



March 2019 Flood Impact on the Stability of Ambal Salt Ridge in the Gotvand Dam Reservoir, Southern Iran

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Abstract

Ambal salt ridge is a unique exposure of salt piercement in the reservoir of Gotvand dam in the southwest of Iran. It is composed of evaporitic Gachsaran Formation of Oilgo-Miocene Age. This structurally controlled piercement is accompanied by subsidence and sliding of highly soluble layers into the dam reservoir. The region is affected by neotectonic activity due to proximity to two known active faults namely, Lahbari and Pir-Ahmad thrust faults. Based on a four year field observation and monitoring, a gradual and continuous sliding is occurring that is intensified by ground water circulation through evaporite karstic sinkholes and fracture systems. The subsidence and sliding of the Gachsaran evaporitic layers increased significantly after a severe flash flooding in March 2019. The water level rising due to flood event caused filling and saturation of the existing sinkholes in the salt ridge that facilitated and prompted development of land sliding. The situation is expected to be more critical if a moderate to high earthquake would happen since the dam lies in an active tectonic zone of the Zagros Fold Belt. Land subsidence and sliding was facilitated by high fracturing due to neotectonic activity. Finally, based on the Newmark method, slide potential of the largest landslide body of the Ambal ridge was calculated considering geotechnical parameters obtained from core drilling and partial saturation of the salt body during March, 2019 flooding of Karun River.

Keywords

Gotvand dam • Landslide • Ambal salt • Slope stability

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1 Introduction

Floods and landslides can have severe and even disastrous consequences with fatalities, diseases, construction and infrastructure failures. The risks related to a flood or landslide can be described as the potential for loss, damage, or destruction of an asset as the result of a hazard exposing a vulnerability related to the event (Werner et al. 2010).

Floods cause damage by inundation, erosion, and by the impact of detritus against man's structures or by its deposition on valuable property. Each of these kinds of damage is influenced by the geology of the watershed contributing to the flooded region. Some dams are built solely to create a flood control reservoir. However, most reservoirs, called multi-purpose reservoirs, serve many objectives. When flood control is required, some of the storage space of the reservoir reserved for other purposes may also serve flood control, but not on a planned basis. Landslides occur on slopes in a variety of geological materials and develop through a variety of mechanisms and causes including river flooding (Bolt et al. 1977). Hazards arising from the earth's surface processes in terms of flooding and short-term climatic effects and as well as slope instability are widely recognized as ever-present dangers (Bromhead 1999; Andersson-Skold and Nyberg 2016). In addition to flooding, moderate to large earthquakes can also trigger landslides that could be dangerous for dam body (Keefer 1984). Reservoirs are one of the most important water resources in arid regions and play an important role in managing the limited surface runoff for different uses and controlling flash flooding (Jalali et al. 2019). However, the environmental impacts related to reservoirs and dams (e.g., hydrological, geomorphic, ecological) are a serious and growing concern in river basin management and environmental protection programs (Casale and Margottini 1999).

Scientific advances lead to periodical revisions of the influence of neotectonic activity on engineering structures (Marín-Córdova et al. 2004). The activity of faults and

related salt tectonics have affected engineering structures in the Zagros fold belt including the Gotvand Dam (Fig. 1) in Khuzestan Province of southwest Iran (Barjasteh 2012, 2013). The dam is a rockfill dam with a height of 182 m mainly built to generate hydroelectric power and provide flood control. The average annual runoff volume at the dam section is about 13.3 billion m^3 and the reservoir capacity with a length of 90 km is about 5.1 billion m^3 at the maximum normal operation elevation (234 masl). The stability of the dam reservoir becomes an important question as the existence of Ambal salt piercement could unfavourably damage highly fertile downstream farms and agricultural land (Hassanvand et al. 2011). The Karun River is the most important stream in the country originating and recharging from high Zagros mountain range. The River provides water for many cities, villages, agricultural projects and industrial factories along its nearly 380 km length downstream the reservoir of the Gotvand Dam.

This study was based on a four-year field observation and monitoring of land subsidence and sliding of the Ambal Salt Ridge. The study was accompanied by periodic site visits of the area especially after heavy rainfalls and fluctuations of the reservoir water level. During each site visit, the trends of newly formed fissures were recorded and subsequently compared to the last recorded ones. The number of the newly developed sinkholes and their extent were also

evaluated and recorded and finally compared to the previous ones. Additionally, the situation and extent of the observed fissures and sinkholes and location of subsided lands were assessed and checked on the available Google Earth images. The subsidence and sliding of the Gachsaran evaporitic layers on the Ambal Salt Ridge were significantly increased after a severe flash flooding in March 2019 according to the last field trip on May 2019.

2 The Reservoir Hydrology and Geology

The dam and its reservoir are located in a semi-arid environment that experiences high summer temperatures up to 50 °C and many months without rain. The dry season generally starts in middle to late April and lasts for 6 months. The rains return in October, but most precipitations are from December onwards. (Fig. 2), mostly occurring during the early spring. Rising river levels, sometimes up to about 3 m can result in significant salt dissolution and slope failure along the Ambal ridge section, mostly in the form of slides and block toppling. Mean annual rainfall is 420 mm based on meteorological data from the Gotvand site, but totals have varied widely from one year to the next. The rainfall events tend to be sporadic, short and intense and such storm events result in appreciable water level rises in the Karun River.

Fig. 1 Geographical location of the Gotvand Dam (oval) and Ambal Ridge in Karun River basin (after Aghdam et al. 2012)

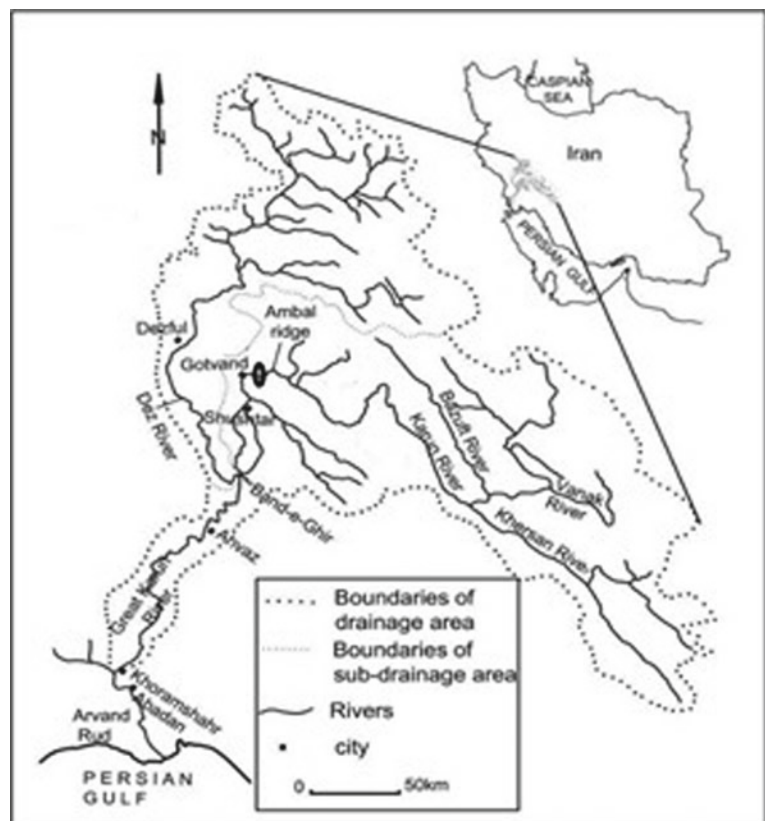
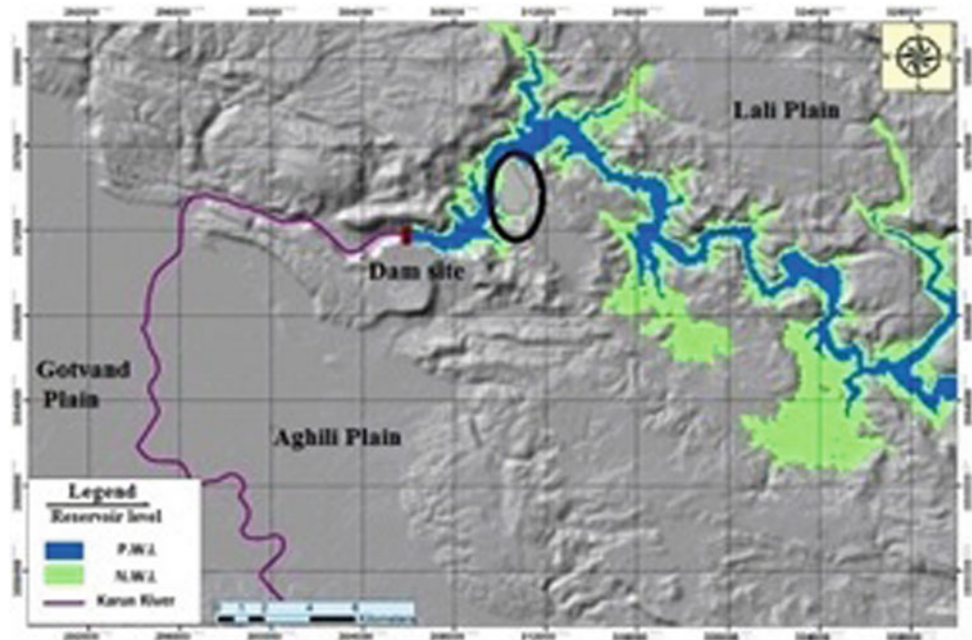


Fig. 2 Digital elevation model (DEM) of the Gotvand dam and reservoir region and location of Ambal ridge (black ellipse)



The Gotvand dam and reservoir are located in the Zagros Active Fold Belt from the seismotectonic point of view (Berberian 1995) in the northern part of Dezful Embayment structural unit. Fault plane solutions of the earthquakes in the region consistently show high-angle (40–50°) reverse faulting (Tatar 2012) with an estimated depth range from 8 to 13 km and 4–6 magnitudes. As part of Zagros Simply Folded Zone, the study area is comprised of parallel, long anticlines and Karun River syncline (Stocklin and Setudehnia 1977; Barjasteh 2018). The most important faults in the region are: Pir- Ahmad, Lahbari, Andeka, Lali and Shushtar thrust faults (Fig. 3) among which the first two are

known as active faults (Barjasteh et al. 2017). The reservoir area is dominated by Lali Anticline which strikes NW–SE.

The reservoir area is dominated by Lali Anticline which strikes NW–SE. The Ambal salt ridge is located on the Lali Anticline and is occupied by Gachsaran Formation outcrop (Fig. 4). This Formation was named after the Gachsaran Oilfield in Khuzestan Province, where it is best developed (James and Wynd 1965). It was divided into seven members based on a type section composed of intervals from the well logs in the mentioned oil field (Stocklin and Setudehnia 1977). Members two, three, four and six have extensive salt units. The non-salt part of Gachsaran Formation is divided

Fig. 3 Google earth view of the main morphotectonic lineaments in the area including Lahbari active fault (thick red) and Lali-Ahvaz (thick yellow) lineament

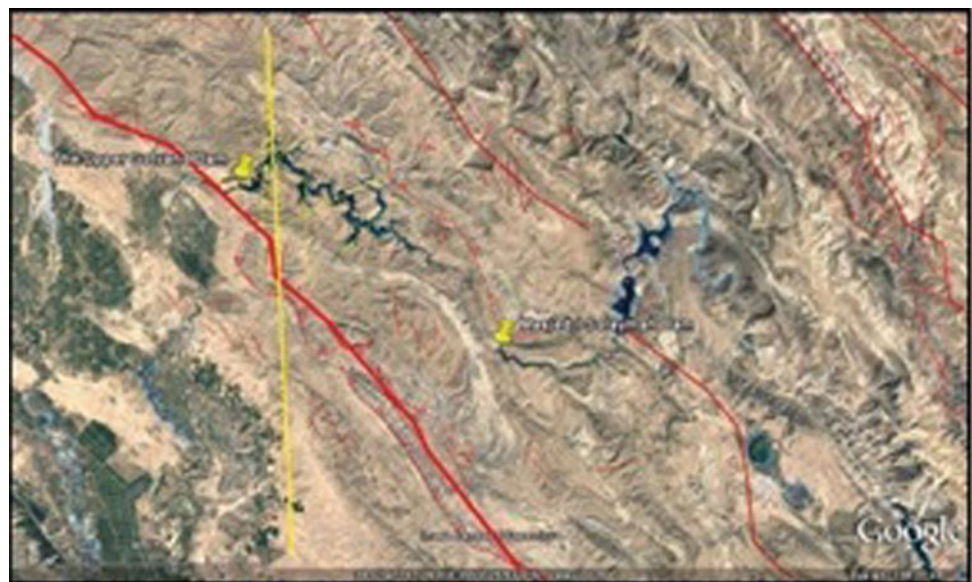
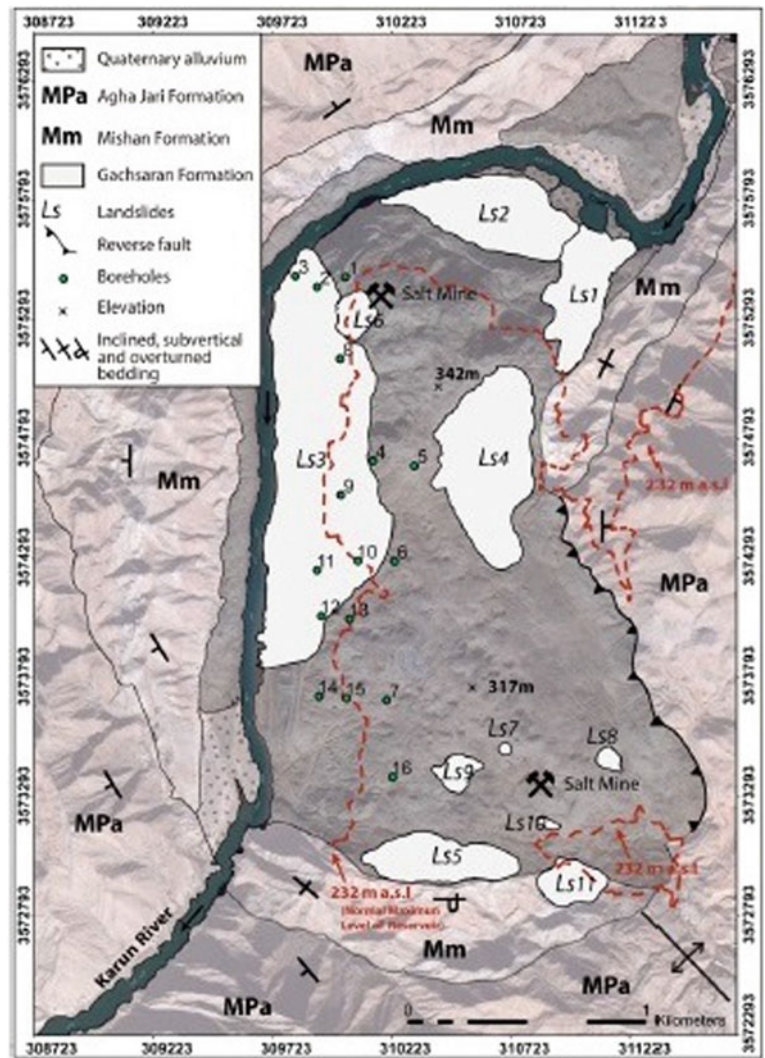


Fig. 5 Geomorphological map of the Ambal ridge (after Gutiérrez and Lizaga 2016) showing the distribution of the mapped landslides



3 Slope Stability

Based on the Newmark method (1965) as noted by Eq. 1, slide potential of the largest (Ls3) landslide body (Gutiérrez and Lizaga 2016) on the western flank of the Ambal piercement within the reservoir region was calculated (Eq. 1) applying geotechnical parameters obtained from the drilled bore holes besides partial saturation of the considered slope during March 2019 flooding (Fig. 8). In the Newmark method, the dynamic stability is related to static stability and the static factor of safety (FS) can be obtained by simple relationship (Jibson 2009). The Newmark (1965), the paper should start with the title section which has a showed that the critical acceleration of a potential landslide block is a simple function of the static factor of safety and the landslide geometry (Eq. 2).

$$ac = (FS-1)g \sin \alpha, \tag{1}$$

where ac is the critical (yield) acceleration in terms of g , the acceleration due to earth's gravity; FS is the static factor of safety; and α is the angle from the horizontal that the center of mass of the potential landslide block first moves.

$$FS = \frac{C'}{\gamma t \sin \alpha} + \frac{\tan \phi'}{\tan \alpha} - \frac{m\gamma_w \tan \phi'}{\gamma \tan \alpha}, \tag{2}$$

With regard to the available values for the geotechnical parameters of the Gachsaran Formation at Ambal ridge (Baghdashtaki et al. 2010) that is cohesion (zero) and internal friction angle (32°) and considering relevant saturated values for rock, FS was conservatively estimated to be equal to 1.086. After computing the static factor of safety regarding to the seismicity of the region (Fig. 9), the critical acceleration which can trigger initial sliding was estimated as 0.042 g that is much lower than the DBL value (0.27 g) of the dam site (Maleki and Behnam 2005). Accordingly, Ls3 landslide body shows highly critical condition during

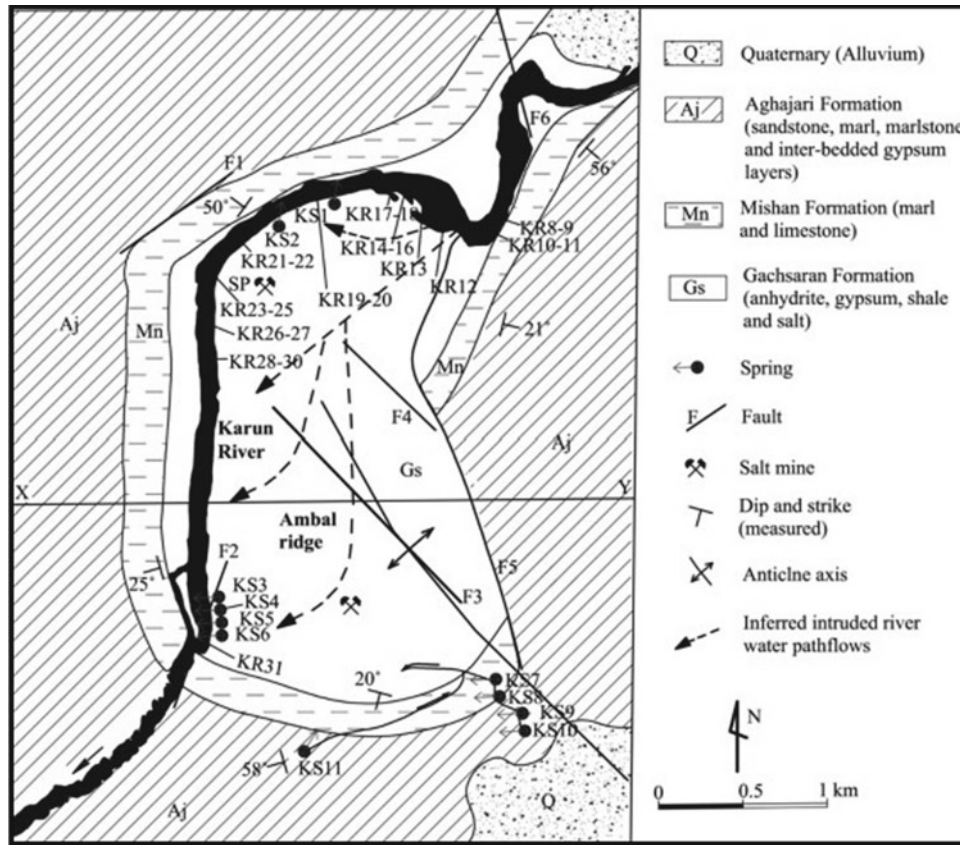


Fig. 6 Geological map of the Ambal ridge showing its groundwater regime (Aghdam et al. 2012)



Fig. 7 Progressive sliding and subsidence of the reservoir margin before (top) and after (bottom) the March 2019

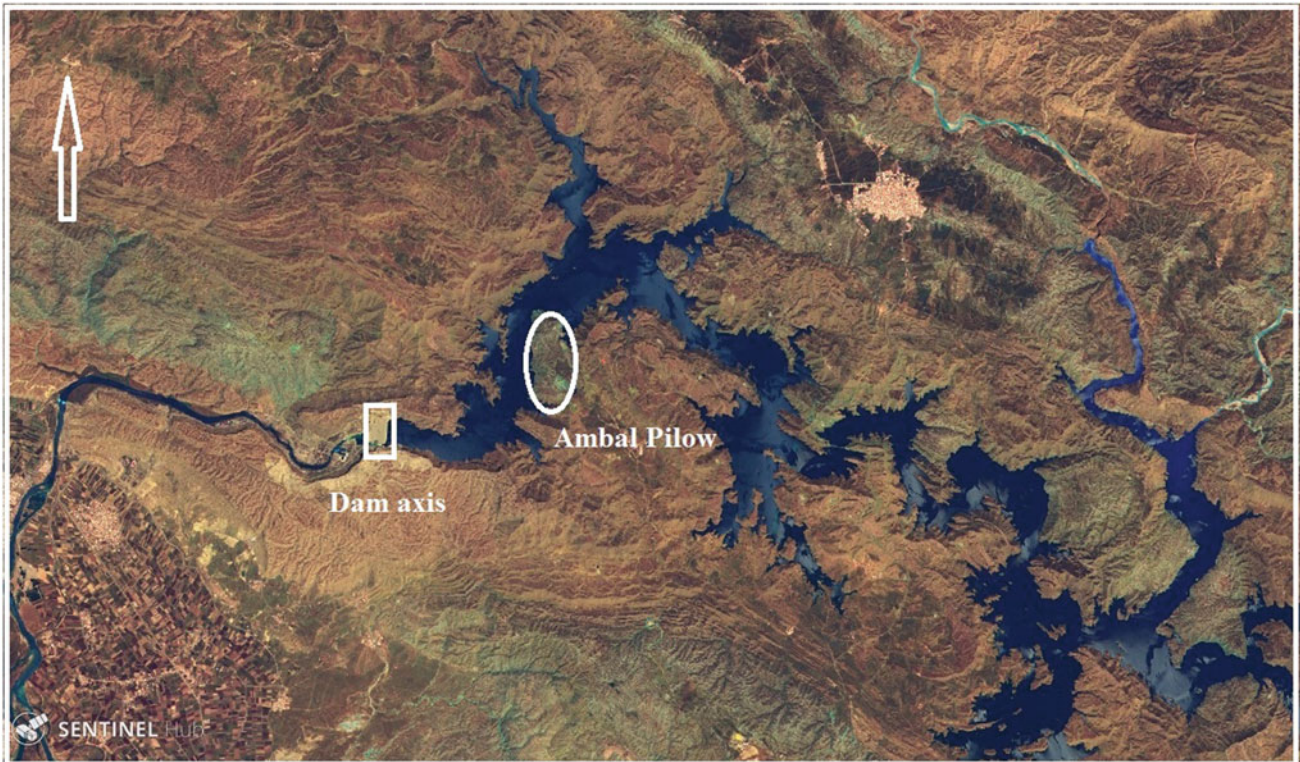
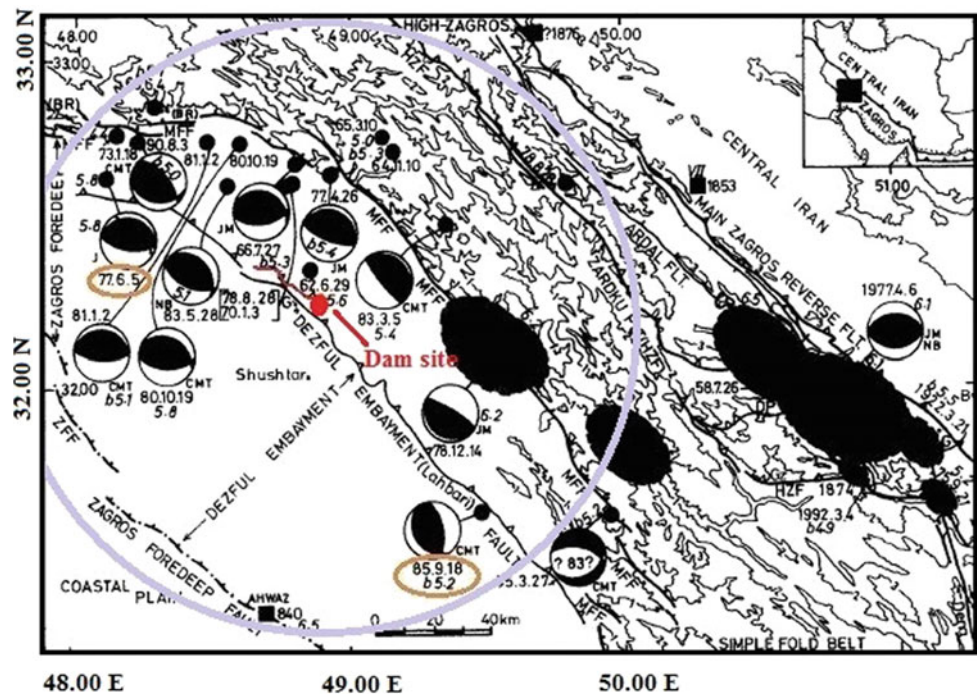


Fig. 8 Sentinel-2 image of the dam and reservoir region after the 2019 Karun River flooding (26.4.2019)

Fig. 9 Regional seismotectonic map in 100 km radius around the dam site (after Berberian 1995)



earthquake loading taking into account its partial saturation due to the March 2019 flooding. Such a condition could also be harmful for the dam body. Previous slope stability

analyses (Water Institute 2005; Baghadastaki et al. 2010) indicated a little larger safety factors but with lower ground water levels (Fig. 10) or smaller DBL values.

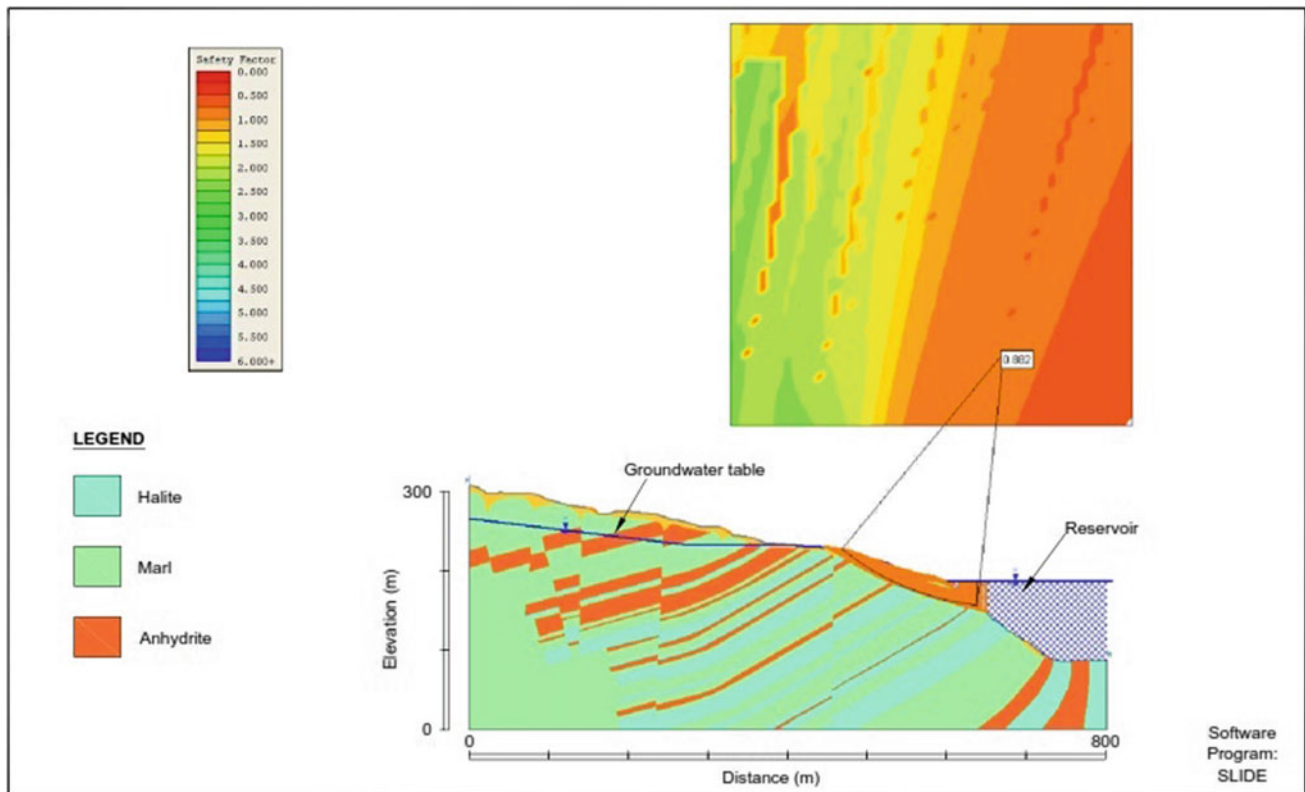


Fig. 10 Stability analysis of the upper section of the Ambal ridge (after Water Institute 2005)

4 Conclusions

The occurrence of Ambal salt ridge as an active halokinetic structure in the Gotvand Dam Reservoir imposed some problems to the project including subsidence and land sliding of highly soluble layers into the dam reservoir. The ridge is accompanied by several landslides and sinkholes. Periodic field investigations accompanied by satellite image observation show that Ambal salt pillow in the left bank of the reservoir is continuously sliding into the reservoir since its impounding. The gradual development of landslides is partly due to the halokinetic rise of the Ambal ridge and partly to the tectonic uplift of the region resulting from the regional tectonic compressive regime. The event of a severe flash flooding in March 2019 increased the reservoir water level to exceed the maximum normal operation elevation up to an elevation of about 236 masl, so that the subsidence and sliding of the Gachsaran evaporitic layers were significantly increased. As a result, the increase of ground water level saturated the existing sinkholes at different elevations that facilitated sliding of soluble layers. Considering tectonic activity of the region and regarding to the effect of moderate to large earthquakes to trigger landslides, based on the Newmark method, slide potential of the largest (Ls3) landslide body (Ls3) on the western flank of the Ambal

piercement was calculated. It was shown that the landslide body has a low safety factor nearly 1.086 and could be critical during earthquake loading.

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