects.

A preliminary report about the road defects was submitted to PWHD - Nablus in March 2012. However, as a follow up to the submitted preliminary report, the CTRU is requested to do further investigation of the causes of these defects and to suggest remedial measures to overcome the problems at Nablus – Al-Bathan road.

Therefore, this report provides details analysis of the causes of these defects for the study location (station 2+100) and provides appropriate recommendations to control the defects.

2. Description of the Problem

Based on visual observations, every year Nablus – Al-Bathan road suffers longitudinal cracks in several places along the eastern side of the road, as shown in Figure 1. In addition to that local lands sliding along the eastern and western sides are usually observed yearly, as shown in Figure 2.

Figure 1: Typical cracks that occurs yearly along Nablus – Al-Bathan Road.

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Figure 2 : Local land sliding occurs yearly along Nablus – Al-Bathan Road.

In 2009 PWHD - Nablus did major rehabilitation to the road, such as widening and reconstruction the road.

In March 2012, large longitudinal cracks along the eastern side of the road at station 2+100 occurred and this required that PWHD – Nablus to do rehabilitation to this part of the road.

The rehabilitation conducted by PWHD - Nablus at station 2+100 was replacing the body of the of the road to a depth of about 4 m by several layers of boulders and base course and supporting the road by big boulders in the eastern side to a depth of about 6 m below the ground surface. This is shown in Figure 3.

Figure 3: Remedial measures to fix the problem at station 2+100 in March 2012.

During the construction of the remedial measures large settlement occurred in the eastern part of the road next to the big boulders, and large sliding occurred in the eastern side of the road and extended down to the bottom of the valley. This is shown in Figures 4 and 5.

Figure 4: Large settlements in eastern side next to big boulders.

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Figure 5: Landsliding in eastern side of the road and extended down to the bottom of the valley.

As a result of this, PWHD - Nablus requested the Construction and Transportation Research Unit (CTRU) of An-Najah National University (NNU) to evaluate these defects. A preliminary report about the road defects was submitted to PWHD - Nablus in

March 2012. However, as a follow up to the submitted preliminary report, the CTRU was requested to do further investigation of the causes of these defects and to suggest remedial measures to overcome the problems at Nablus – Al-Bathan road.

3. Description of the Study Area

In order to better understand the causes of the longitudinal cracks and slope instability, it is important to describe soil strata and the conditions of the area under consideration. As recommended by the preliminary report geophysical exploration was carried out at the study area. In addition to that, two trial pits were excavated east of the road at the bottom of the valley to a depth of about 7.5 m below the existing ground surface. Figure 6 shows the soil strata at Section No. 2 at station 2+100 (Section No. 2 is considered the most critical section along the road where the problems of settlement and slope instability occurred and it is almost at the middle of big boulders).

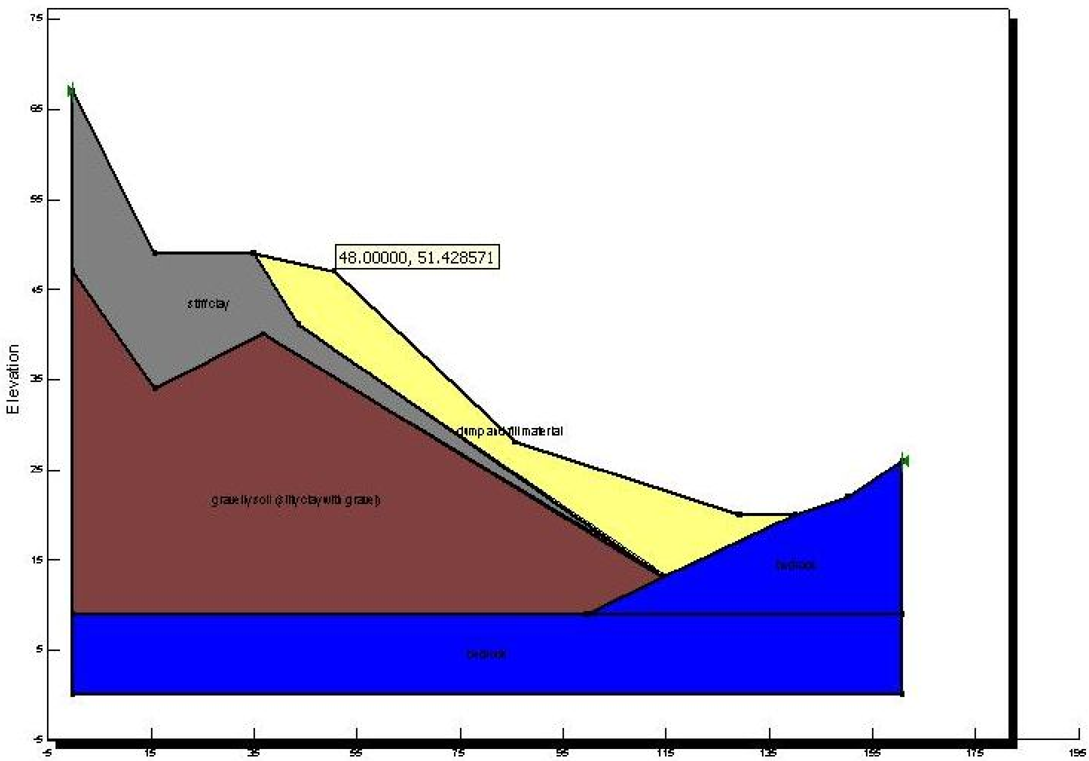

Figure 6: Soil strata at Section No. 2 at station 2+100.

The summary of soil properties as found from the seismic geophysical investigation by using seismograph 24 channels, trial pits, lab tests and eye observations in the site are defined as follows:

Dump and fill material

- Shear velocity (Vs) = 105 – 140 m/sec
- Soil may be described as: Soft soil
- Yellowish color in GeoStudio (in Figure 1)
- Cohesion (c) = 7 kN/m^2
- Angle of internal friction (φ) = 15 º
- Unit weight (γ) = 15 kN/m^3

Stiff clay

- Shear velocity (Vs) = 390 m/sec
- Soil may be described as: Medium stiff to hard clay and silt
- Grayish color in GeoStudio (in Figure 1)
- Cohesion (c) = 40 kN/m^2
- Angle of internal friction (φ) = 7 º
- Unit weight (γ) = 16.5 kN/m^3

Gravelly soil

- Shear velocity (Vs) = 670 - 1080 m/sec
- Silty clay with gravel (% of gravel > 20%)
- Brownish color in GeoStudio (in Figure 1)
- Cohesion (c) = 5 kN/m^2
- Angle of internal friction (φ) = 28 º
- Unit weight (γ) = 17 kN/m^3

Marley Limestone

- Shear velocity (Vs) ≥ 1660 m/sec
- Well graded aggregate
- Bluish color in GeoStudio (in Figure 1)
- Define in GeoStudio as bedrock

Base Course soil

- Well graded aggregate

- Reddish color in GeoStudio (in Figure 1)
- Cohesion (c) = 0 kN/m^2
- Angle of internal friction (φ) = 40 º
- Unit weight (γ) = 20 kN/m^3

The section of the road at Station 2+100 where problems occurred may be described as follows: it has 4 m fill materials of several layers of base course and boulders. Longitudinal cracks, large settlement and slope instability were noticed in eastern side of the road. However, the western side of the road including the ditch did not suffer any instability problems.

Big boulders to a depth of about 6 m below the existing ground surface were constructed to the support the body of the road at station 2+100. This is illustrated in Figure 3.

It is important to note that water drainage ditch along the western side of the road exist. The ditch does not suffer any type of damages or cracks along it.

After the large displacement occurred at Station 2+100, horizontal (lateral) and vertical (settlement) displacements along the big boulders were recorded from 29/3/2012 to 28/5/2012 and are shown in Figures 7 and 8.

The properties of soil mentioned above are based on average values. However, worst soil properties may be expected at this site and this is due to increased soil moisture because of rainfall.

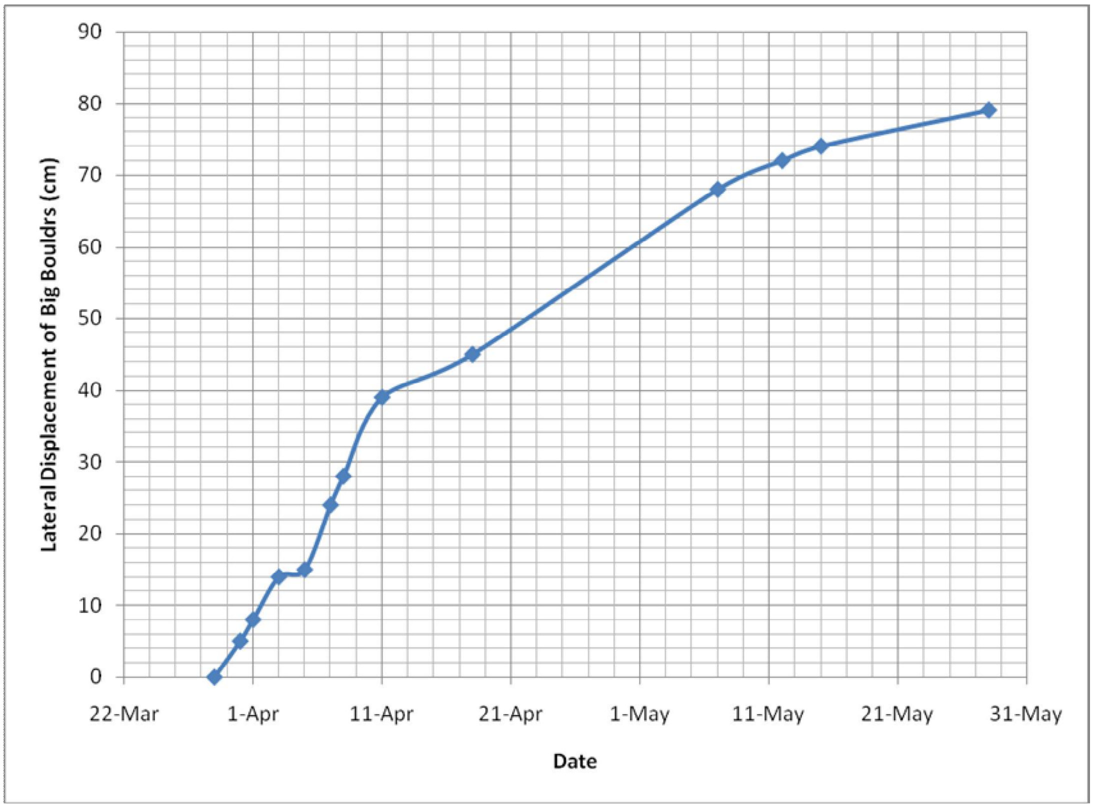

Figure 7: Horizontal (Lateral) displacements along the big boulders.

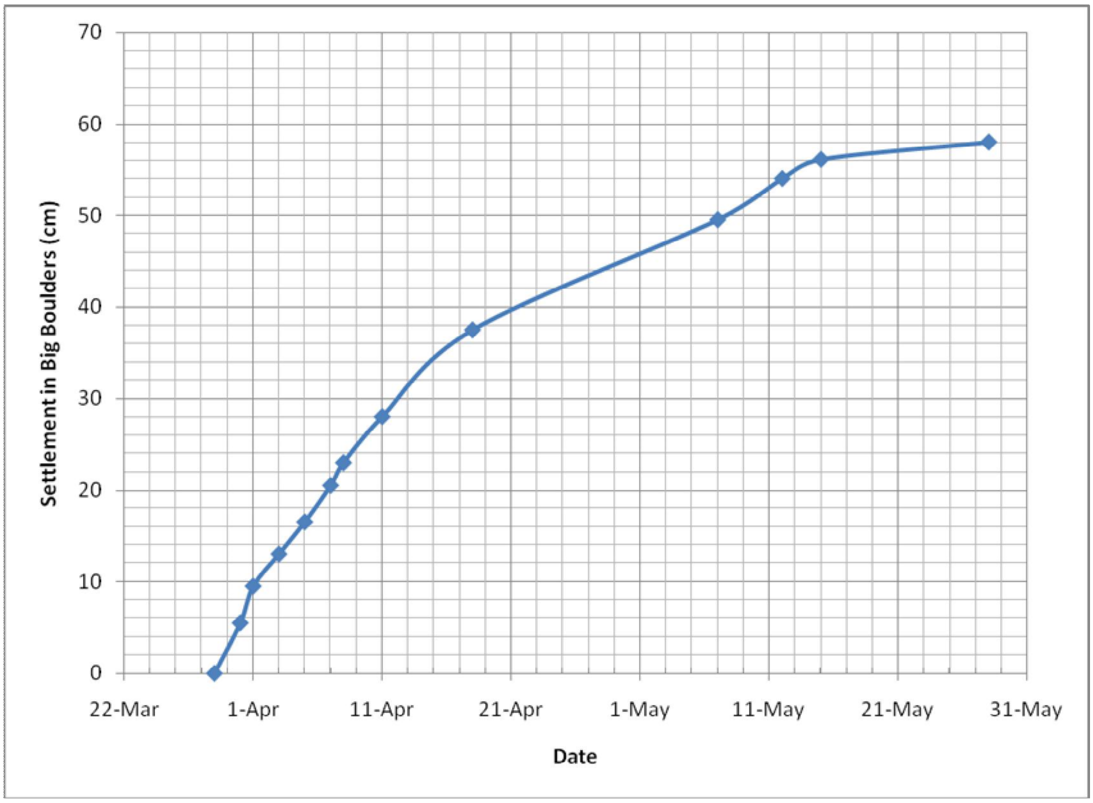

Figure 8 Vertical (Settlement) displacements along the big boulders.

4. Slope Stability Analysis

Slope stability analysis using software GeoStudio2007 was carried out for several conditions along the critical section (Section No. 2) at station 2+100 where the major problems occurred. Table 1 below shows analysis results summary. Figures 9 to 24 illustrate slope stability analyses for all conditions and are presented at the end of this report.

Table 1 Summary results of slope stability analysis.

No.	Conditions	Description	Factor of Safety		Notes
			Western Side	Eastern Side	
1	Base Case	Original soil strata without any soil improvement.	2.0 (Figure 9)	1.06 (Figure 10) 1.52 (Figure 11)	Figure 10 across the dump and fill material. Figure 11 across the road.
2	Road body improvement and big boulders	Improving the body of the road to a depth of 4 m and inserting big boulders to a depth of 6 m.	3.9 (Figure 12)	0.98 (Figure 13) 1.02 (Figure 14)	Figure 13 across the dump and fill material. Figure 14 across the road.
3	Improving the dump and fill soil	Replacing the dump and fill soil or mixing it with boulders (improve it) to increase its shear strength.		1.64 (Figure 15)	
4	Improving the soil down the hill and add more soil	Replace or improve the dump and fill soil and adding more soils down the hill to increase stability without big boulders.		1.88 (Figure 17)	Figure 16 shows the soil to be added down the hill in the eastern side.
5	Reducing the height of big boulders	Reducing the height of big boulders by 2 m.	2.02 (Figure 18)	1.71 (Figure 19)	
6	Reducing the height of big boulders and improving the soil	Reducing the height of big boulders by 2 m. and improving or replacing the dump and fill materials		1.86 (Figure 20)	

No.	Conditions	Description	Factor of Safety		Notes
			Western Side	Eastern Side	
7	Reducing the height of big boulders, improving the soil and add more soil	Reducing the height of big boulders by 2 m, improving or replacing the dump and fill materials and then adding more soil down the hill.	4.5 (Figure 22)	2.64 (Figure 21)	
8	Extending the soil in the western side	Checking stability of the western side by extending the slope 30 m horizontally and 35 m vertically over the basic condition.	1.1 (Figure 23)		
9	Using big boulders down the hill in the eastern side.	Moving surplus big boulders down to bottom of the eastern valley 50 m horizontally eastern of the top big boulders to support the bottom of the slope.		2.1 (Figure 24)	

5. Analysis of the Results and Causes of the Problem

In general, the factor of safety for slope required for any temporary structures is 1.3 and that for permanent structures it is 1.8.

It is clear that the site in general suffers slope instability and hence, landsliding may occur at any moment especially in the eastern side of the road and in the fill and dump materials that support the body of the road. This is because the factor of safety found ranges between 1.06 and 1.52. The western side of the site has a factor of safety = 2.0 and hence it may be considered safe regarding that the soil properties do not change. However, this is not the case, i.e., the soil properties may be changed at this site due to weather conditions (rainfall). This will reduce the factor of safety and local landsliding may occur in western side of the site and actually several of them were noticed during the site visit.

After improving the road by inserting 4 m thickness of several layers of boulders and base course and stacking big boulders at a depth of about 6 m from the original ground surface at the eastern side of the road to support the body of the road, the factor of safety for western side increased to become 3.9. However, the factor of safety for the eastern side decreased to become in the range of 0.98 to 1.02.

If the dump and fill soil to the east of the road is improved, for example by compaction or replacing the soil, then the factor of safety is increased to become 1.64. However, if more fill is added to eastern side down the valley, then the factor of safety increased more and become 1.88.

If big boulders is reduced by 2 m with original soil (no soil improvement), then the factor of safety for western side becomes 2 and factor of safety for eastern side becomes 1.71. If soil improvements are done for the dump and fill materials then the factor of safety for the eastern side becomes 1.86, and if more soil is added to the eastern side down the hill, then the factor of safety for eastern side becomes 2.64 and for the western side it becomes 4.5.

If the western side of the site extended to the west with a slope of 50 degrees, then the factor of safety of the western side would be decreased to become 1.1.

6. Conclusions

From the above analyses and results, the following points may be concluded regarding Nablus – Al-Bathan road:

- Local failures in terms of local landsliding may occur in both the western and eastern side of the site, hence causing cracks and settlements in road. This was due to high unsupported slopes at both sides, the type of the soil found at the site including the dump and fill materials and the soil deep under the road, in addition to that the weather conditions which reduces the strength parameters of the soil.
- Inserting the big boulders at Station 2+100, stabilize the western part of the road and side, however, reduced the factor of safety from 1.02 to 0.98 for the eastern side of the boulders.
- Improving the dump and fill materials and inserting more soil down the valley of the eastern part would increase the factor of safety of slope stability and would reduce local sliding and settlement in the road.
- Reducing the height of big boulders by 2 m would increase the factor of safety of the eastern side of site.

7. Recommendations

Based on the previous analyses and results, it is clear that no guaranteed solution can be found for this existing situation of the site under consideration, due to complex soil type, deep strong soil layer, high slopes and weather conditions. Hence, local failures in terms of landsliding and settlement that will cause cracks to the whole Nablus – Al-Bathan road are expected eventually and specially during bad weather conditions.

The following recommendations are suggested solutions to reduce the problem and not to eliminate it:

- ✓ Reducing the height of big boulders by 2 m.
- ✓ Surplus big boulders can be used to support the slope down the hill and in this case they should rest on good soil layer.
- ✓ Reducing the level of the dump and fill materials by flattening the slope at the eastern side of the road to 1.5 horizontal and 1 vertical.
- ✓ Adding more good soil down the hill of the eastern side of the site and design drainage system by using different sizes of boulders and gravels. This is to drain rainfall water and ensure no erosion of the soil.
- ✓ The removed dump and fill materials at the eastern side of the site can be used down in the valley after improving it by mixing it with boulders.
- ✓ Regarding the western side, no new loads should be inserted on the top of the slope, such as, new buildings, fill or dump materials, etc.
- ✓ Western and eastern slopes should be checked on regular basis as a continuous procedure for any problems and cracks found should be closed and compacted.
- ✓ It is better to increase the stabilization of the soil by planting the slopes with special types of trees.

As planning strategy the following recommendations should be considered:

- ✓ **As a strategic solution to this road, it is recommended to search for an alternative new route that should be located on good soil strata.**
- ✓ **Western and eastern part of the alignments of the road is considered dangerous areas for building construction due to lack of slope stability, hence this zone should be considered as a green area and no construction permits should be allowed on this area.**

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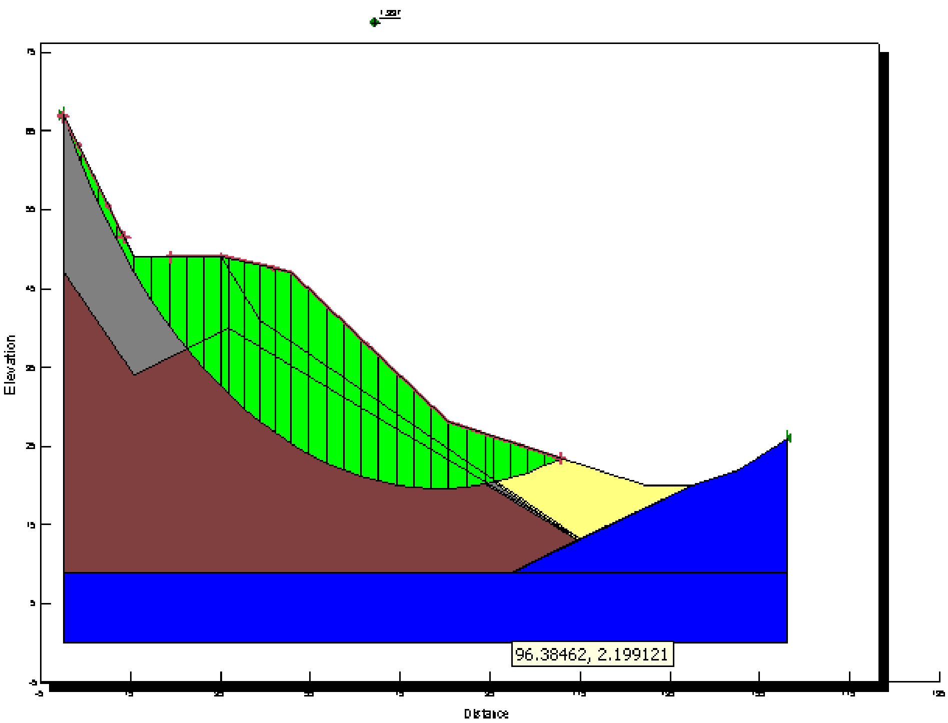

Figure 9: Slope stability analysis for western side (Factor of safety = 2.0).
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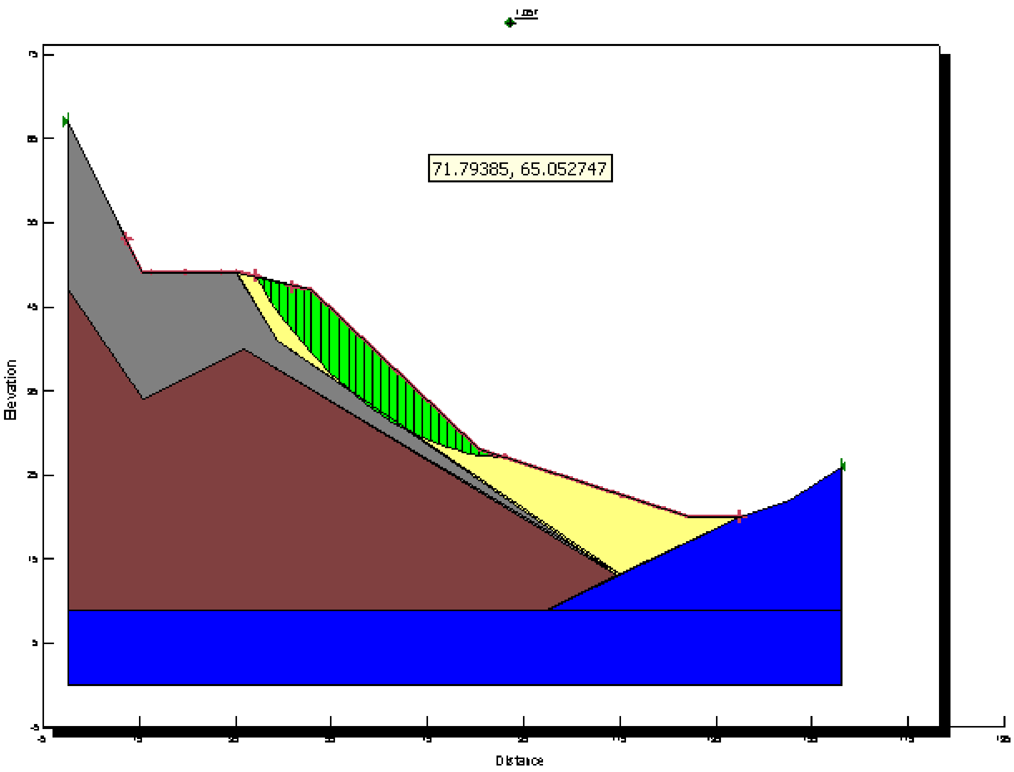

Figure 10: Slope stability analysis for eastern side in the fill materials (Factor of Safety = 1.06).

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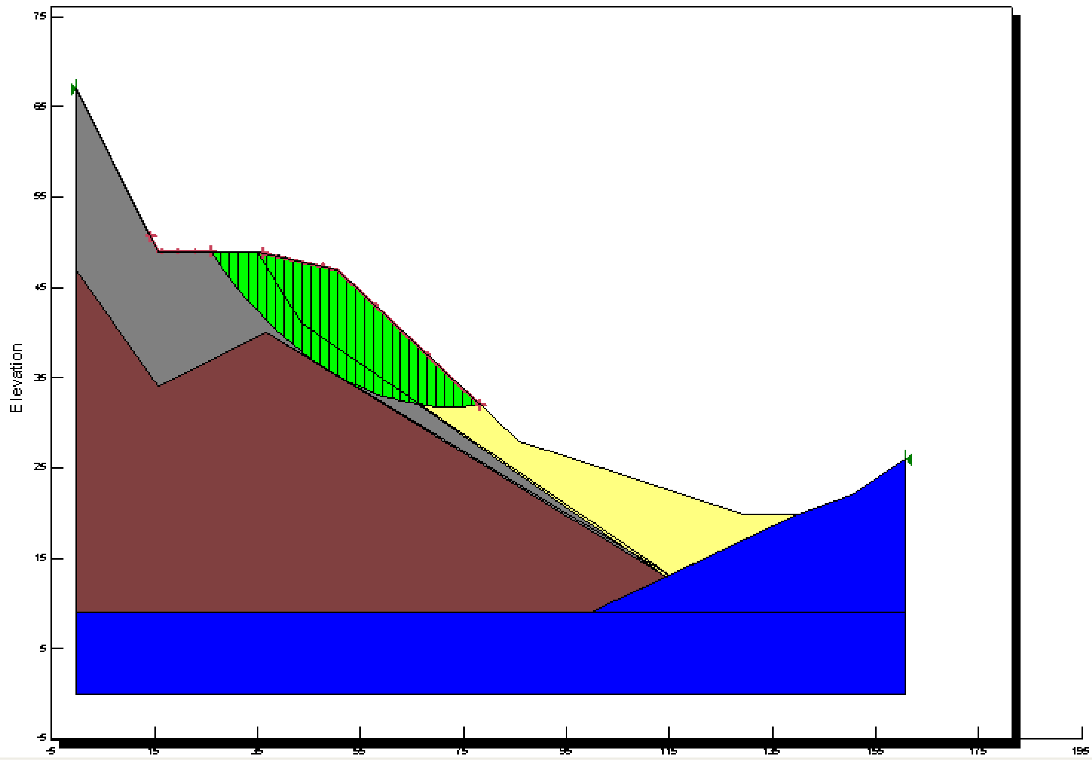

Figure 11: Slope stability analysis for eastern side across the road (Factor of Safety = 1.52).

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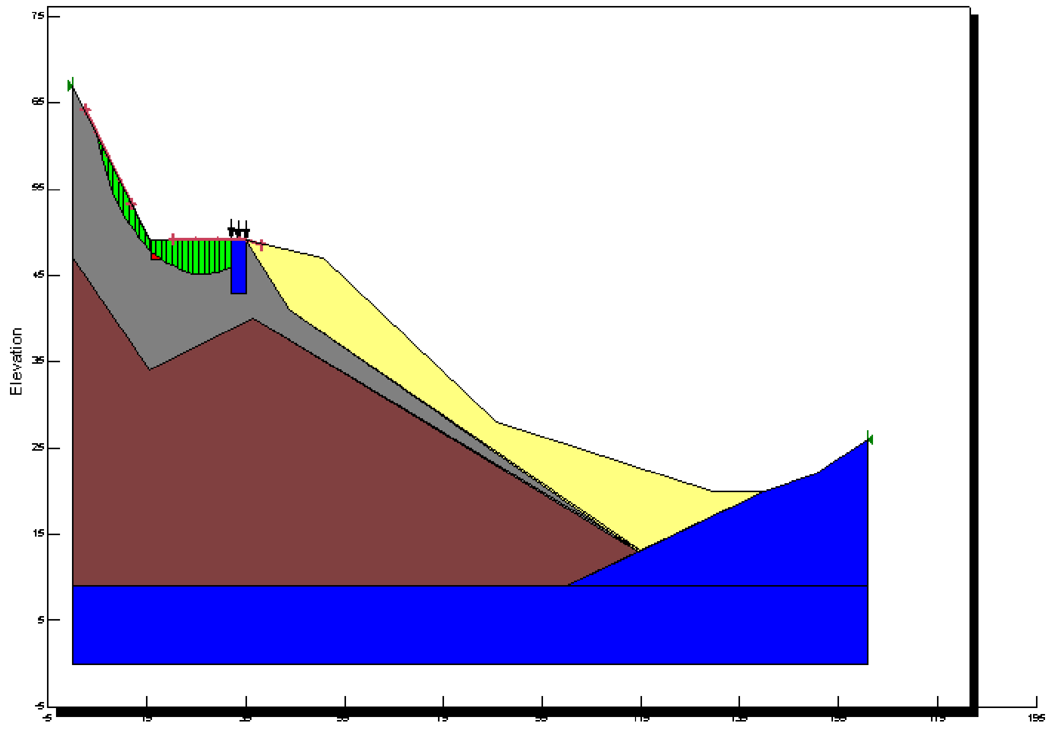

Figure 12: Slope stability analysis for western side with soil improvement and big boulders (Factor of Safety = 3.9).

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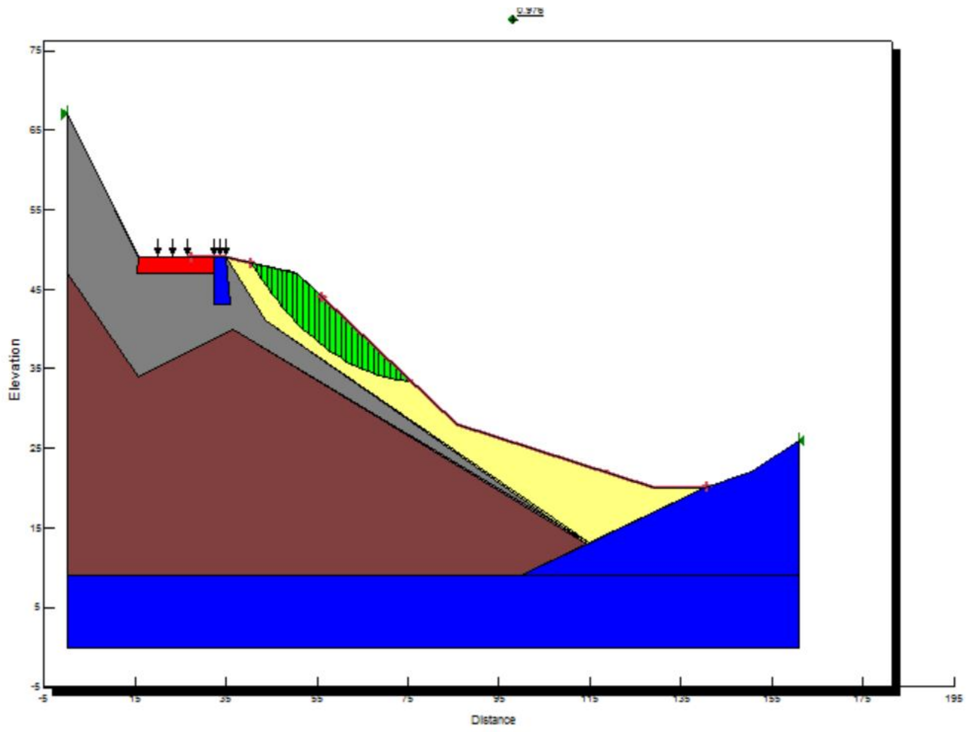

Figure 13: Slope stability analysis for eastern side with soil improvement and big boulders (Factor of Safety = 0.98).

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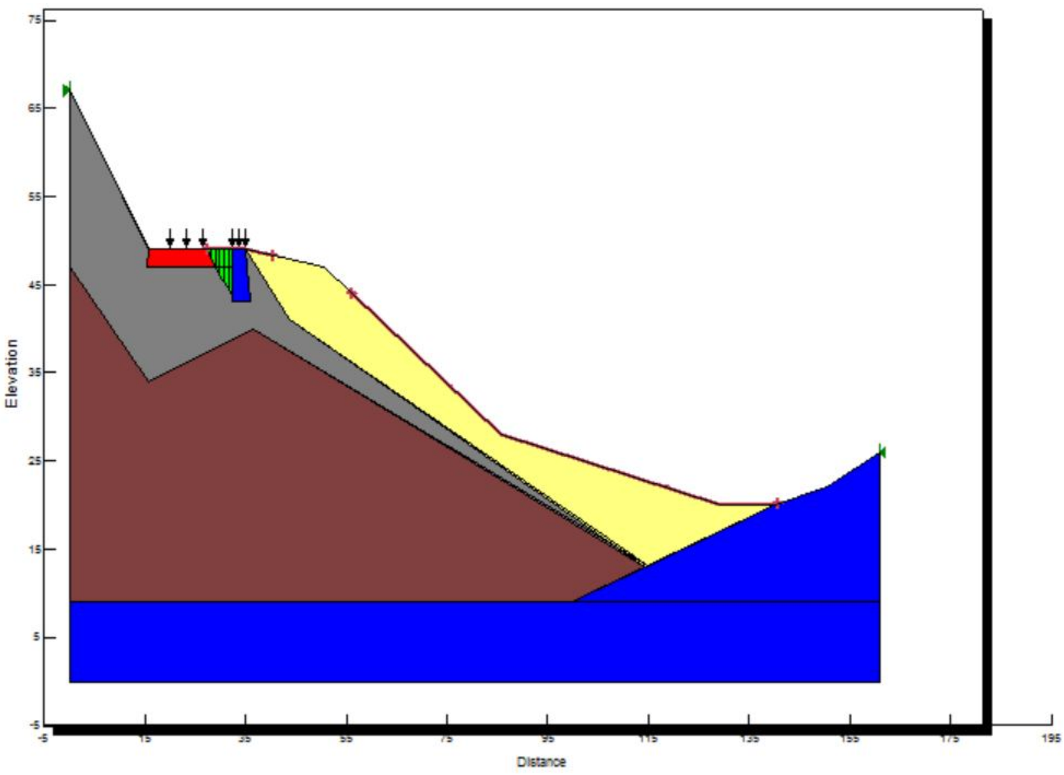

Figure 14: Slope stability analysis for eastern side with soil improvement and big boulders behind the big boulder (Factor of Safety = 1.02).

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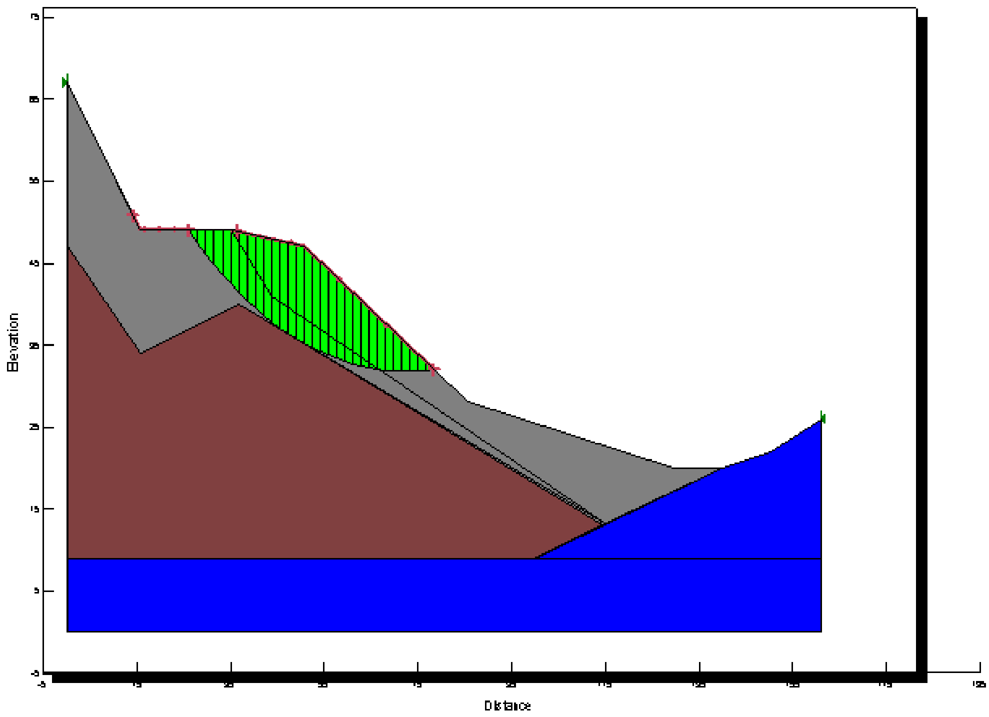

Figure 15: Slope stability analysis for eastern side after improving the soil down the hill (Factor of Safety = 1.64).

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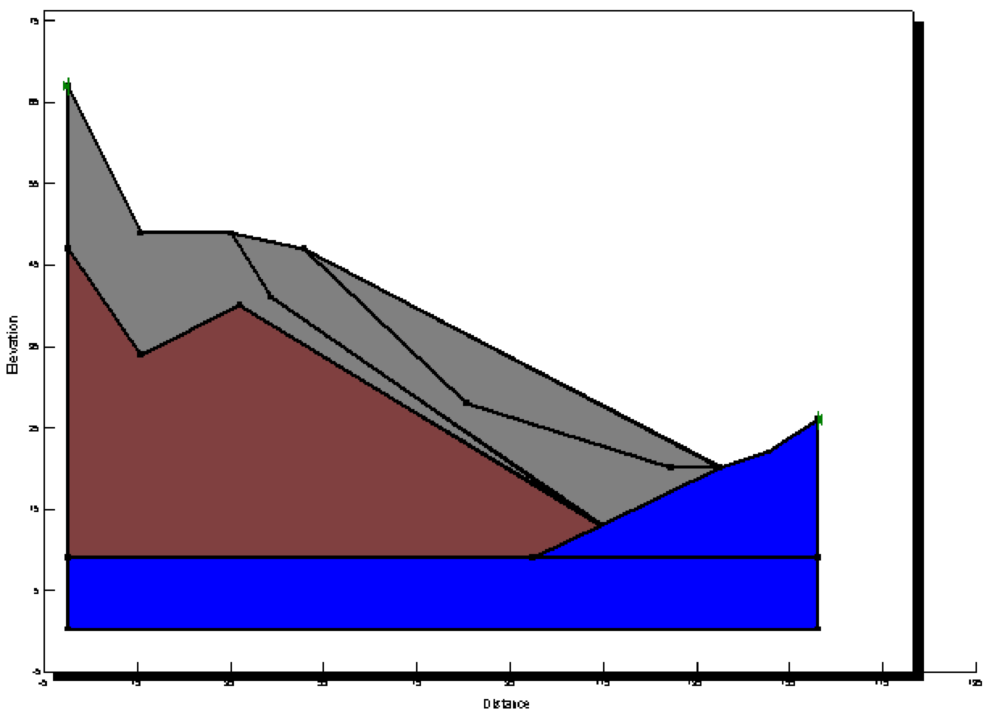

Figure 16: Improving the soil down the hill and add more soil.

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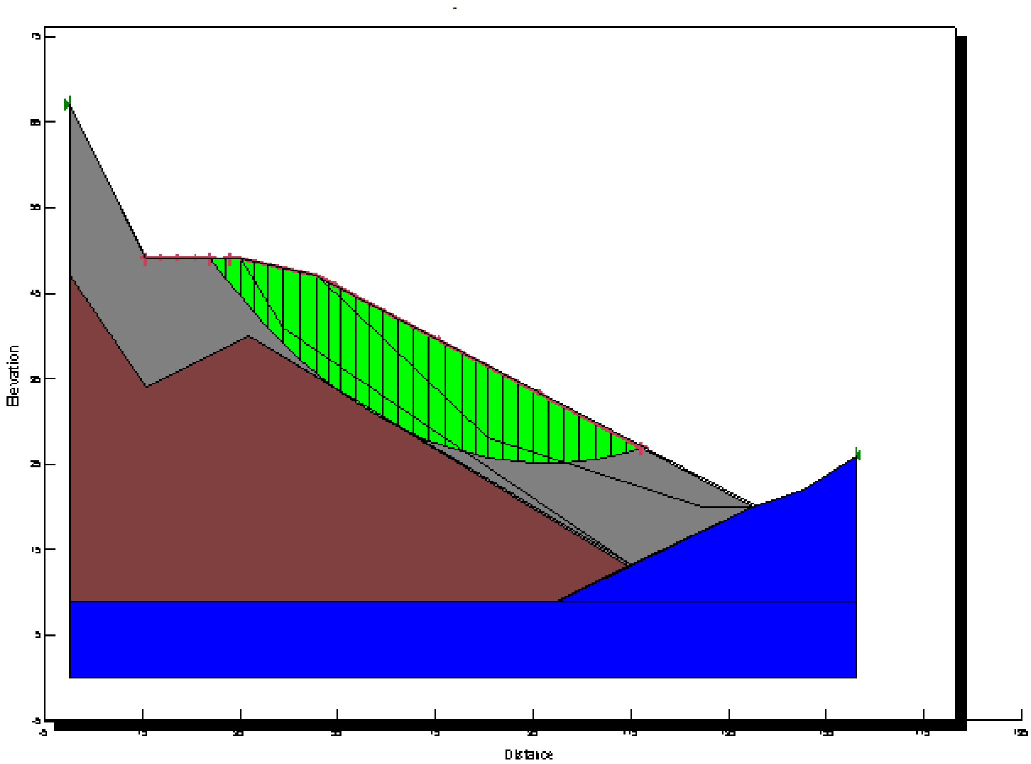

Figure 17: Improving and add more soil down the hill (Factor of Safety = 1.88)

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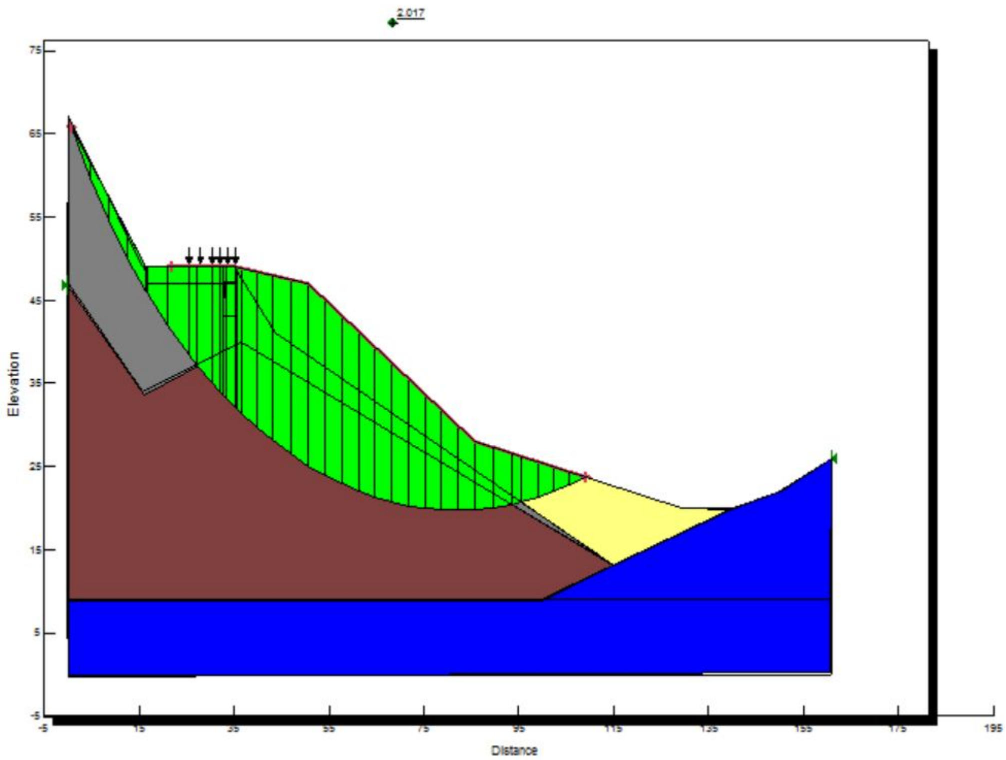

Figure 18 : Reducing the height of big boulders factor of safety = 2.02 upper part western side.

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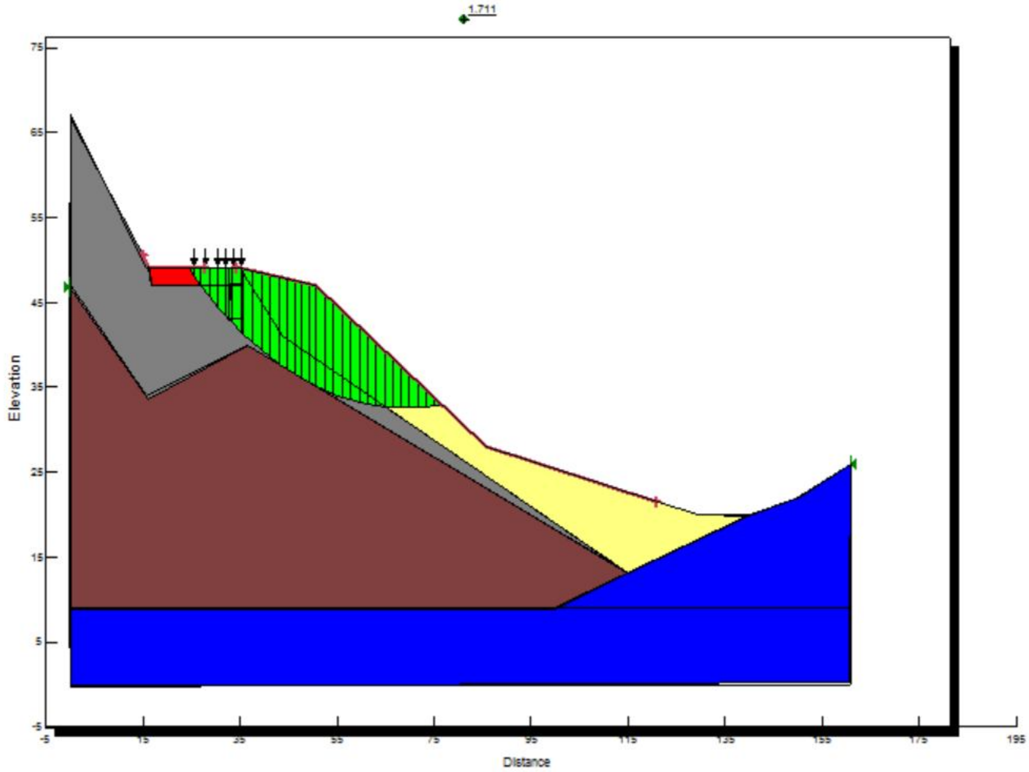

Figure 19: Reducing the height of big boulders factor of safety = 1.71 eastern side

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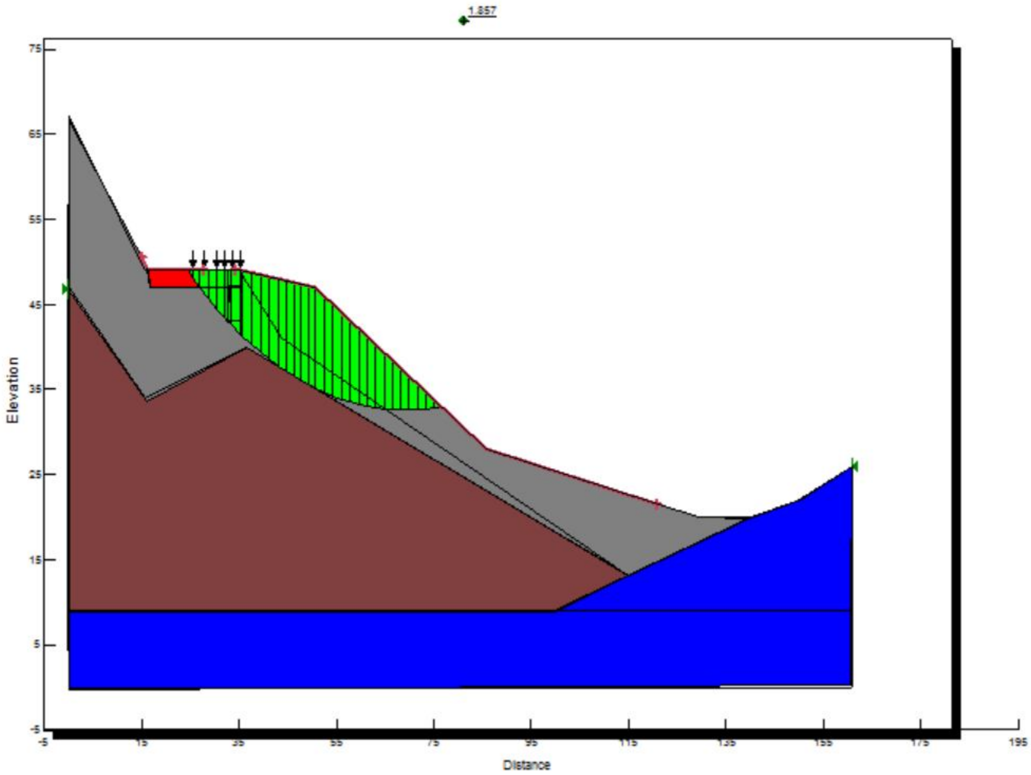

Figure 20: Reducing the height of big boulders and improving the soil factor of safety = 1.86 eastern side

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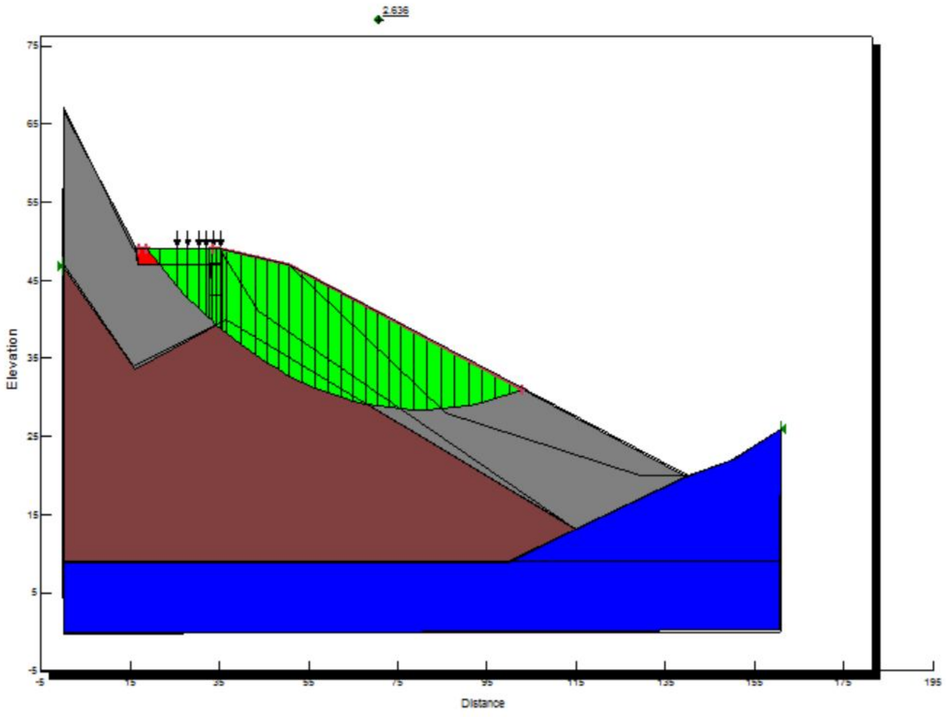

Figure 21: Reducing the height of big boulders and improving the soil and more soil factor of safety = 2.64 eastern side

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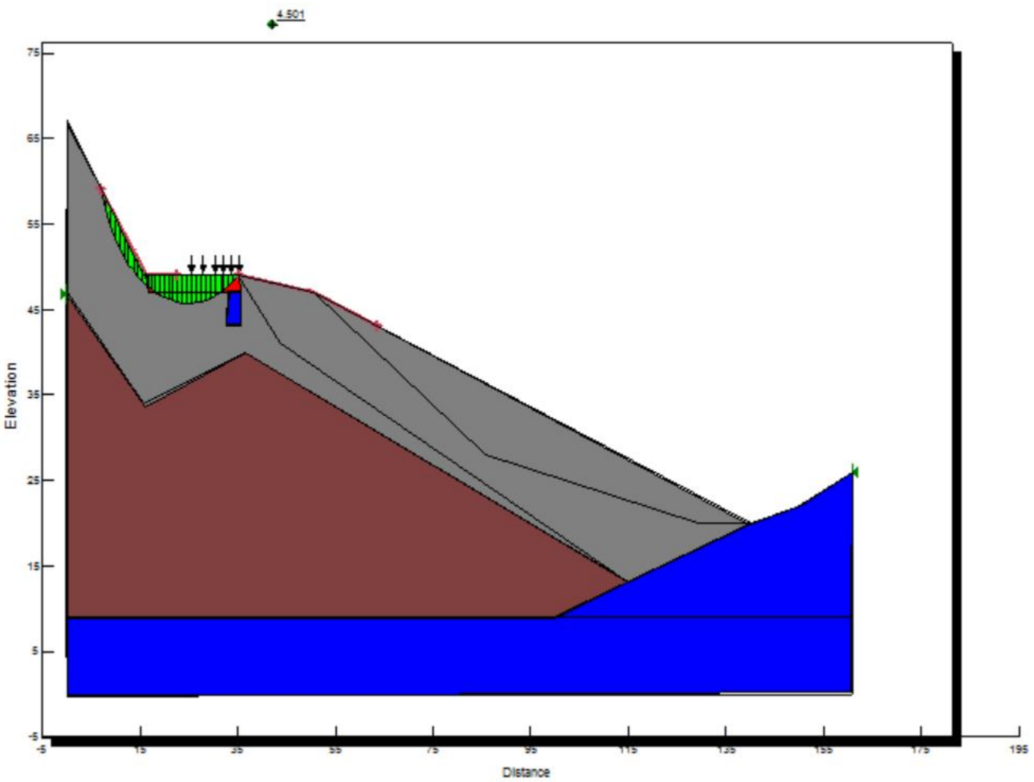

Figure 22 :Reducing the height of big boulders and improving the soil and more soil factor of safety = 4.5 western side

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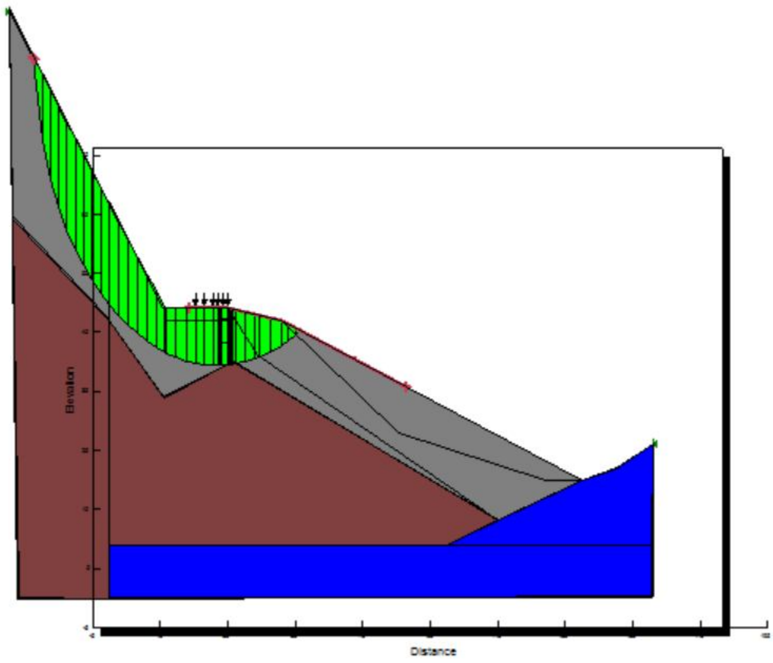

Figure 23: Reducing the height of big boulders and improving the soil and more soil extended in the western side by 30 m horizontal and 35 m vertical the factor of safety = 1.1 western side soil.

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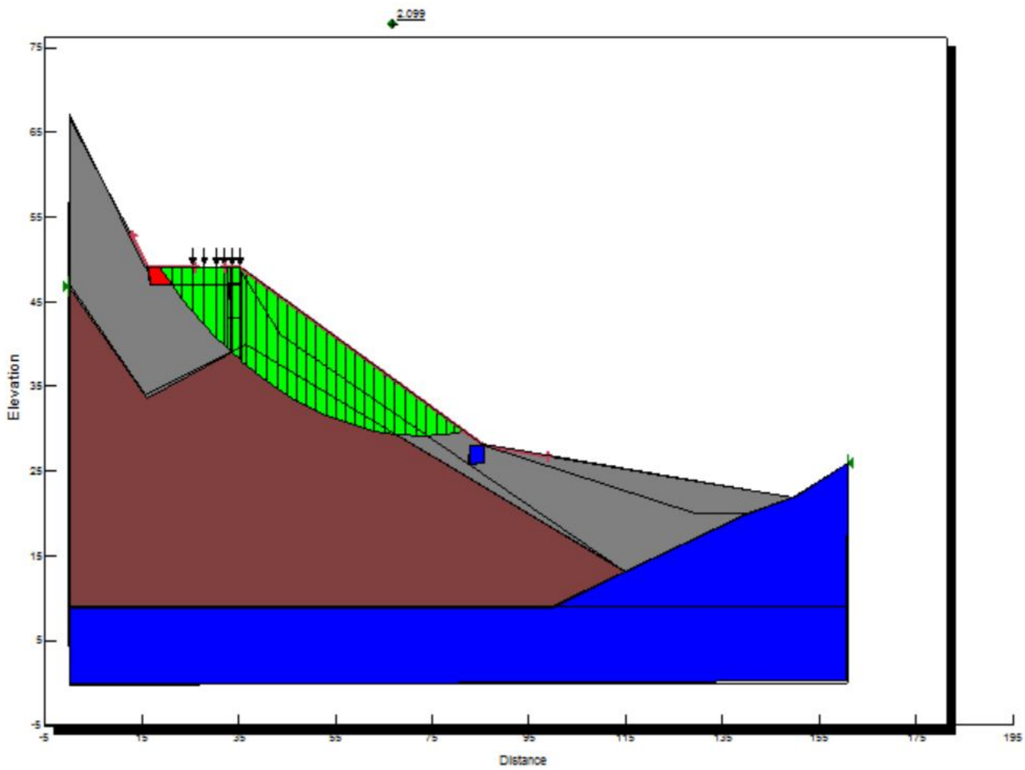

Figure 24: Inserting 2 m of big boulders down the hill 50 m horizontally eastern of the top big boulders (Factor of safety = 2.1).