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DAMMING HUNZA RIVER BY MASSIVE ATTABAD LANDSLIDE, STORY OF A RISK MANAGEMENT INITIATIVE FROM HUNZA, PAKISTAN

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ABSTRACT

The mountainous region of northern Pakistan is seismically active as Indian plate is subducting beneath the Eurasian plate. Various geological phenomena are active due to the mountain building and landslides are one of the most destructive natural disasters in the Karakoram range. The northern part of Pakistan, Gilgit-Baltistan, falling in this region is no exception to that. Attabad was a remote village situated on the right bank of Hunza River at a ground distance of almost 125 km from Gilgit city. The area falls into Darkut-Karakoram metamorphic complex composed of granites, granodiorite, and gneiss. A devastating landslide occurred on 4th January 2010, as mode of circular failure which blocked the Hunza River forming a lake behind. The debris material hit the opposite rock cliff, due to narrow gorge the landslide mass travelled downstream 1.5km with huge debris surges, hitting 8 houses in lower Attabad which came under rubble and 19 people died. Aga Khan Agency for Habitat previously FOCUS Pakistan developed an inventory of active landslides across the KKH in Hunza in 2000-2001, however this landslide was not identified. Later in 2002 after the Astore earthquake initial cracks developed at the top of the slope. The 8th October Kashmir earthquake destabilized and U-shaped demarcation appeared across the slope. Anthropogenic activities like irrigation of lands, seepage of water from rain and snow melt water further destabilized the land. Finally, an earthquake in November 2009 in Hindukush region triggered the landslide and brittle failure occurred on 4th January 2010.

KEYWORDS: Darkut Metamorphic Complex, seismic events, Early warning system, circular failure

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1. INTRODUCTION

1.1 Background

Attabad which is a remote village situated on the right bank of Hunza River (downstream direction) at a ground distance of almost 20-25km from Tehsil headquarter Aliabad in N_E direction. The village constitutes round about 100 settlements, two middle schools (one AKES and one is Government middle school) one dispensary where only first aid treatment was available. The area was settled on slope profile a landslide prone area, which is activated several times in past and the locals were evacuated from the area.

The process of landslide started during the long lasting rains in early 1993-94 as a result of which rock falls events were noticed at the lower and eastern ends of the slope. In 2002 the particular area became active Local Council informed FOCUS Pakistan to assess the situation, as a response FOUCS Geologist visited the area and

assessed the situation. At that time the upper scarp was visible and down ward movement was 5-13 feet while the aperture was 1-4 feet. The remaining stable rock segments were visible at places supporting the unconsolidated material. The surface boulders were sunk into the slope and some were detached from their position. The findings of this assessment was that there were 23 houses on the moving slope, a potential threat exists there, Human lives, settlements and cultivated lands were vulnerable. If this slope movement occurs, it will block the Hunza

River causing the submergence of KKH and the nearby village (Ayeenabad), similarly a flash flood will occur which will sweep the lands along the bank of river towards downstream. The assessment report was shared with the local council and government.

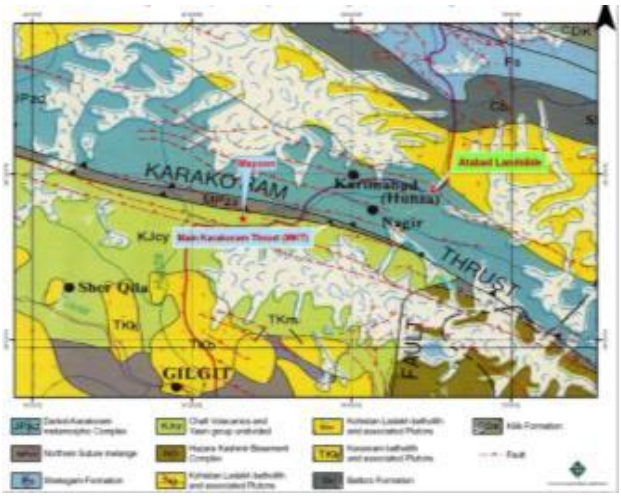

Figure 1: geologic map of region.

1.2 Geologic and Tectonic setting

The problematic area is a slope varying from 25^0 to 75^0. An overburden of maximum 15 meter thickness is underlain by granite rock from head to the toe of the slope. Overburden is of colluvial nature comprising of boulders, cobbles and gravels with some sand and silt. Boulders and cobbles are sub angular to sub rounded with sandy and silty matrix. The rock exposed at the toe and head of the slope is highly foliated, jointed and moderately weathered. The foliation is striking east- west and dipping into the slope. One set of joints is dipping towards slope at steeper angle while another joint set is found to be almost vertical and striking at right angle to the slope face. In addition to major joints sets other joints are also found [1].

Attabad area falls into Darkut-Karakoram metamorphic complex according to the geological map of Pakistan. They are dominantly granodiorite composition. High grade metamorphism of the rocks up to gneiss grade has been reported. Bed rocks are massive in nature with maximum strength.

Two main faults in north Pakistan i.e., Main Karakoram Thrust (MKT) and Karakoram fault are passing near by the Attabad one on SW side and other on NE, respectively. These two faults are the source of seismicity in Gilgit-Baltistan. There are also some minor and active faults in the region; Upper Hunza Fault, Raikot-Sassi Fault, Sassi Fault, Stak Fault, and Shamran Fault are known active source of seismicity [2] .

2. SEISMIC AND ANTHROPOGENIC ACTIVITIES AND ITS IMPACTS ON ATABAD LANDSLIDE

1.1 Seismic activities

Earthquake events have great impact on the activation of the landslides worldwide in addition to other factors like rain and anthropogenic activities. The Attabad landslide is one of the examples which have been activated by the earthquake event in 2002.According to the notable and local population, there was a heavy rainfall (long lasting) and cause intensive rock fall along the slope (now problematic), affecting the land property without any loss of life. Just after the long lasting rains locals have observed some

displacement adjacent to the contact between rock slope and slope material, but these were remained at same position without any further changes for long time [3]. It is likely that this cracking was caused by a damaging earthquake, which has occurred at the junction of Astore valley and Indus valley on the 16th November 2002 [4].

Date	Time	LAT	LON	DEP	MAG	MT
11/6/2007	15:46.7	38.155	73.264	131.3	5.5	mwc
10/26/2007	50:06.7	35.304	76.753	10	5.2	mwc
2/11/2007	39:18.4	36.728	72.971	53.8	5.1	mwc

The initial crack at the top of the slope has developed after the Astore earthquake as noticed by the local community and FOCUS Geologist visit the landslide after that event. Monitoring points were installed and the cracks were monitored by CERT (community emergency response team) volunteer. Lateral movement and downward movement data of that visit is mentioned here;

Downward movement of the slope (DWM)

DWM at P 1= 5-10ft, DWM at P3=4ft

DWM at P4=3.5ft, DWM at P6=13ft

Lateral movement or aperture of the cracks (LM)

LM at P1=3ft, LM at P2=1-1.5ft

LM at P3=4ft, LM at P4=2ft

After the earthquake event of Astore 2002 cracks became widened and from 2002-04 the landslide remained dormant. No changes were recorded during this time period.

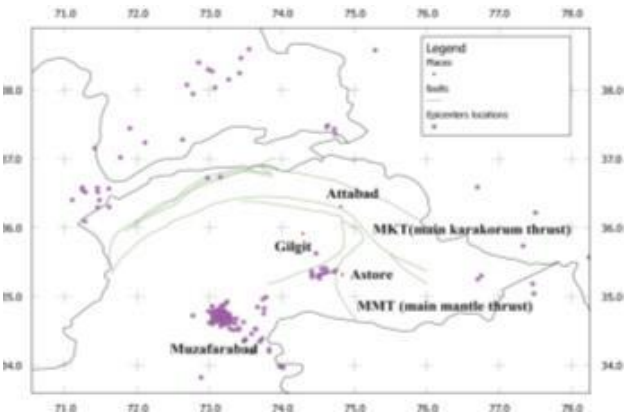

Figure 2: Map showing the seismic event occurred from 2002-2009 in the surrounding of Attabad. The earthquake events which have impacted the landslide are highlighted

The devastating earthquake of Kashmir occurred on 8th October 2005 having a magnitude of 7.6. There was no apparent increase in the ground cracking problem noted following the 2005 major Kashmir earthquake [4]. However new tensional cracks were observed on the NW side of the slope and cracks also appeared in 3 houses due to dynamic loading of the unstable slope after the Kashmir earthquake as reported by the locals. The monitoring data on the specific points is not available as at that time the data was maintained in hard form, therefore it is difficult to show the exact change in the cracks dimension, however according to the locals changes were occurred after the landslide which were also reported in newspaper.

Further tensional cracks systems were inspected by FOCUS in 2007, and their location, size and form indicative of a buildup and release of the stresses. These stresses may have been related to the 2005 earthquake as it was distinctly felt by many people in Hunza [4].

Three events have been recorded according to the USGS database 1st on 11th February 2007, 2nd

on 26th October 2007 and 3rd on 6th November 2007.

1.2 Seismic activities

The first settlement at Attabad started in early 1825, at the time there were only 15 families who came from Altit village. For the purpose of cultivation irrigation channels were constructed to irrigate the land. The people were residing at the old clutter area local name "Khun" (cluster of houses). With the passage of time and increase in the population the people started construct new irrigation channel to settle on the eastern slope gradually where the current landslide event has occurred on 4th January 2010. The eastern slope gradually cultivated and developed and almost 23 houses settled before the activation of landslide in 2002. In 2003 a Tajik seismologist [5] visited the area and suggested to leave the areas and use the unstable slope for the purpose of cultivation of trees and gardening through the drip irrigation. Control irrigation system and if possible repairing of the water channels. However local people ignored his suggestions and continued to live there and grown the crops. After the 2005 earthquake new cracks were developed on the eastern side of the slope, tensional cracks were also observed in 3 houses (according to the locals). Demarcation (development of the crack) of the whole slope occurred in 2007 and new tensional cracks develop throughout the slope and in almost 10 houses out of 23.

Even after the development of the tension cracks in the field and in structures people didn't stop the irrigation of water to the fields. Water from the channels, irrigation water and sewerage water was continuously infiltrating in to the slope which further destabilized the landslide due to the increased saturation.

3. SEISMIC AND ANTHROPOGENIC ACTIVITIES AND ITS IMPACTS ON ATABAD LANDSLIDE

3.1 Seismic activities

The devastating landslide incident occurred on the 4th of January, 2010 at 11:30 Am, landslide (rock fall) events started 2 days back from the same area. The people were already evacuated from Attabad (Bala) due to the movement of the landslide. The whole slope mass including hard rock and unconsolidated material has detached suddenly from the hard rock slope. The debris material has hit the opposite side rock ridge and landslide mass diverted with air pressure due to narrow gorge towards upstream and downstream direction in form of debris surges. As a result of debris surges downstream 8 houses came under the rubble in which 19 people reported to be killed.

Figure 3: A NE aerial view of the Attabad landslide Source: FOCUS Pakistan, it triggered from the left side and blocked the narrow gorge of Hunza River and KKH. The debris material traveled 800m upstream and 1200m downstream while the length of the actual blockage was almost 950m.Totally the spread of the landslide debris was approximately 3km. The downstream surges damaged 8 houses in which 19 deaths occurred. Lacustrine deposits clay and silt

material spread at the upper surface of the landslide mass and it was squeezed out from the riverbed.

Rock fall events started two days earlier of the landslide disaster and it continued till the event. According to one of the eye witnessed who was at Attabad village, said that a crack started from eastern end and moved towards NW side and crack started to open from western side and connected with the eastern crack fumes came out with the opening of the crack. At the same time multiple cracks developed in the whole landslide mass. The slopes slipped down 100ft cracking sounds were heard and the rock mass stopped for a while and then moved down at once and hit the river terrace. The river terrace material composed of cobbles, pebbles, clay and silt were squeezed and the whole river terrace material spread at over the whole debris material which was unique thing.

Figure 4: An aerial View of Attabad landslide, Source: FOCUS Pakistan, according to the interpretation of the features developed after the landslide, the landslide event occurred in 3 stages. First the central eastern portion came down as result the left portion came down due to dragging force and at the third stage; upper rock ridge came as observed at the top of the clay deposits above the debris mass. Minor time difference anticipated between the 1st and 2nd portion which the 3rd phase came after the settlement of the whole debris mass.

3.2 Attabad Landslide

Attabad landslide created a dam along the Hunza River. KKH the strategic road between China and Pakistan was also blocked after this event and almost 25000 people trapped in Gojal valley. The people of the valley depend on for their income resources on trade, agriculture as potatoes are the cash crop of the valley. But they couldn't grow potatoes as they cannot transport fertilizer and potatoes to sell in the marked. So the people of the valley faced problems in terms of transportation, trade, agriculture, financial crises physiological and educational hindrance.

There was no any trigger for the landslide. The weather conditions were cold and dry, but not exceptionally so, but there were no recorded seismic events of sufficient magnitude to trigger the landslide. Thus, it appears that this is a time dependent failure [6].

3.3 Attabad Lake Monitoring

Instantly after the formation of the dam, storage of water started at the back and lake formation initiated. FOCUS Pakistan geologist along with the CERT volunteers started the monitoring of the lake both upstream and downstream at the spillway and recorded the changes in the water level in the lake. For the 1st week the rate of water level rise in the lake was higher and after that the water level rise gradually decreased with the increasing in the area of lake. The fig.4 below show the trend of water level changes in the lake from 1st February to 1st July 2010.

In the initial days the rate of water level rise was higher i.e. 24ft/day as the area of the lake was less, but with the increase in the lake dimensions the rate of water rise gradually fell down.

Seepage of water at the toe of the barrier started in the 1st week of March that also decreased the water level rise in the lake. However, in the month of April and May again the rate of water level increased gradually due to the increase in the discharge of water from the different glacier sources and streams.

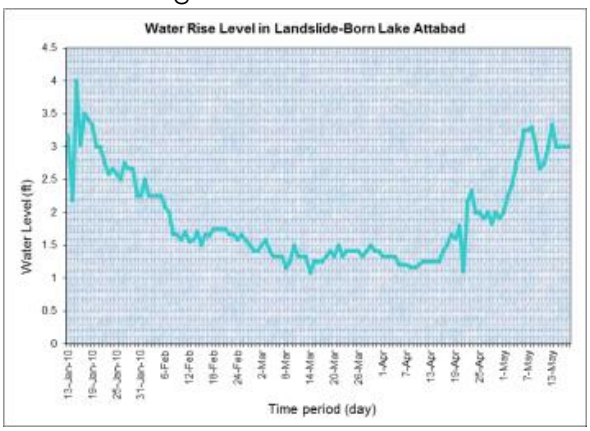

Figure 5: Showing the trend of water rise in the lake from 13th Jan to 13th May 2010. Data from 5th to 12th Jan is not reflected in this graph as rate of change in the lakes level was higher in the 1st week of January, due to which remaining data was not clearly visible and rate of change for the remaining days was not that much higher and difference was comparatively less. Therefore, to indicate the data clearly on the graph 1st few days' data not reflected.

The discharge rates in the winter and early spring remained low in Gojal tehsil 825cusecs to 1100 cusec till mid-April. After that the discharge rate gradually increased from the mid of April. The peak discharge in the valley remains from mid of June-August mid.

On 21st May 2010, the excavation of the spillway was almost 51ft i.e. 15.54m and the excavation of the saddle was stopped for the safety purpose by the FWO (Frontier Works Organization). The total height of was spillway before the exaction was 414ft from the river bed, if we subtract 51ft (excavated portion) from total height, the remaining was 364ft. Considering 363ft height, freeboard at that time, rate of water change the possible overtopping date was anticipated and shared with the local government and NDMA.

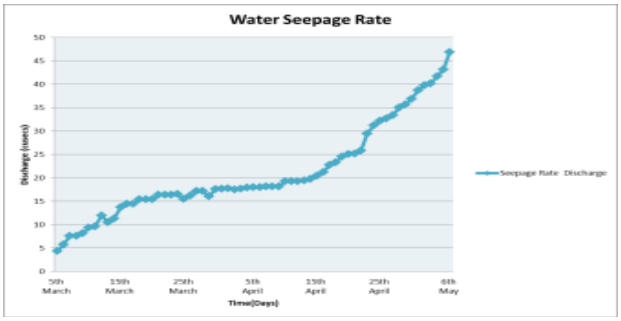

Figure 6: The graph reflects the rate of change of seepage at the toe of the Attabad landslide from 5th March to 6th May. Due to the safety and security reason the data collection on the seepage stopped as over topping from the spillway was near.

At the time of overtopping the lake had reached a length of 21km, and an estimated volume of about

450x10, 000000 m³ of water [7]. The newly developed lake inundated four villages i.e. Ayeenabad, Shishkat, Gulmit and Hussaini in which 171 houses were also submerged. It also destroyed almost 23km of KKH (Karakorum High-Way) including five bridges on road both RRC and wooden. People of the Gojal faced severe problems in transportation as they have to travel through boats across the lake.With increase in the lake length and volume of water in the reservoir, the pressure built on the Attabad Lake. Initial sounds/blasts were heard in the month of April 2010 at Shishkat village. The local people became anxious about the development of sounds and intensity of the sounds increased at nigh time. Second time sounds were also heard on 28th May one day before the overtopping. On the request of the local government FOUCUS Pakistan conducted the assessment of the sounds, may be these develop due to the

collapsing of the banks or possible settlements along the river terraces. But this was not the case. If we study the geological map of Pakistan six offshoots are running parallel to MKT (Main Karakorum Thrust) from Chalt to Attabad as shown in fig.1 above. The sounds were coming possibly from the settlement of the local faults due to the reservoir pressure built up as a result in increase in the water volume in the Attabad Lake.

4 EARLY WARNING SYSTEM AND ITS MECHANISM

4.1 Early warning system

After the formation of the lake and increasing level of water at the back of the landslide, the threat was also increasing with the passage of time. Villages at the upstream were submerging with increasing level of water while downstream the threat of dam outburst floods. According to the [7] four scenarios were stated, considering the worst -case scenario and possible impact on the downstream low-lying areas, an early warning system was crucial. FOCCUS Pakistan felt then need of the EWS, installed the Early Warning System with the close coordination of local government. FOCUS Pakistan provided the technical assistance/services including the established of the camp and installment of the early warning system from Attabad to Gilgit.

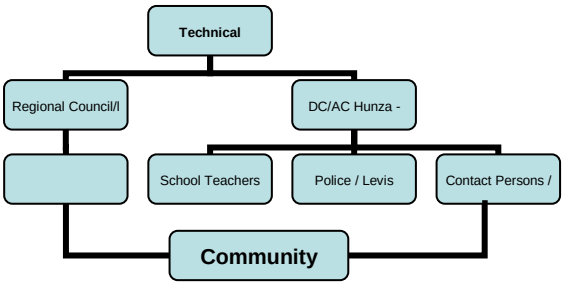

Figure 7: The above sketch shows the structure of the Early Warning System. Technical persons from both Government and FOCUS Pakistan were at the Attabad monitoring camp. In case of any unforeseen situation at the barrier, the technical person will inform the DC and regional councils. On the behalf of the government DC will declare the activation of EWS. Then through the orders government school teachers, police/levis and contact persons to respond to the emergency situation. On the other hand the councils will inform the CERT and contact person to be ready to response to the emergency situation. The final benefit will be for the communities at risk of the dam outburst flood.

4.2 Lake Monitoring Mechanism

FOCUS HVRA team in close collaboration with the government agencies PWD & police jointly developed a monitoring mechanism and the lake was monitored, and situation reports were shared with the local government and FOCUS management for planning and implantation. CCTV cameras were installed above the lake barrier are being used by FOCUS Pakistan staff to monitor the lake round the clock.

Figure 8: CCTV cameras installed at the

4.3 Early warning mechanism

The early warning systems were installed at 12 vulnerable locations starting from Salmanabad to Danyore. EWS was based on cellular Telenor sim, SMS will be sending to the sim and all the systems will be triggered at once giving alarm singles. In case of any emergency situation at the Attabad DC Hunza would be informed and he was the final authority to give orders for the trigger of the EWS.

Figure 9: Map showing the locations of the Early warning system installed from Attabad to Gilgit.

4.4 Demarcation of Vulnerable areas downstream

Considering the worst-case scenario in case of Attabad dam outburst and possible impact on the downstream, vulnerable villages and hotpots were highlighted and risk population was shared with the government and relevant stakeholders. In this context an exercise for the demarcation of vulnerable locations was done with the help of local government of District Gilgit and Hunza-Nagar, for this expertise of AKCSP were used. Safer areas were considered above 60m from the current river flow and populations leaving below were highlighted under the threat of Lake Outburst Flood.

Potential landslides activation like Salmanabad, Phaker, Miacher, Khanabad, Mayoon and Hussainabad were also highlighted and shared with the local government and accordingly risky communities were educated and prepared to face the potential risk in case of Lake Outburst.

CONCLUSION

Attabad landslide disaster was one of the huge disasters in History of Pakistan as it blocked the Hunza River, KKH and upstream villages were submerged and remain cutoff for the rest of the country. In the first part the impact of the seismic events on the Attabad landslide is done, however due to the unavailability of the sufficient data on ground monitoring of the landslide and exact changes in the cracks after the earthquake events, linking of the exact changes was difficult, instead general changes are linked. The second part shows the analysis of the lake monitoring data including water level rise, seepage, and flow data. Moreover, lake monitoring mechanism and early warning systems installed for monitoring and early warning to vulnerable communities settled on the low laying areas along the Hunza River till Gilgit is also discussed in this paper. Overall, it was well coordinated efforts by government, AKDN, Army and other stakeholders to reduce the impact of growing lake and in case outburst preparations were in placed considering the worst-case scenario. Vulnerable communities were trained, and prepared, early warning system activated, safer areas identified, evacuation drills conducted to timely evacuated through the pre-identified routs to safer locations.

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