# Rockfall hazard assessment in the right abutment of sefidrud dam, Gilan (Iran)

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**Abstract**

Sefidrud dam is one of the four largest dams of Gilan Province, Iran. The height and crest length of the dam are 106-and 425 m, respectively. In the right abutment, the intersection of bedding plane with four joint sets has initiated wedge and toppling failures and falling blocks with the potential southwest trends. In the present research, rockfall modeling (at four seeders) was performed to assess the hazards related to these falling blocks. The obtained results indicate that the maximum run-out distance for seeders 3 and 4 are 230.1 and 230.7 m, respectively. These values present that dam is not affected by the coverage distance and block amplitude. In comparison, for seeders 1 and 2 all blocks pass over the Qazvin-Rasht freeway and fall down into the dam. The maximum bounce height, maximum velocity, and maximum kinetic energy at seeder 2 are 12 m, 13.7 m/s, and 15,000 kJ, respectively. Therefore, rockfall occurrence may pose some safety risks to the cars in the freeway and also the dam itself. As some remedies to deal with this situation, it is suggested removing loose blocks and installing rockfall-retaining structures such as protection barrier at the elevation 245 m.

**Keywords: Sefidrud Dam, Joints, RocFall Modeling, Coverage Distance, Barrier.**

## 1. INTRODUCTION

Rockfall mainly occurs when the downward forces acting on rock mass changes probably due to the morphological changes in rock slope face caused by natural or anthropogenic factors [1]. These events occur due to various reasons. In the study area, rockfall is probably triggered due to the presence of discontinuities, topography, lithology of the rock, slope angle size/shape of the falling blocks, and the slope surface parameters. There are some simulation tools developed and tested to simulate rockfall and also to compute the trajectory of falling blocks [2, 3, and 4]. The present study was conducted to investigate the rockfall hazard of the right abutment of the Sefidrud dam using RocFall software [5]. An extensive fieldwork was performed to identify and to record the vulnerable locations and dimensions of overhanging rock blocks to analyze the possibility of rockfall at four locations and its damage extent. Discontinuity survey was performed to record the joint and bedding parameters.

## 2. DESCRIPTION OF THE STUDY AREA

Sefidrud dam (originally named Manjil dam) is a buttress dam on the Sefidrud river in the Alborz mountain range, located near Manjil city in Gilan Province, Iran. It was constructed to store water for irrigation and produce hydroelectric power. The dam is 106m height and forms a reservoir with a capacity of 1.82 km$^3$. The situation and aerial photograph of the study area are displayed in Fig. 1.

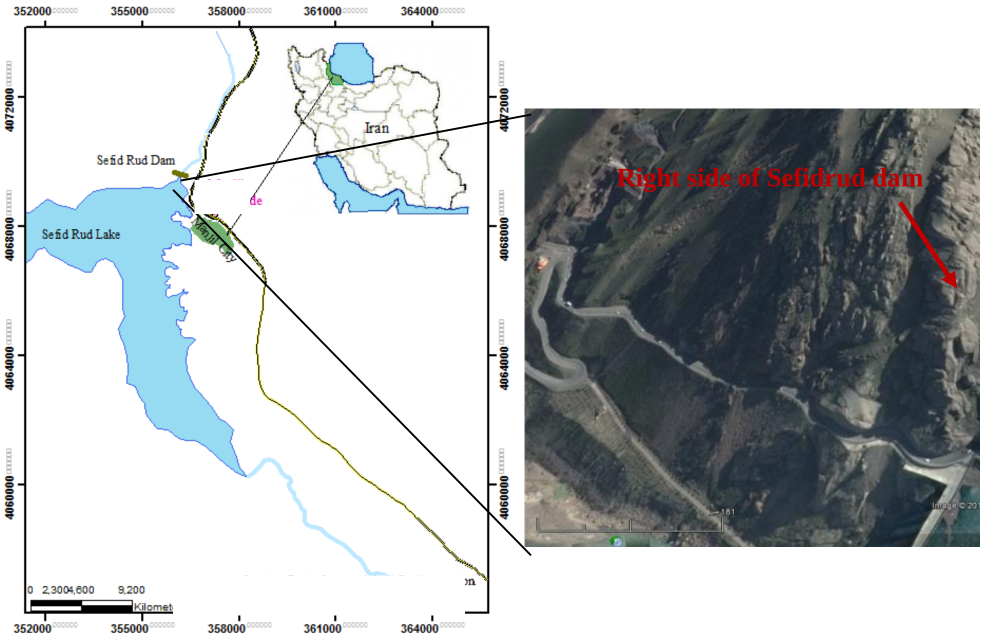



**Fig. 1: Location and an aerial photograph of the right abutment dam**

## 3. GEOLOGICAL AND STRUCTURAL SETTING

The Sefidrud dam was constructed in a deep valley. The dip and direction of the right abutment are about 40-45°and 255°, respectively. The abutment is approximately perpendicular to the freeway and dam axis (N70E). The geological units and structure of study area were analyzed based on information obtained from field investigations and 1:25,000 geological map of Rudbar (Khalil Abad) [6]. The geological map and cross-section of the study area are depicted in Fig. 2. As shown in this figure, the rockfall in this area mainly occurs in the middle Eocene Karaj Formation. Outcrops of this formation consist of massive light gray to cream andesite tuffs. The trend and dip/dip direction of these layers are NW-SE and 70-75°-SW, respectively. Fig. 3a–b represents typical photomicrographs of this rock. The petrographic studies show that the rock is andesite. The rock type was characterized by rectangular plagioclase feldspar, rock fragments, and quartz with porphyroid texture (Fig. 2). These samples have a stream microlites matrix composed mainly of feldspar and quartz with curved grain boundaries. The main minor minerals include bent biotites, which represent applied pressures. The compositions of the fragments are granites, chert, diorite containing biotites and pyroxenes with angular grain boundaries, indicating that the temperature of the magma has not high enough to melt it. Moreover, their burnt margins suggest the presence of high oxygen content. The coarse grains existing in these rocks illustrate some imbalance evidence including gluten, skeletal, zoning, and segment zoning (Figs. 3 and 4). The rock units of the region have a slight to moderate alteration. Sericitization and chloritiztion of biotite and plagioclase, and identitzation olivine and pyroxene have also occurred in these rocks.

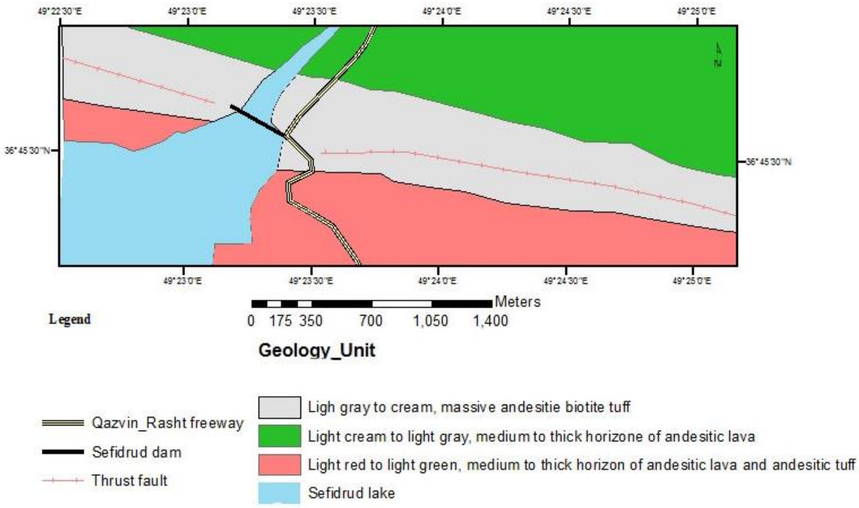



**Fig. 2: Geological setting of the study area**

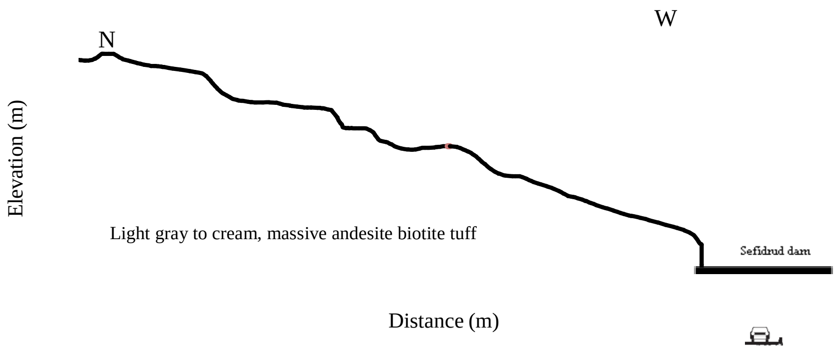



**Fig. 3: Cross sections of the right abutment and the dam axis and the freeway under rockfall risk**

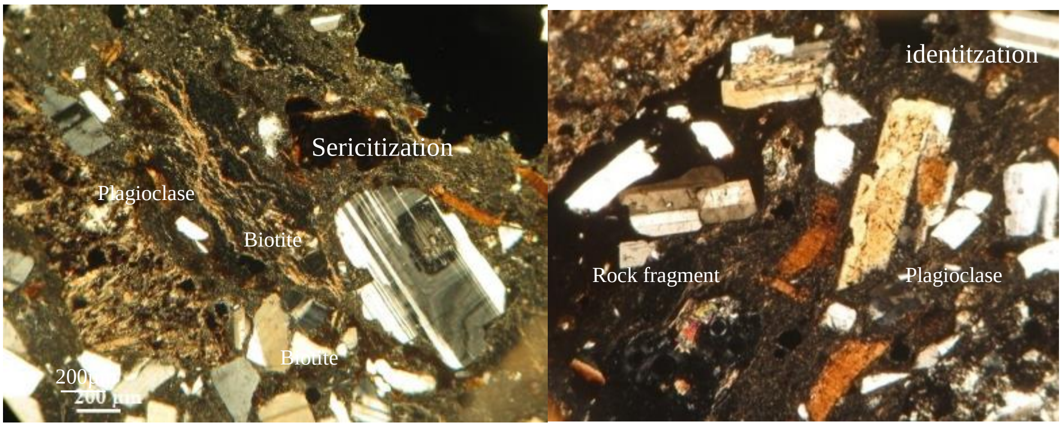
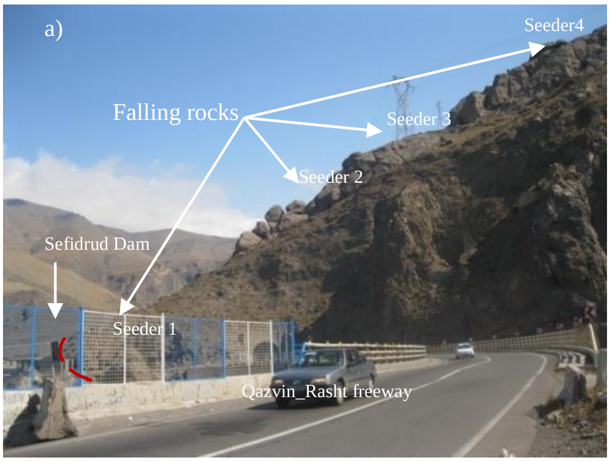



**Fig. 4: Microscopic images of andesite outcrops in the right abutment dam**

## 4. KINEMATIC ANALYSIS

Through a field survey, scanline recording was carried out to determine discontinuity parameters such as spacing, orientation, continuity, roughness, and aperture. Scanline locations were at least 10 m long in the horizontal and were chosen as being the best representatives of the rock mass and discontinuity properties. The dip/dip direction measurements were plotted on stereonets using dips V.5.1 software [7]. Stereonets and spacing of the discontinuities obtained from scanline surveys are given in Fig. 5. The friction angles were calculated from direct shear tests for the rock to determine the potential types of failure. As can be seen in the figure, slope face dips at an angle of 45º toward the azimuth 255º. Also, the measured friction angle of the slope is 35º.Fourdiscontinuity sets were used in this analysis. One set dips about 45º in the direction 75º, the second one dips about 50º in the direction 245º, the third one dips 40º in the direction 254º, and the fourth one (bedding) dips 73º in the direction 183º (Fig. 5). Some large wedges with potential sliding trends can be formed by the intersection of existing joints. As shown in Fig. 5, the wedges resulted from the intersection of bedding plane with joint set 1 and joint set 2are unstable and has sliding potential along the trend calculated at 50º/245º and 37º/255º (dip/dip direction). Moreover, the stereonet plots and related analysis show that there is a potential for planar and toppling sliding/failure in the abutments owing to the following reasons:1) the dip direction of joint set 3 is the opposite to that of the slope and 2) dip direction of joint set 2 is in line with the slope. It is noteworthy that due to the low dip of J2 compared to slope dip, there is a chance of planar failure.



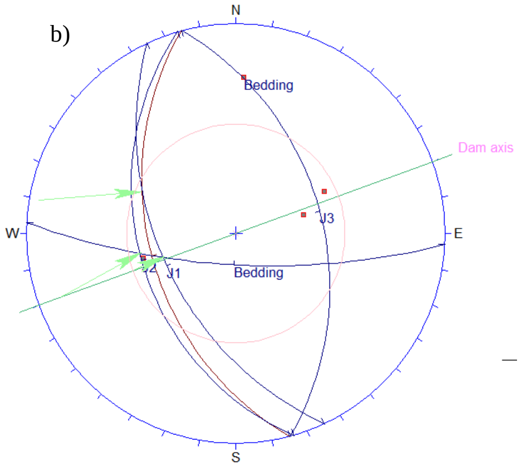




**Fig. 5: a) A field photograph of right abutment dam showing the falling rock at the four locations toward the dam and road (view toward the northwest) and b) A stereonet showing the main sets, friction angle, and slope face plotted in dips V.5.1**

## 5. ROCKFALL ASSESSMENTS

Rockfall assessments were carried out in four seeders using RocFall program [6]. Table 1 shows the values of the parameters used in rockfall simulations. Some of the crucial parameters required to design block trajectories and rockfall simulations are slope geometry, surface roughness, and coefficient of restitution. The size of the falling blocks has been determined directly from the field. Different rock masses with 200 kg and of 150,000 kg at different elevations were considered in the analysis. Accordingly, four seeders were chosen for the ultimate analysis performed in this work. The specifications of these seeds are as follows: seeder 1: (elevation = 263.5, weight = 200kg), seeder 2: (elevation = 304.1, weight = 150,000 kg), seeder 3: (elevation = 336.4, weight = 150,000kg), and seeder4: (Elevation = 338.1, weight = 150,000kg). The bounce height, total kinetic energy, and translational velocity were also calculated in this work. The unit weight of falling rocks was measured to be γ= 22.3 kN/m3 through the laboratory tests. The results of a typical rockfall analysis and variation of the run-out distance are shown in Fig. 6.

**Table 1: Parameters used in rockfall analysis**

| Parameters | | Values |
|---|---|---|
| Rock | Number of rockfalls | 10 |
| | Min. velocity cutoff (m/s) | 0.1 |
| | Initial velocity (m/s) | 0 |
| | Coefficient of normal restitution | 0.48±0.05 |
| | Coefficient of tangential restitution | 0.89±0.05 |
| | Friction angle (°) | 35±2 |
| | Slope roughness | 2±0.5 |
| Asphalt | Coefficient of normal restitution | 0.4±0.04 |
| | Coefficient of tangential restitution | 0. 9±0.04 |
| | Friction angle (°) | 30±2 |
| | Slope roughness | 0 |

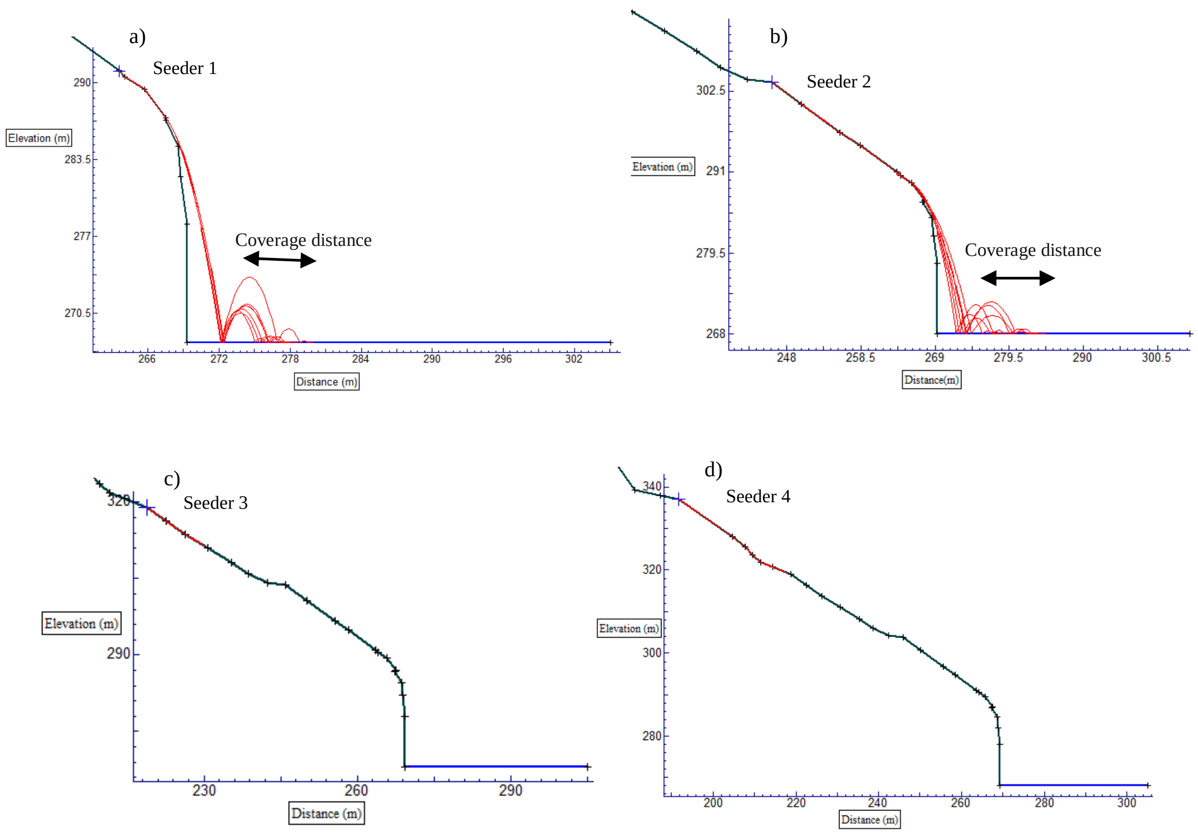



**Fig. 6: Potential trajectories of falling boulders for different seeders at the right abutment of the Sefidrud dam**

## 6. RESULTS AND DISCUSSIONS

As presented in Figs. 6c and d, the maximum run-out distances for seeders 3 and 4 are 230.1 and 230.7m, respectively, suggesting that the dam is not affected by the coverage distance and block amplitude. In comparison, for seeders 1and 2 all blocks pass the freeway and fall down into the dam. Therefore, if rockfall happens, the safety of the cars at the freeway will be under question. Total kinetic energy, translational velocities, and bounce height for the 200 kg at elevation 290 and 150000 kg at elevation 304.1 m are shown in Figs. 7a, b, c, and d, respectively. The maximum total kinetic energy varies from 15.9 kJ to 15,000kJ for 200kg to 150,000 kg mass, respectively. Also, the maximum translational velocities range from 12.5 to 13.7 m/s, which indicate that an increase in the masses of the falling blocks does not have much effect on the translational velocity. Bounce height reached the maximum value of 12.7 and 3.8 m for fallen blocks with the masses of 200 kg and 150,000 kg, respectively (Fig. 7a). In order to prevent further damages, it is suggested to utilize some remedies such as protective barriers to overcome the future problems caused (Fig. 8). Rockfall barriers are key protection systems in mountainous regions worldwide. They are designed to intercept and capture falling rocks. Most systems are composed of flexible steel wire-nets connected to wire-rope cables, which are in turn attached to steel posts and anchored to the ground.

## 7. CONCLUSIONS

Based on simulation results, it is observed that the dam and the Qazvin-Rasht freeway are exposed to the risk of damage induced by the probable future rockfall. Hence, the proper protective measures are required to minimize the risk of the damage to the dam and the life of the passengers in the Qazvin-Rasht freeway. The extensive usage of the Manjil city for tourism, infrastructure, and residential areas results in an increasing need for protecting the civil installations against natural hazards. Removal of loose blocks and also installation of the rockfall retaining structures such as protection barrier at the elevation 245m of the dam are suggested as some remedies for dealing with this situation. Moreover, barriers provide rockfall protection by stopping falling rock blocks and also absorbing the kinetic energy of the falling blocks.

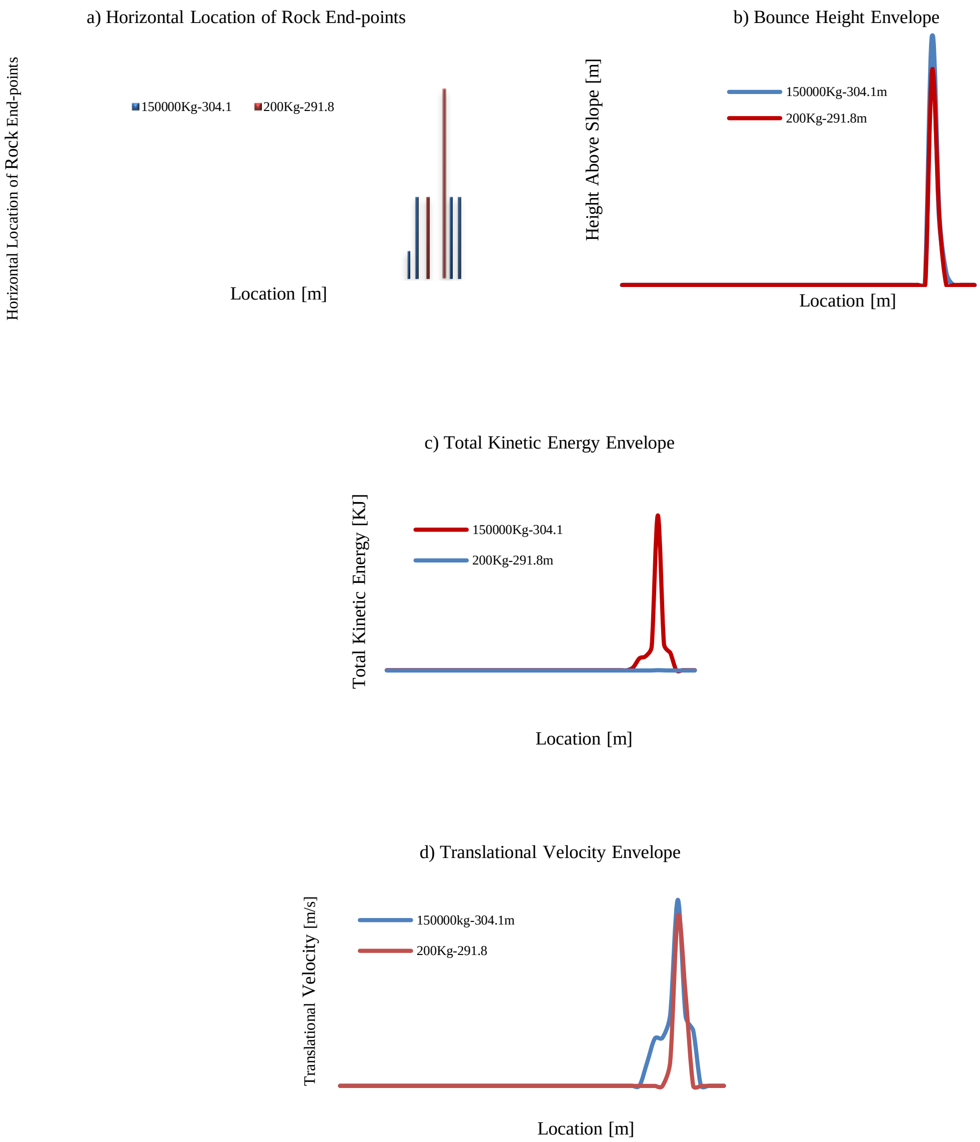



**Fig. 7: a) Rockfall simulation outputs an end-point, b) Bounce heights, c) Total kinetic energies, and d) Translational velocities of the falling blocks**

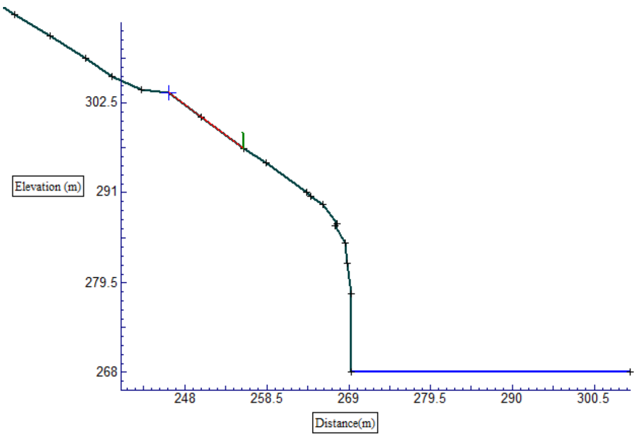



**Fig. 8 Critical location of the protection barrier**

## 8. REFERENCES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