a Green dam

This little gem was passed on to me by a colleague in the North Okanagan Valley of BC who knew full well how I fancied myself as god's gift to dams. Or maybe it was only because I lived in a village quite close to the site.

The thing about dams is that big dams come with big budgets and small dams come with big problems, little money and less thinking time. This dam fell all too comfortably into the latter category – a pressing environmental problem with no funding. But it was a dam nevertheless, and one with human elements such as would have attracted the sympathy of that other old fool, Don Quixote.

Background of Problem

Figure 1 shows the farm owner with his corn field behind him, standing beside the 2006 failure scarp that had just then materialized. At this point the natural creek gully once was about 85m (280ft) wide and 24m (78ft) high. The ground under him is now earthfill.

Figure 1. Initial failure looking East

The original natural gully of this unnamed stream cut the present farm into two separate parcels, making irrigation difficult and substantially reduced the arable area of the property. So, I suppose because of their good and noble Dutch heritage, between 2001 and 2005 the gully was in-filled. For this they used the granular spoil made available from excavations needed for their house and various farm buildings.

The stream flow was carried under the earthfill in a 450mm (18") plastic pipe, and then, beyond the northern extremity of the infill, it was carried down the gully sidewall in a 500mm (20") metal pipe to re-enter the natural channel a safe distance beyond the toe of the embankment.

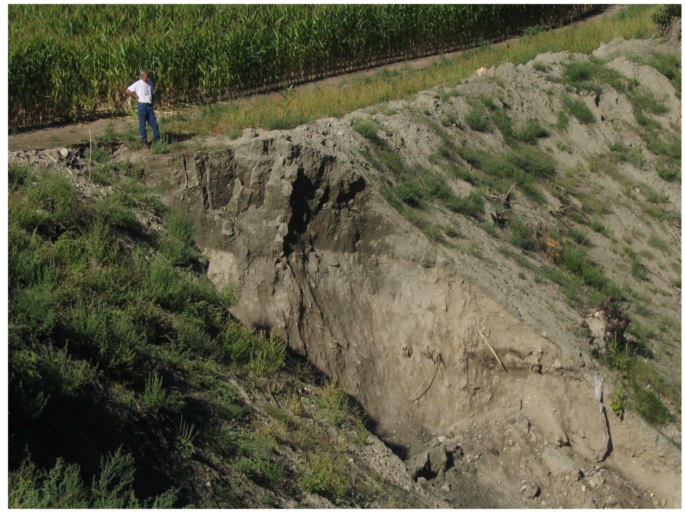

Figure 2. Initial failure looking West

Figure 2 lets us see the two soil types used for filling. The lower fill is a not altogether garbage-free granular material derived from the glaciofluvial spoil from the building sites. The darker upper soil layer is a silty material intended to make for a better growth bed because of its higher moisture retention potential.

The cause of the failure was not due to any deficiency in earthfill stability, but rather, to a most unfortunate malfunction of the automated irrigation system. A mounted rotating watering nozzle set to move in a straight line away from the slope at about 17m/hour (55ft/hour), while delivering a water jet of about 70m^3/hour (250gpm), got stuck. Overnight, for about 11 hours, it remained immobilized with its jet impinging on the ground about 30m behind the crest of the escarpment. The large concentrated seepage forces so close to the edge were enough to bring down the slope. This would not have been much of a repair problem for the farmhands if it hadn't been for the position of the failure with respect to fish habitat. Figure 3 makes this clear.

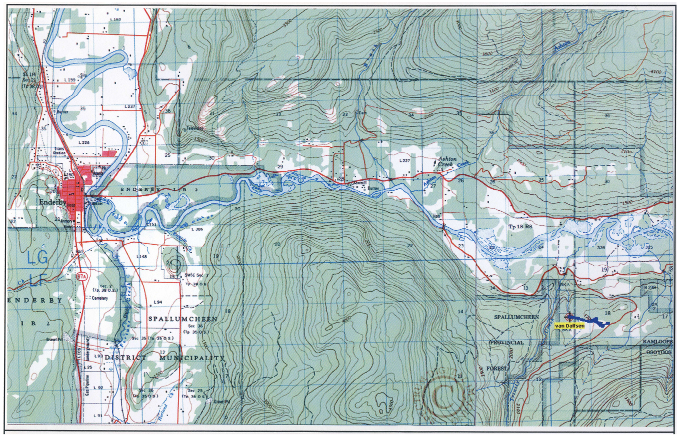

Figure 3. site location & the Shuswap River

Department of Fisheries and Oceans (DFO) determined that fish habitat had been affected along Trinity Creek, a tributary of Shuswap River by the sediment entering from the canalized creek; the fine silt and clay fraction from the growth layer had reached this popular sport-fishing stream. The farmers were thereby exposed to a criminal charge based on an environmental offense - such being the Rule of the Land.

in Unusual Circumstances

Towards the end of September 2006 I visited the site for the first time and talked with the family about what we might do to rehabilitate the slope, and how we might go about it. The owner and his son wanted to do all the work themselves, using materials to be found on their property, and using the farm equipment they already had. This included a plentiful source of good granular material, and a limited source of silt; a brother had a rock-outcrop next door. They had an excavator, a dozer, a concrete mixer, and a 10-ton truck. Their field compactor was too light and too wide for what was needed here; a vibrating roller compactor would have to be rented. So basically, apart from already having most of what was needed, they had a strong desire to fix their problem themselves.

What they, my potential client, wanted of me was verbal direction and a few site visits to make sure what they were doing was in line with my requirement and to nudge them towards better compliance. Having seen what they had built themselves around the farm, and being certain that they were strongly motivated to solve their problem properly, I agreed to work with them. However, in order to supplement this minimalist engineering supervision assignment I required that they send me photographs of what they had accomplished each day. As it turned out, because of their rural setting, Internet access was limited to a landline telephone connection which proved not to be a practical means for transmitting detailed colour photographs.

a Failure that was all Mine

In this, the "central interior" region of British Columbia, I know that the ground can be covered with snow as early as mid-October, so if you were to look at a new site you should get there before then. With that in mind, starting a earthfill remediation in the last few days of September was not such a good idea; but I didn't say "No!"

They began by lowering an excavator down the slope to the bottom using the dozer as a cable anchor behind the crest. Fresh granular material was dumped into the failure scar from the top while the excavator used its bucket to both move the new fill into place, and then effect some compaction by tamping horizontally. While the scar was being filled in the field I was designing hydraulic control structure options in the office. When I gave the construction crew a choice between a metal conduit, a "morning glory" intake, and a concrete spillway chute, they opted for the spillway. They worked long and hard so that by the time the weather shut us down at the start of November we had in place a concrete ogee and spillway discharge contained within a small earthfill dam.

Then, towards the end of March the following year (2007) I got a call to say our efforts to rebuilding the slope had failed, destroying the concrete spillway as it came down. Not a happy moment for any of this team of three. And as our team was made up of two dairy-farmers and one geotechnical engineer, there could be no doubt who owned this failure, nor who would be held responsible.

Figure 4 records a sufficient cause for the failure.

Figure 4. disjointed drainage pipe within slope fill

The geology exposed here is imported fill over glacial till and underlain by glaciofluvial soil. The black plastic corrugated pipe is the one carrying the full creek flow which was left in place as a water diversion measure during these repairs. Flow is from right to left of the picture. As neither end of the pipe joint is damaged and its glacial till bed remains intact, it seem to me that the failure came about as follows: The eastern (picture-left) rill through the till was initiated by some mechanism which pulled the connection loose, leading to collapse of the ground above it. The downward motion of that falling fill pushed the uphill side of the black pipe over the edge of its still-competent bedding. By this stage the full flow disgorged into the slope, resulting in the slope failure. This sequence is suggested by the brown discolouration (likely dissolved fertilizer) of the western rill indicating that shortly after the first leaking formed the eastern rill, the overhead fill collapsed, pulling the pipe apart.

The question of what caused the initial parting of the pipe connection is irrelevant now, but I believe it may have been either due to the excavator bucket tamping, or to water discharge from an open-ended drain gone unobserved.

Luckily the soil involved in this slope failure was a relatively clean granular material and therefore neither silt nor clay reached Trinity Creek. Nevertheless, DFO called me to their regional offices in Salmon Arm to provide a witness statement. This entailed an hour-long voice record of my answers to DFO questions explaining what had gone wrong. The fact that I had previously told this very same officer that I loved fish too, especially halibut and chips, was just another case of my errant humour returning to haunt me.

Fortunately for me, the farmers and the DFO didn’t fire me, and for whatever reason let me try again. I’m fairly sure it was not from following the old axiom of incremental human progress: “try, fail, try again, fail better”.

Round Two

This time we had the whole summer ahead of us and a better idea of what was to be found within the escarpment. Both failure scars exposed a fill which contained long branches and even some garbage; such is clear evidence of poorly selected material which had not been compacted in layers. Despite this, the overall shear strength was shown to be adequate for the slope angle, since it took uncommon concentrations of seepage forces to bring it down locally. So I was happy with the 30° (58%) slope but now wanted it compacted in 300mm (12”) lifts, and this, after branches and other foreign matter had been removed. And more importantly, all pipes across the face were to be treated as if they were open to the field infiltration (water conduits) and depressurized accordingly.

The farmers, having experienced the work involved in building a concrete spillway, this time opted for a metal pipe to carry the creek flow through a dam and down the slope. Following agreement on these constraints I designed what was needed, and produced eight small coloured sketches, using straightforward text annotations, detailing all that was to be done. These are shown immediately following the end of this article.

Still there was no access for equipment to the toe, and the dozer and compactor were eased down the face by an anchored cable behind the crest. To begin with, small trees and debris were removed from the toe area, and then the existing slope was cut back to the natural gully walls. Spoil mined from the overhead slope, after hand-removal of foreign matter, was then compacted.

Figure 5. the full construction crew

Figure 5 shows the father & son team discussing their next move. As can be seen here, their progress involved working under a collapsing face so that their safety relied upon the protection of their vehicles, and of course, constant SA - situation awareness.

The following photographs show the finished work:

Figure 6 is a view (looking SE) of the 450mm (18”) plastic pipe carrying the steam flow as it enters the little surge pool upstream of the dam.

Figure 6. flow from piped stream entering surge pool

Fig. 7 shows the concrete intake structure where a 914mm (36”) galvanized steel pipe carries the flow through the little earthfill dam.

Figure 7. intake structure

Figure 8. downstream view looking East

Figure 8 was taken from the left abutment and shows the downstream side of the dam and the discharge pipe running down the slope.

Figure 9 is a view from the crest looking towards the left abutment and showing the downstream berm as well as an air-ventilated hut. This small concrete chamber contains the hydraulically designed concrete forming required for making the transition between the larger intake pipe and the smaller, but very steep outlet pipe.

Figure 9. pipe transition housing

Figure 10 shows the "belt and braces" approach to pipe connections of the steeply inclined outlet pipe.

Figure 10. belt & braces

Figure 11 shows how a pre-existing partially buried natural rock block was used as a means to safely dissipate the hydraulic energy (impulse- momentum principle) at the toe of the slope.

Figure 11. energy dissipation at toe

Figure 12 shows that the treatment of open-ended drainage pipes of various size and origin had been successfully drained to the slope face. The clarity of the water indicated that retrogressive erosion was not weakening the slope.

Figure 12. seepage clear & controlled

Figure 13 is an "as-built" sketch showing the main parts of the complete works.

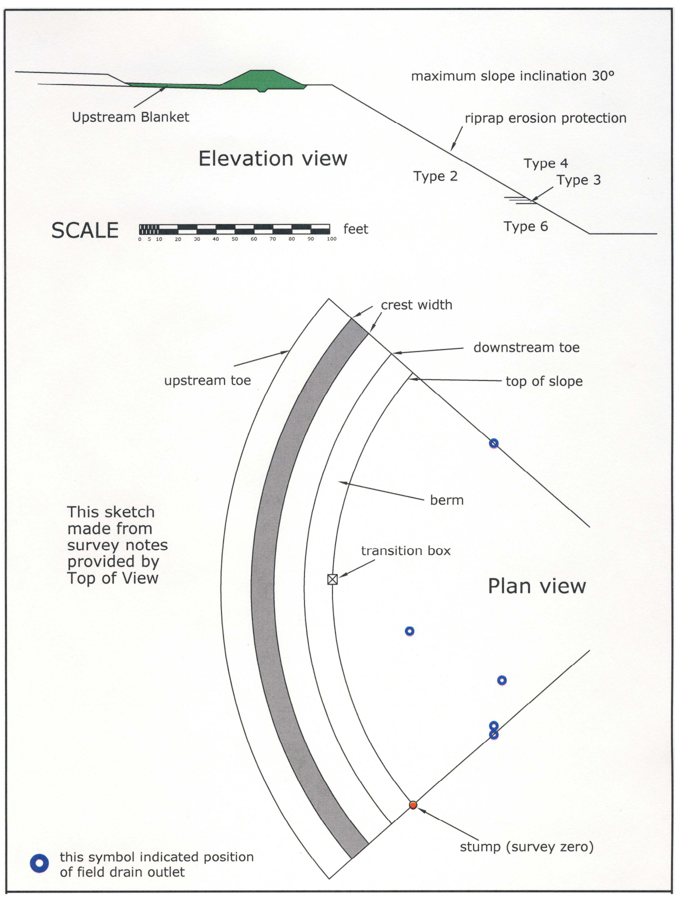

Figure 13. as-built sketch

the Need to Learn from Failures

I pretty well knew what I was letting myself in for on this job because similar things had happened to me more than once on site visits to remote mines. And I must admit I did relished those times. The pattern goes something like this: The mine manager says ". . . instead of you writing me e-mails from Vancouver telling me what you want done why don't we go out to the dam now and you can show us." So you point out the material you want and he calls in the equipment. Then, after one cycle of hauling trucks, the manager says "I gotta get back to the office – see you at supper." And now you are left to play with the big toys yourself.

This may be fun but in these litigious times it can be expensive fun. Playing the joint role of designer and supervisor can lead to reasonable, but in hindsight code-violating, relaxation of construction standards. When the sun is now not too high above the trees, and before you lose the daylight and things freeze up overnight, strict compliance with perfection of procedures and materials can get overruled by necessity, especially by a well-seasoned engineer. A good technician would not do that - no matter what. The point I'm trying to make here is that being a one-man band is not a good idea. And this is the mistake I made on this job. I would have expected a full time inspector/technician to have both searching for other drain pipes, and also noticed whatever fill deformation attended tamping by the excavator bucket.

Failures such as mine here are most uncommon in engineering. In fact, we are normally so successful in our efforts that engineering is taken for granted by society, with the result that, as a profession, we go unseen – no drama, no doubts, no excitement. And children grow up thinking an engineer is the 2IC of a locomotive.

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