**The landslide at Attabad in Hunza, Gilgit/Baltistan: current situation and hazard management needs**
**Initial indicative report prepared for Focus Humanitarian Assistance, Pakistan, based upon a rapid field assessment on 26th February – 4th March 2010.**

Author: Professor David Petley, International Landslide Centre, Durham University, United Kingdom
Version 1.01 Final: 4th March 2010

**Executive summary**

This report provides a summary of the key findings of a visit to Pakistan, including a short field visit to the landslide dam at Attabad in Hunza. A full report will be available within a few days. This report makes a series of recommendations regarding management of the hazard at Hunza, and both upstream and downstream, for consideration.

Key recommendations include (NB this list is not exhaustive):

- There is a ***substantive risk*** of an outburst event caused by the landslide dam in Hunza;
- An outburst event is most ***likely during or shortly after water flows across the spillway***. However, such an event could be triggered by a range of other processes, some of which may provide little warning;
- If such an event occurs, ***there is the potential for a large flood wave to travel downstream as far as Tarbela Dam***. This wave would greatly endanger the downstream population and could cause damage to infrastructure;
- The ***safe level is considered to be 60 m above the current river level***, although further, more details work should be undertaken to verify this. Populations located between the river level and the safe level should be evacuated prior to the arrival of the wave. This will require ***precautionary evacuations for those people living immediately downstream of the dam***; and emergency ***evacuation plans for those further downstream***.
- There is also substantive ***risk to people living close to terrace edges and on unstable slopes***; these populations should also be protected through evacuation;
- A flood wave would also cause ***substantive damage to infrastructure downstream***, and the impact of the flood will ***pose problems in terms of livelihoods and welfare***.
- If the dam does not breach in the initial flow event, ***an expert group needs to be convened to determine the point at which an all clear can be given***. This group must be convened before the overtopping event starts.
- If the ***dam does not breach there will be a long term hazard at the site*** that will continue to threaten downstream communities. This will require a long term monitoring effort and a disaster plan to move the affected population at short notice. ***Management of this hazard will require considerable investment***;
- There will be ***substantive impacts on the upstream communities*** regardless of the future state of the dam. The nature of these impacts depends upon whether a collapse event does occur;
- Whilst constructing the spillway is undoubtedly an ***appropriate first step, a great deal more work is urgently required in terms of the management of the hazard***, in particular outside of the area between Attabad and Gilgit, which Focus are working upon. The ***downstream communities are facing a level of risk that is not tolerable – immediate action*** is required ***at national level to protect the population between Attabad and Tarbela Dam***.
- ***Thought is needed regarding the decision to protect the dam against erosion***. Consideration should be given to intentionally allowing an outburst event with an evacuated population in order to manage the landslide hazard;
- A ***substantive monitoring effort is required*** without delay;
- ***Four alert states*** are recommended, ***underpinned by a robust communications plan*** and an ***awareness and evacuation plan*** for the potentially-affected population ***as far as Tarbela Dam***.

- There is an urgent need to determine ***the likely date upon which water may flow across the spillway***. This should be disseminated and recalculated regularly, with caveats that this is an estimate. Where the date is changed, the reasons for this should be explained fully.

## 1. The landslide

The 4th January 2010 landslide at Attabad in Hunza, N. Pakistan was a complex failure on a slope with known stability issues. Previous work at the site, primarily by geologists from Focus Humanitarian Assistance, allowed evacuation of the potentially unstable area. No fatalities were recorded in this zone, primarily as a result of these actions to relocate the population. However, the slide mass, which has an initial estimated volume of 30 million $m^3$, fell from the northern valley wall onto saturated lacustrine sediments that had probably been deposited in the river bed in a lake formed by the 1858 landslide dam at Salmanabad, a few kilometres downstream. These sediments were mobilised though undrained loading and possibly liquefaction to form two mudflows. One mudflow travelled upstream for about 500 m, whilst the other flowed downstream for about 1.5 km. This latter flow hit a small settlement close to the river at Sarat, killing 19 people. This secondary mudflow event could not have been foreseen

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The emplaced landslide mass consists of a c.140 m high (at the saddle – the lowest point) rock and debris dposit, blocking the valley for a distance of over a kilometre. The main part of the landslide dam is a colluvial material consisting of a fine, sandy matrix with isolated clasts (rock blocks) of granite and granodiorite. The clasts are generally angular, ranging in size from a few centimetres to >10 metres. The deposit is matrix supported (i.e. the blocks are mosting not in contact with each other, probably deriving primarily from a pre-existing colluvial deposit on the hillside at Attabad. On the upstream side of the dam on the south side of the landslide there is a large rockslide deposit formed primarily of large and very large boulders, with little or no matrix support. This deposit appears to represent a late stage collapse of a large block of bedrock. The saddle of the landslide and the downstream face is mantled with a thick layer of the lacustrine deposit, consisting primarily of clay- and silt-sized particles, with some rounded fluvially-transported pebbles and cobbles . This material has a very low plasticity index and appears to have low permeability. The surface of the material appears dries readily to leave a reasonably thin but strong surface layer, underlain by material with a high water content. This material behaves in an unusual manner, deforming readily when loaded without the surface layer breaking. This is proving to be problematic for the plant at the site, which breaks through the crust and becomes bogged down in the wet materials beneath.

The morphology of the landslide deposit is not unusual. The main landslide mass has banked up on the far (south) side of the valley, leaving a saddle on the near (north) side. The upstream face of the landslide mass is reasonably steep, but with no signs of significant instability. The downstream face is less steep as it is mantled along its whole length by the mudflow deposit. Three distinct mudflow channels are evident, although the mudflow deposit covers the entire downstream slope. Compression ridges are evident in this material, as are pools of water on the lower slope. Staining on the rockwalls show that during the passage of the mudflow the landslide was c. 5 m thicker than at present, indicating high mobility when saturated.

A large landslide lake has developed on the upstream side of the landslide. At the time of writing this is c.11.5 km long and >60 m deep. The lake level is currently rising at c0.6 m per day. The freeboard is currently c.60 m. The dam appears to be essentially stable under current conditions, with only minor seepage on the downstream face, primarily associated with drainage of the mudflow deposit, and few signs of slope distress.

## 2. Mitigation works

Current mitigation works consist of:

1. The construction of a spillway. This is intended to be c.40 m wide by c. 30 m deep across the saddle of the landslide. At present the channel is reported to be 14 m deep (although it is not clear that this is the case at the saddle, the highest point of the channel). Excavation is currently primarily in the lacustrine clay. However, in some places the underlying colluvium has been reached and there is clear evidence that further excavation will strip most of the lacustrine deposit from the base of the landslide at the saddle. Excavation work is currently quite rapid, but is likely to slow as the colluviums becomes the main material to be moved. The intention is reportedly to line the base of the channel with large boulders derived from the landslide to

prevent erosion, allowing the dam to remain intact. It is unclear whether this will be effective against typical peak summer flood flows of c.2200 cumecs.

2. **Relocation of affected populations.** Evacuations have been undertaken of the population whose properties are being inundated by the lake; those within a few kilometres of the dam in the direct path of a potential flood wave; and those from Attabad village. Evacuations have been organised primarily by Focus.
3. **Monitoring and alert systems.** Focus are monitoring the site 24 hours per day and have set up a warning system for several imperilled communities downstream to Gilgit. These people have been made aware of the hazard and have been trained in the action that they should take should a flood occur.

There is little doubt that construction of the spillway is an appropriate ***first step*** towards reducing the hazard at this site. However, there appears to be a strong sense of optimism by government agencies that failure of landslide dam can be prevented by lining the channel with boulders. Two concerns emerge at this point:

1. It is unclear that this mitigation approach will prevent an outburst flood, and thus, excluding the work of Focus on the section of the Hunza to Gilgit, there is ***a lack of adequate preparation for a potential flood.*** This needs urgent consideration and action at government level;
2. It is unclear that attempts to prevent an outburst flood are actually appropriate – an alternative strategy of allowing an outburst flood to occur, having relocated the population, is an appropriate approach that may have merit.

### 3. Future scenarios

Scenarios for the future behaviour of the landslide dam are as follows:

| Scenario | Estimated likelihood | Advantages | Disadvantages |
|---|---|---|---|
| Successful spillway construction: landslide survives initial over-topping | Possible but not probable | a. No outburst flood | a. Long term hazard for downstream communities;<br>b. Loss of c. 30 km of KKH;<br>c. Medium term isolation of upstream communities |
| Landslide dam breach through erosion of spillway or downstream face | Probable | a. Hazard will reduce after flood<br>b. If outburst is slow, limited (though far from negligible) downstream damage<br>c. KKH could be reopened comperatively quickly<br>d. Preparation for flood is possible | a. Potential for severe flooding downstream, especially if breach is rapid;<br>b. Likely substantive sedimentation at Tarbela Dam |
| Landslide into lake from slopes upstream of Attabad triggers dam failure | Low, but this is reportedly the model of failure in the 1858 valley blocking landslide event | a. Hazard will reduce after flood<br>b. KKH can be reopened comparatively quickly<br>c. Preparation for flood is possible, although more difficult than for an dam breach through erosion | a. Severe flooding downstream highly likely;<br>b. Substantive sedimentation at Tarbela Dam |
| Piping / seepage failure (plus sometimes failure may occur due to slope instability on the downstream face) | Seepage possible but chances are reduced by presence of low permeability lacustrine deposit. Downstream slope failure unlikely due to low slope angles. | a. Hazard will reduce after flood<br>b. KKH can be reopened comparatively quickly<br>c. Preparation for flood is possible, although more difficult | a. Severe flooding downstream highly likely;<br>b. Substantive sedimentation at Tarbela Dam |
| Earthquake-induced dam collapse | Improbable in short term; more likely if dam survives initial overtopping | a. Hazard will reduce after flood | a. Severe flooding downstream highly likely;<br>b. Substantive sedimentation at Tarbela Dam;<br>c. Very difficult to prepare for and to respond to the event. |

It is impossible to determine which of these scenarios will occur. The collapse of the landslide dam due to erosion of the spillway or the downstream face must be considered to be very possible, such that it is essential that the downstream community is prepared and protected. Whilst Focus have been active in undertaking this work in the section of the Hunza from Attabad to Gilgit, there is a ***need for increased action in this respect from NDMA and associated government agencies***, especially with respect to the population from Gilgit to Tarbela.

**4. Likely outburst flood scenarios**

Outburst flood scenarios can be determined using three approaches:

a. **Flood modelling:** Flood modelling can provide an indication of the areas impacted by a flood wave. Two flood models have been run for the section between Attabad and Gilgit, based upon a 12,000 cumec flood wave (see below b. below). These indicate flood waves of c. 10-20 m above peak summer flow, and thus substantial inundation of downstream areas. However, such models require some very basic initial limiting assumptions, most notably the peak discharge, which are critical in determining the outcome of the model. Thus, flood models should be considered to be indicative at best, and should not be relied upon to provide the correct inundation amounts. It is also important to note issues associated with flood wave attenuation, detailed in c. below, which suggest that the flood will remain substantive well beyond that forecast by conventional flood attenuation models.

b. **Data driven analyses:** Data collected from the failure of previous landslide dam events from around the world allow quantification of the potential peak flood discharge using a range of regression analyses. Most of these analyses yield peak discharges in the range 12,000-26,000 cumecs, with the potential for a peak discharge of >40,000 cumecs should very rapid collapse occur.

c. **Analyses of past landslide flood events on the Hunza / Indus:** In 1858 a landslide dam formed at Salmanabad, just downstream of Attabad. Collapse of this landslide dam reportedly occurred as a result of a landslide into the lake near to Gulmit. Peak flood heights were reportedly 10 – 20 m above peak summer flows at Gilgit, 20 m at Chilas, 15 m at Attock, 10-15 m at Tarbela. The flood induced severe erosion of river terraces and a reverse wave reportedly travelled 50 km up the Kabul River. A flood wave of similar magnitude occurred in 1841 as a result of the failure of a landslide dam on the Lichar Spur of Nanga Parbat. This flood was sufficiently large to kill >1400 Sikh soldiers of the British Army at Attock. Glacial lake outburst floods (GLOFs) have also been recorded on this river on various occasions, with similar flood heights extending to Tarbela. As well as providing an indication of the magnitude of previous flood events, these data also strong suggest that floods on the Hunza / Indus river systems maintain substantial peak stages (flood heights) over distances of hundreds of kilometres, probably due to the gorge-like morphology of sections of the valley downstream. It is clear that conventional flood attenuation models are not appropriate for this river valley and should not be used as the basis for preparation and response in these downstream areas.

Thus, it is clear that:

a. There is a substantive risk of failure of the landslide dam, and resultant outburst flood, as the lake level approaches the spillway. The risk will *initially* peak during the first few days when water is flowing across the spillway and may decline thereafter. Subsequent periods of high risk will occur during flood events and in the event of a large seismic event.

b. There is an urgent and essential need to prepare for a large outburst flood event which may affect the population and infrastructure along the Hunza / Indus river valley from Attabad to Tarbela. Such preparation should start immediately.

c. There is a need to monitor continuously the state of the dam and to have an appropriate warning system in place;

d. There is a need to develop a set of alert states such that controlled evacuations and preparations can be arranged.

## 5. Potentially affected population

Just below the deposit of the 1858 Salmanabad landslide a terrace has been identified that is located c. 60 m above the current (low flow) river level. Deposits and boulders on this terrace suggest that the surface has not been affected by the 1858 flood or recent GLOFs. This is considered to be the *probable* safe level for a potential outburst flood from the landslide at Attabad. Thus, for preparedness purposes the following population have been considered to be at risk:

- Those located within 60 m of the current river level between Attabad and Tarbela Dam. Those located between Attabad and Gilgit are at the highest risk as the time for the flood wave to reach these areas could be very short. Precautionary evacuations are required for this population prior to a potential flood.
- Those located within 200 m of the edge of terraces that might be affected (eroded) by the flood. It is important to ensure that the population does not move to these locations to watch the flood wave pass through the valley;
- Those located on potentially unstable slopes (existing or potential landslides) downstream of the landslide dam.
- Those living on slopes above the lake, as rapid drawdown of the water level can induce landslides in this area (as per the Hattian landslide in Azad and Jammu Kashmir in Feb 2010);
- Boat users during the outburst flood. The boat service should be suspended immediately upon water starting to flow through the spillway.

## 6. Alert states

The following four alert states are proposed:

| Alert state | Trigger | Suggested actions |
|---|---|---|
| 1: Landslide aware | Current state | Development of preparedness and evacuation plans for all potentially-affected communities; development of communication system; 24 hour monitoring of the dam state; evacuation drills undertaken; recovery and rehabilitation plans developed; basic living necessities stockpiled. |
| 2: Landslide alert | Lake level reaches agreed level (10 m?) below the spillway | Evacuations of all population between Attabad and Gilgit located within 60 m of current water level, plus those close to terrace edges and on known landslides; full monitoring team in place 24 hours per day. Downstream communities warned of potential need to relocate at short notice |
| 3: Landslide warning | Water starts to flow across spillway as a result of continual increase in lake level | Evacuation of all potentially evacuated population to Gilgit; Population downstream prepared to move relocate. Communication system fully operational. KKH closed between Attabad and Gilgit. |
| 4: Severe landslide warning | Sudden increase in flow through or over the dam AND/OR development of erosion and scour of spillway or downstream face | Evacuation of all population below 60 m level between Attabad and Tarbela, plus those at a similar level in tributary valleys, plus those close to terrace edges and on known landslides; Tarbela dam prepared for rapid inflow event; KKH closed and all sections of road below the 60 m level cleared; all bridges on KKH and associated roads closed; emergency response plan activated. |

All people involved in the management of the landslide and its associated hazards, and all of potentially affected population, should be aware of these alert states. Clear criteria should be established for the transition from one state to another, and those on the ground must be delegated with responsibility to change the alert state. Those responsible for changing the alert state must feel that they can do so without fear of recrimination should the event

prove to be a false alarm. By the same token, those on the ground must be provided with the best possible information upon which to base a decision so as to ensure that both false alarms and delays are minimised. Those on the ground should have access to technical advice from experts 24 hours per day.

**7. Monitoring and warning**

It is essential that a 24 hour monitoring service is initiated as soon as possible, and must be fully in place by the time that a Level 2 alert is issued. Focus has an initial monitoring system in place – this is a good start but it requires a much more substantive effort at government level. This monitoring effort must be backed up by a clear communication plan. It is possible that it will be necessary to move directly to a Level 4 alert (should for example a landslide occur on the slopes upstream of the landslide dam). It is essential that all of the potentially affected population can be informed and relocated in time.

Monitoring should include:

- Seepage and movement of the downstream face of the landslide:
  - Monitoring should examine the development of seepage in both time and space. Particular attention should be placed upon the relationship between observed seepage and rainfall (a rain gauge should be installed); the volumes of seepage; and the location of seepage on the dam face. New seepage points may appear at progressively higher level on the dam face if seepage is due to flow through the dam core.
  - The turbidity of the water should also be observed. Turbid (sediment-laden) water may indicate the development of internal erosion of the landslide).
  - Care should also be taken to ensure that a downstream slope failure is not developing by monitoring deformation of the downstream face.
- The rate of rise of the lake level and the rate of inflow to allow forecasting of the date of flow in the spillway
  - It is essential that realistic estimates are provided of the likely date at which Level 2 and Level 3 alerts are declared. These dates should be recalculated frequently and the population informed of changes, and the reasons why these have occurred.
- The stability of the slope at Attabad :
  - There is the potential for further slope failures from the slope above the landslide dam site. These could affect the integrity of the spillway and they represent a hazard to the workers on the dam, especially during rainfall. Active monitoring of these slopes should be initiated;
- The state of the slopes above the lake:
  - A potential mode of failure of the dam is a landslide on the slopes above the landslide lake. The probability of this occurring increases with time because:
    - The length of lake banks increases as the lake becomes larger;
    - Slope failures increase in likelihood as groundwater levels rise in response to the growth of the lake;
    - The likelihood of a wave overtopping the dam increases as the freeboard reduces.
  - Monitoring should include:
    - Regular (weekly) inspection of the slopes by an expert, ideally by helicopter, to determine whether cracks are opening on the slopes;
    - Recording of rockfall activity, and in particular notable increases in rockfall rates at particular locations, which may indicate that instability is developing.

The population downstream of Gilgit is likely to be unaware of the risks associated with the landslide. It is essential that appropriate plans are developed to protect this population, including improved awareness, evacuation plans and communication protocols. This must be the ***responsibility of government agencies*** – it is beyond the scope and capability of FOCUS. There is an urgent need to start this process immediately.

8. All-clear and long term monitoring

If the dam survives the initial overtopping event then it is essential to ensure that a system is in place to determine when the all-clear can be sounded. It is important to understand that in many cases landslide dams survive an initial flow event before rapid breaching is initiated. Data on the performance of the channel (flow rate and volume, depth of flow, channel geometry, downslope state) should be collected and an expert group established to analyse the situation in order to determine when the all-clear can be announced. If the lake breaches then this group should determine the all-clear state, which is likely to be the point at which the lake is mostly drained, the flow through the dam has returned to normal flow levels and the high flow has reached Tarbela. It is essential to ensure that Tarbela has sufficient storage capacity to absorb the flood. There will be a residual risk of slope failures both upstream and downstream of the landslide site, which the group may need to consider separately.

If the dam does survive then a number of other critical points will occur in the future. These are likely to be:

- The first large flood wave after the initial flow event;
- Successively larger flood events (i.e. the 1 in 2 year flood; the 1 in five year flood, etc)
- The first strong seismic event (NB this is an area of high seismic hazard)

To maintain the safety of the downstream population high intensity monitoring will be required in the medium to long term, and an appropriate plan established to allow the population to be protected.

There will also need to be a programme of engineering works on the dam to reduce risk to tolerable levels. This is likely to require engineering works to properly stabilise and protect the channel, the slopes adjacent to the spillway, and slopes on the downstream face. There will also be a need to construct >25 km of Karakoram Highway, including a new bridge to replace the one at Shishkat.

In the event of an outburst flood there will need to be an extensive reconstruction effort downstream of Attabad, and reconstruction of the currently inundated / buried road. Either eventuality will have a substantive impact on trade that depends upon the KKH and on the population in the affected areas.

Conclusion

The level of hazard associated with a potential outburst flood from the landslide dam is too high to be tolerable. Such a flood is not inevitable, but the possibility is sufficiently strong that action is required to protect the downstream communities.

Key recommendations of this report include (NB this list is not exhaustive):

- There is a ***substantive risk*** of an outburst event caused by the landslide dam in Hunza;
- An outburst event is most ***likely during or shortly after water flows across the spillway***. However, such an event could be triggered by a range of other processes, some of which may provide little warning;
- If such an event occurs, ***there is the potential for a large flood wave to travel downstream as far as Tarbela Dam***. This wave would greatly endanger the downstream population and could cause damage to infrastructure;
- The ***safe level is considered to be 60 m above the current river level,*** although further, more details work should be undertaken to verify this. Populations located between the river level and the safe level should be evacuated prior to the arrival of the wave. This will require ***precautionary evacuations for those people living immediately downstream of the dam***; and emergency ***evacuation plans for those further downstream***.
- There is also substantive ***risk to people living close to terrace edges and on unstable slopes***; these populations should also be protected through evacuation;

- A flood wave would also cause ***substantive damage to infrastructure downstream***, and the impact of the flood will ***pose problems in terms of livelihoods and welfare***;
- If the dam does not breach in the initial flow event, ***an expert group needs to be convened to determine the point at which an all clear can be given***. This group must be convened before the overtopping event starts.
- If the ***dam does not breach there will be a long term hazard at the site*** that will continue to threaten downstream communities. This will require a long term monitoring effort and a disaster plan to move the affected population at short notice. ***Management of this hazard will require considerable investment***;
- There will be ***substantive impacts on the upstream communities*** regardless of the future state of the dam. The nature of these impacts depends upon whether a collapse event does occur;
- Whilst constructing the spillway is undoubtedly an ***appropriate first step***, ***a great deal more work is urgently required in terms of the management of the hazard***, in particular outside of the area between Attabad and Gilgit, which Focus are working upon. The ***downstream communities are facing a level of risk that is not tolerable – immediate action*** is required ***at national level to protect the population between Attabad and Tarbela Dam***.
- ***Thought is needed regarding the decision to protect the dam against erosion***. Consideration should be given to intentionally allowing an outburst event with an evacuated population in order to manage the landslide hazard;
- A ***substantive monitoring effort is required*** without delay;
- ***Four alert states*** are recommended, ***underpinned by a robust communications plan*** and an ***awareness and evacuation*** plan for the potentially-affected population ***as far as Tarbela Dam***.
- There is an urgent need to determine ***the likely date upon which water may flow across the spillway***. This should be disseminated and recalculated regularly, with caveats that this is an estimate. Where the date is changed, the reasons for this should be explained fully.

*David Petley*
*4th March 2010*
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