RE-EVALUATION OF AVALANCHE MITIGATION MEASURES FOR JUNEAU

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ABSTRACT: Juneau, Alaska's state capital, has a serious avalanche problem. The last major avalanche event in 1962 was the catalyst to propose for the first time avalanche mitigation measures. In 1972 a comprehensive geophysical hazard study was performed where avalanche hazard zones were suggested. The zones were re-evaluated in 1992. In 2011 the SLF was mandated to investigate mitigation measures to decrease the avalanche risk in the two most dangerous avalanche paths. Beside structural mitigation measures such as snow supporting structures or earth dams, the application of fixed installed remote-controlled exploders was investigated as well. The buyout of homes seems to be one way to effectively reduce the avalanche risk on the long-term. At present the only avalanche safety measures consist of an avalanche response plan, information and training for residents / responders and an avalanche forecasting program. In this paper we focus on the most dangerous Behrends Avenue avalanche path.

KEYWORDS: avalanche mitigation, avalanche dynamics modeling, hazard map

1. INTRODUCTION

Juneau, Alaska's state capital is situated at sea level on the Gastineau Channel in a glacial valley in Southeast Alaska. Steep-sided mountains surround the city. Sixty-two homes, a hotel and a boat harbor as well as the main East/West Highway in the city are located in the runout of avalanche paths originating from the 970 m high Mt. Juneau (Fig. 1). Small avalanches reach the most exposed houses nearly every winter. Large avalanches are rare. Juneau is considered to be one of the largest municipal avalanche hazards in the United States. However to date there are still no structural protection measures in place, which can be attributed to the complexity of the avalanche situation. The City and Borough of Juneau has an avalanche forecaster on staff to deliver daily avalanche bulletins to the community and to educate the public about living in a community with avalanche problems. The avalanche bulletins notify the public of times when avalanche areas are highly endangered and should be avoided. The City and Borough of Juneau does not issue orders to evacuate the hazard zones. In 2011 the SLF was mandated to investigate mitigation measures to decrease the avalanche risk (SLF, 2011).

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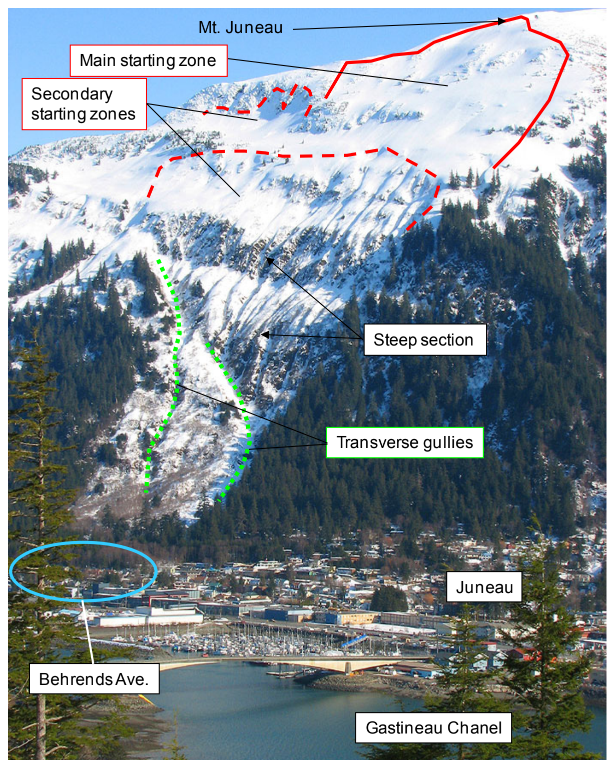

Fig. 1: Overview of Behrends Avenue path (Photo David Kent, April 3, 2007, www.westjuneau.com)

2. AVALANCHE SITUATION

The starting zone of the Behrends Avenue avalanche path is situated on the south-west flank of Mt. Juneau (see Fig. 1 and Fig. 6). The terrain is very complex. There are different small depressions with widths of 50 m to 150 m and mean slope angles between 35° and 45°. These are separated by small pronounced ridges. The starting zone is interrupted by several steep cliff bands with heights of 10 to 80 m and estimated inclines of 50°. Some flat terrain terraces are also situated in the starting zone. The main starting zone is situated between an elevation of 970 m (ridge to the top of Mt. Juneau) and 500 m (top of big cliff band; Fig. 1). The maximal width of the starting zone is 500 m. The potential starting zone is very large with an area of 25 hectares. The mean inclination is 40°. Between the elevations of 500 m and 250 m the terrain is very steep (mean inclination 42°). This steep part of the avalanche track favors the formation of powder snow avalanches. Two diagonal gullies are situated below the steep part. The 10 m to 30 m deep gullies tend to channel smaller avalanches and deflect them in southeasterly direction. However large avalanches will only be partly deflected by the two gullies. The cross-section is much too small to discharge the entire avalanche flow. The flow of large avalanches is rather unconfined. At 300 m the width of frequent avalanches is captured by the tree damage. There are no big trees along a 270 m wide path. Moreover, the forest along the western limit of the avalanche seems to be younger compared to the forest stand further away (Fig. 2). We estimate the age of the trees to be around 50 to 150 years.

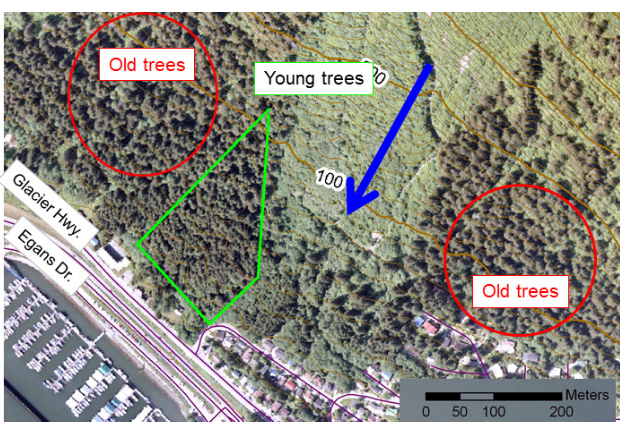

Fig. 2: Runout zone of Behrends Avenue avalanche path with forest pattern.

Below the elevation of 150 m the track is less than 30° and over the last 150 m above Behrends Avenue the slope inclination is 15°. Such slope angles do not retard dry snow avalanches. The favourable characteristics of the Behrends Avenue avalanche path is that the starting zone is relatively well structured into different smaller pockets and that cold temperatures combined with unusually deep snowfalls are relatively seldom. Given these factors we think the release of small avalanches is much more likely compared to the release of the whole starting zone in an extreme avalanche.

3. WEATHER AND SNOW CLIMATE

Juneau lies within an area of maritime influence which prevails over the coastal areas of south eastern Alaska, additionally it lies in the path of most storms that cross the Gulf of Alaska. Consequently, the area has little sunshine, generally moderate temperatures and abundant precipitation (Colman, 1986). The predominant wind direction is from the south along the Gastineau Channel. There are periods of comparatively severe cold temperatures, which are caused by strong northerly winds, locally known as Taku winds. On Mt. Juneau these winds (dominantly north-east) can cause important snow drift accumulations in the upper starting zones of the Behrends Avenue avalanche path. The snow line often fluctuates between sea level and the elevation of the starting zones, which causes a wide range of snow conditions in the avalanche paths. Normally the snowpack consists of thawed and refrozen layers. This favors a greater frequency of wet snow avalanche conditions as opposed to extreme dry snow avalanche conditions which explains the seldom occurrence of extreme dry snow avalanches. Unfortunately there are no weather stations with a long observation period at the elevation of the starting zones at Mt. Juneau. The extreme snow heights in the starting zones on Mt. Juneau are estimated to vary between 6 and 8 m, particularly for depressions where even larger snow heights must be expected. In the Juneau area fracture depths of extreme avalanches typically vary between 2 and 4 m (personal communication by B. Glude). We assume that an extreme avalanche (return period up to 300 years) on Mt. Juneau might have an average fracture depth of 1.5 to 2.0 m.

4. AVALANCHE HISTORY AND PREVIOUS INVESTIGATIONS

A very comprehensive avalanche history of Behrends Avenue avalanche path was compiled by Fredstone and Fesler (Mears et al., 1992). Between 1890 and 2011 the avalanche reached tidewater three times and Behrends Avenue nine times (Fig. 3). The avalanche of 1890 which deposited hundreds of tons of snow on the road along Gastineau Channel was the largest recorded event. Small avalanches that stop above the subdivision are observed nearly every winter.

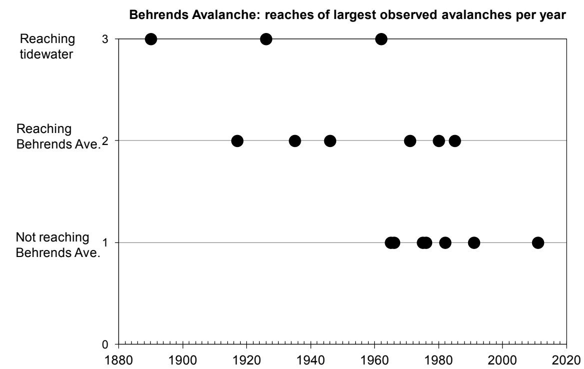

Fig. 3: Reaches of largest observed avalanches per year from 1890 to 2010. The quality of observation is assumed to vary over time.

The most destructive and best documented avalanche in recent years was the 22 March event in 1962. Following a period of heavy precipitation arriving from the north-east, a slab avalanche developing into a powder snow avalanche with a very small dense portion broke loose. The main damages to the houses were caused by the powder blast and by impacts of logs or other debris which were transported by the avalanche (Fig. 4). Despite the weak constructions (mostly wood frame or brick wall buildings), the damages were relatively small. We estimated the impact pressure to vary between 2 and 4 kPa in the Behrends Subdivision. Approximately 35 houses were damaged (Fig. 5). The avalanche nearly entirely destroyed the forest belt above Behrends Avenue.

Fig. 4: View of Behrends Avenue with Gastineau Channel in the background after the 1962 avalanche – collapsed roofs because of overpressure and impacts of trees. The back-walls are not damaged (Alaska Mountain Safety Center).

The first hazard evaluation dates from 1949 when a school was planned to be built in the runout of the Behrends Avenue path. It was concluded that the location is not suited and the school should be built in a less hazardous site. The avalanche event in 1962 was the catalyst to propose avalanche mitigation measures for the first time. Hart (1967) analyzed the 1962 avalanche in the Behrends path in detail and proposed to build different rows of 6 m high avalanche breakers and a 7.5 m high diversion dam in the runout zone. In 1968 La Chapelle (1968) proposed to build a 30 to 45 m high catching dam just above the houses of Behrends Avenue. As such a huge dam would not guarantee a 100% safety La Chapelle concluded that the removal of all buildings is the only way to eliminate the risk from the Behrends Avenue avalanche. In 1972 an expert commission investigated the seismic hazards, the mass wasting hazards and the snow avalanche hazards in the area of the City and Borough of Juneau. For the area of the Behrends Avenue path a detailed hazard map was elaborated (Frutiger, 1972). In 1992 the hazard map of 1972 was re-evaluated (Mears et al., 1992). The severe hazard zone (impact pressure >30 kPa) involves most of the subdivision. In the adjacent special engineering zone the impact pressure of an avalanche with a return period of less than 300 years is smaller than 30 kPa. So far no structural reinforcements of new buildings have been applied in the hazard zones.

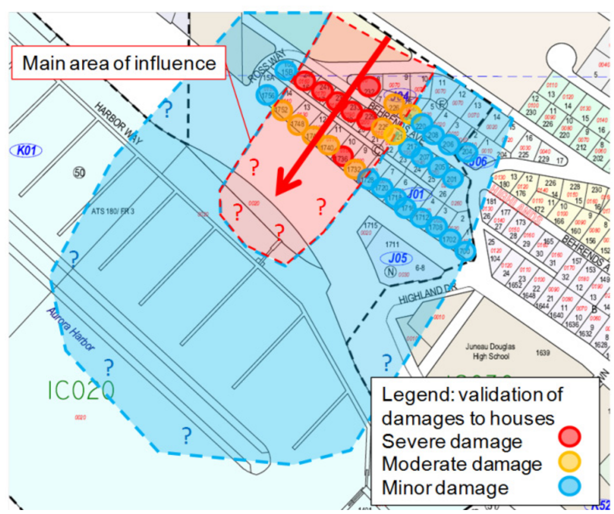

Fig. 5: Overview of the main area of influence of the 1962 avalanche. The validation of the damages to the houses is based on the 1992 report (Mears et al., 1992).

Tab. 1: Avalanche scenarios with different return periods investigated with RAMMS

Scenario	Volume	Volume category	Mean fracture depth
10 years	46'000 m^3	medium	1.2 m
30 years	150'000 m^3	large	1.4 m
300 years	410'000 m^3	large	2.0 m

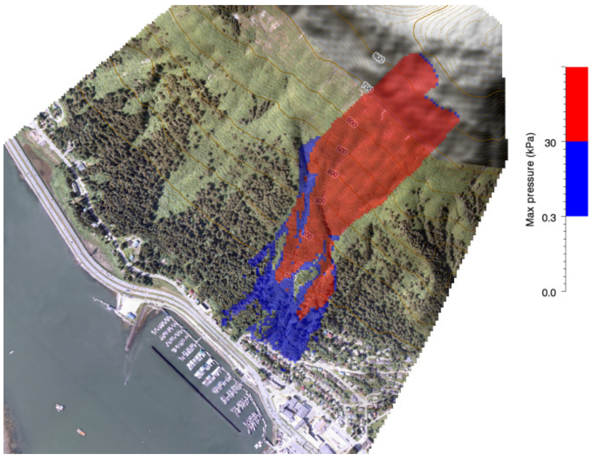

Fig. 6: RAMMS-simulation results of the 10-year Behrends Avenue avalanche. Red = impact pressure > 30 kPa and Blue = impact pressure < 30 kPa. The two gullies deflect most of the avalanche flow.

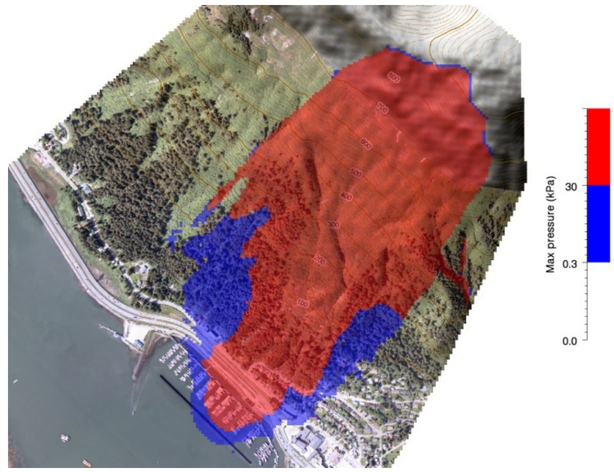

Fig. 7: RAMMS-simulation results of the 300-year Behrends Avenue avalanche. Red = impact pressure > 30 kPa and Blue = impact pressure < 30 kPa.

5. AVALANCHE DYNAMICS CALCULATIONS

For the hazard assessment and for the determination of the design values for protection measures we performed avalanche dynamics calculations with the 2-dimensional avalanche simulation program RAMMS (SLF, 2009) and with the 1-dimensional avalanche dynamics program AVAL-1D (SLF, 1999). AVAL-1D was mainly applied to calculate the effect of powder snow avalanches. The most important input parameters for the avalanche dynamics calculations are the slab thickness, the release area, the friction parameters and the digital terrain data (see Tab. 1). Due to the rather specific climatic situation of Juneau (low elevation, coastal climate, abundant precipitation, cold snow conditions at the elevation of the starting zone, wet snow conditions at sea level) we adapted the elevation limits controlling the friction parameters given in the RAMMS Handbook (SLF, 2009). We used an elevation limit of 500 m a.s.l. instead of 1500 m a.s.l. and 200 m a.s.l. instead of 1000 m a.s.l. The digital terrain model has a grid resolution of 6.1 m (20 ft). We performed avalanche dynamics calculations for return periods of 10, 30 and 300 years:

- The 10-year dense flow avalanche does not reach Behrends Avenue (Fig. 6).
- The 30-year dense flow avalanches stops according to the RAMMS simulations on Egan Drive beside Gastineau Channel. The north-western part of Behrends Avenue is in a zone with avalanche impacts of more than 30 kPa. The main avalanche flow axes are orientated along the two diagonal gullies as well. However the gullies only partly deflect the avalanche. At an elevation of 100 m the avalanche velocity varies between 19 and 24 m/s.
- The 300-year dense flow avalanche reaches Gastineau Channel with an intensity of more than 30 kPa. At Egan Drive the velocity is still 23 m/s with a flow height of 2.7 m (Fig. 7). Most of Behrends Avenue is in the 30 kPa zone; here the velocities are up to 28 m/s with a flow height of 3.6 m. Such avalanche intensities are capable of completely destroying massive buildings. The total flow width is much wider than the present main avalanche path. The 300-year avalanche has the potential to destroy a large part of the forest stand north-west of the main path. The influence of the two gullies on the avalanche flow is small, with the major part of the avalanche overflowing the gullies. According to the simulation the main avalanche flow direction is located at the north-western end of Behrends Avenue.

- The powder snow avalanche calculations were performed for a 30- and 300-year scenario. Due to the steep topography we applied an increased suspension rate of 25%. At Behrends Avenue the maximal pressure in the suspension layer of the 30-year avalanche is 3-4 kPa and for the 300-year avalanche it is 6-9 kPa. Compared to the damages of the avalanche from 1962, we think that such a pressure range is reasonable. The impact pressure of a powder snow avalanche of 3 to 5 kPa can destroy mature forests.

Our hazard assessment mostly confirmed the existing hazard map of 1992. The extent of the hazard zones seems to be underestimated only towards Gastineau channel and in north-western direction. The results of the avalanche dynamics calculations are an important base for the design of the mitigation measures.

6. MEASURES TO REDUCE THE AVALANCHE RISK

6.1 Artificial release of avalanches

Artificial release of avalanches is widely used in ski areas and along traffic routes. The standard methods for protecting settlements are structural mitigation measures such as snow supporting structures or earth dams. New methods for artificial avalanche release (e.g. GAZEX exploder or Wyssen tower) have been developed over the past few years. Autonomous devices allow remote triggering of avalanches independently of visibility and with a good detonation effect. In general, artificial release above settlements should be applied with extreme caution and should remain an exception. The main risk of artificial release above settlements is triggering an avalanche that is too large to manage and results in damage. Important points are the evaluation of the terrain features with regard to the effectiveness of artificial avalanche release, the potential for triggering secondary avalanches and the existing damage potential (Stoffel and Margreth, 2009). The terrain features on Mt. Juneau are not considered to be very favorable to release avalanches artificially. This is mainly because the potential starting zone is very large and because the topography is very steep, which even favors small avalanches to reach the subdivision. A further negative point is the secondary avalanche release in the adjacent avalanche path especially during unstable snow conditions with a widespread weak layer. The damage potential is huge especially because most of the buildings have no protection measures and seem to be very vulnerable against avalanche impacts. In the starting zone there are several locations with favorable slope inclinations of more than 35° where avalanches could easily be triggered. We think that at least 6 detonation points would be necessary (Fig. 8). More problematic are the lower starting zones where fixed installed devices may be destroyed by avalanches releasing above. The weather data and snow information currently available do not seem to be sufficient to adequately assess the snow conditions in the starting zone, especially during a storm period. It cannot be guaranteed to limit the size of an artificially released avalanche in the Behrends Avenue to a volume that is harmless to the subdivision. The preventive closure and evacuation of the endangered area during the artificial release of avalanches would be very demanding and time consuming. We did not recommend applying the artificial release of avalanches in the Behrends Avenue avalanche path under the current conditions. The risk to persons and buildings is much too high.

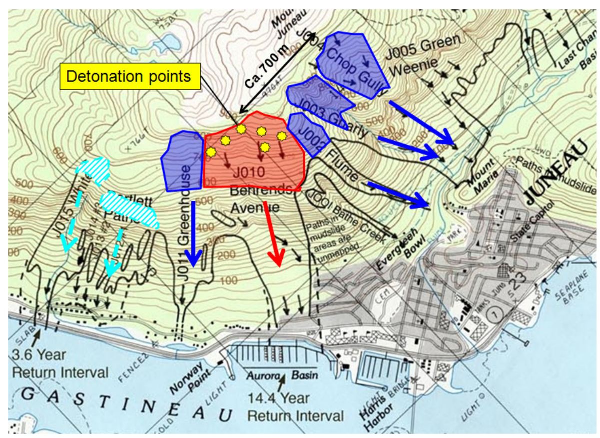

Fig. 8: Avalanche starting zones on the south and south-western side of Mt. Juneau with possible detonation points. Secondary releases in the blue and light blue areas cannot be ruled out if avalanche control is performed in the Behrends Avenue starting zone (map source: Bill Glude, Southeast Alaska Avalanche Centre and USGS).

6.2 Snow supporting structures

Snow supporting structures stabilize the snowpack and prevent the release of avalanches. The area that would require snow supporting structures in Behrends Avenue slide path with 25 hectares is very large. An additional problem of the present starting zone is that there are no long-term snow measurements available. We estimate that the extreme snow depth may vary between 5 and 8 m, which would correspond to a structure height of 3.9 to 6.2 m. We estimated that in total 10'800 m of structures would be required with a total cost of at least 32 Million USD (Fig. 9).

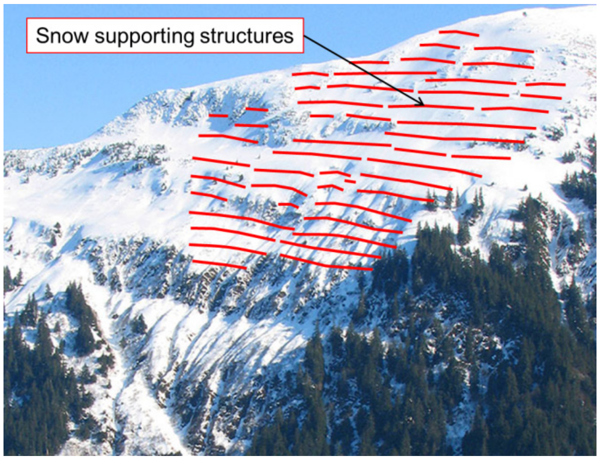

Fig. 9: Sketch of the layout of snow supporting structures on Mt. Juneau.

As there is no experience with the construction, behavior and design of snow supporting structures in Alaska it would be advisable to install a small test site on Mt. Juneau prior to embarking upon such a huge project. Additionally the starting zone is considered to consist of unstable slopes which would require expensive foundations and high maintenance cost. Therefore we did not recommend the construction of snow supporting structures.

6.3 Avalanche dams

We studied different variants of dams. Because the design velocity is very high at 30 m/s a catching dam should have a height of 25 to 35 m (Fig. 10). The main advantage of a catching dam would be that both the subdivision and the highways along Gastineau Channel could be protected. Beside the visual impact and the high cost of estimably 12 Mio USD for a fill volume of 400'000 m^3 our main concern was that a catching dam could not stop completely a large powder snow avalanche. Also with a huge catching dam similar avalanche impacts compared to 1962 would still be possible.

The height of a deflecting dam was estimated to vary between 18 and 25 m depending on the deflecting angle (Fig. 11). The length of dam would be around 300 m and the fill volume between 120'000 and 200'000 m^3. The main disadvantage of deflecting dams is that in the direction of flow the risk is much increased which in a densely populated area is very problematic. Further a deflecting dam cannot stop a large powder snow avalanche. Therefore we did not recommend planning an avalanche dam. The realization of such a structure would cause lengthy discussions and possible lawsuits.

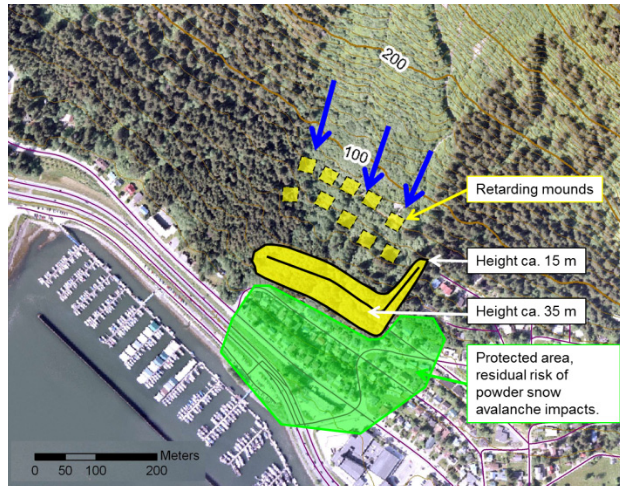

Fig. 10: Avalanche catching dam with two possible lines of retarding mounds.

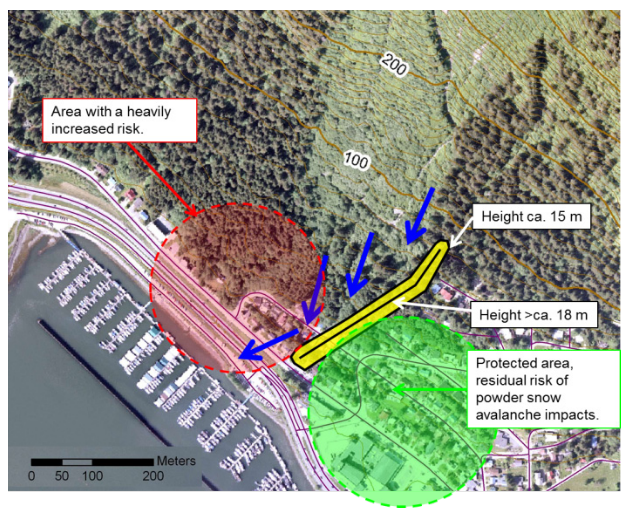

Fig. 11: Avalanche deflecting dam option 2, deflecting angle 30°.

6.4 Direct protection of buildings

The goal of a direct protection is to shelter an individual building exposed to avalanches. The most frequently applied forms are the direct reinforcement of a building with a concrete back-wall without openings and avalanche splitters. In the present situation both possibilities are hardly feasible. There is not sufficient space to build a wall and avalanche splitters would increase the risk to the neighboring buildings. Because the costs of such a direct protection are estimated to be even higher than the value of the building to be protected we concluded direct protection of buildings not to be recommendable.

6.5 Buyout of houses

The most effective way to reduce the avalanche risk in the subdivision were found to be the buyout of the endangered homes by the Government, to prohibit new constructions respectively and to demand the reinforcement of new buildings in the special engineering zone. In regard to the complex avalanche situation where the avalanche risk can hardly effectively be reduced with traditional protection measures the buyout of the endangered homes could be implemented.

7. CONCLUSIONS AND OUTLOOK

The avalanche problem is very serious in the runout zone of Behrends Avenue avalanche path. According to current standards the risk is far beyond an acceptable level. We think that the unacceptable risk to the residents in the hazard zones can be only managed on the short term if the City and Borough of Juneau would order evacuations and close endangered areas during periods of high avalanche danger. As the buildings in the hazard zones have no structural reinforcement people inside these buildings are not safe.

Continuing with the established avalanche hazard evaluation and forecasting service in the community during the winter months is recommended and is a very good starting point to develop an evacuation concept. Moreover, the education and awareness to the public about avalanches is invaluable. While this is improving the situation, we do not think that these measures are sufficient with respect to the serious avalanche problem.

The reduction of the avalanche risk with structural protection measures is prohibitively expensive and therefore not recommended. Furthermore, the artificial release of avalanches is not advisable, mainly because of the danger to people, property and homes. We are of the opinion that the buyout of endangered homes in the avalanche path by the government is the only way to effectively reduce avalanche risk on the long term. The buyout of homes would assure a permanent solution to the avalanche problem.

Following our advice the City and Borough of Juneau is presently establishing a buyout plan for endangered homes. CBJ will be working with homeowners to determine the level of interest and then applying for Hazard Mitigation Grant Program dollars from FEMA to fund the buyouts in the priority areas in the order of highest danger.

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