MAINTENANCE OF DIKES AND DAMS

UPGRADING MEASURES

BY

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INTRODUCTION

Dikes and dams, if properly maintained have an indefinite life. The most recent demonstration of long life was the 1986 failure by piping along a conduit outlet, of a dike (bund) in Sri Lanka, which was built during the seventh century, for a life of over 1000 years!

However, in addition to regular maintenance, dikes and dams may have to be upgraded in order to: -

- Increase their strength or factor of safety
- Provide more freeboard
- Provide additional spillway capacity

The requirement for upgrading can be due to new design criteria such as higher earthquake loadings, which may not have been considered in the original design; or additional safety requirements due to an increase in the downstream population within the flood plain which could be inundated by a dam break; or new spillway capacity required to pass a probable maximum flood. In several countries, legislation now requires inspection and design reviews of major dams. Here in Canada, legislation has already been enacted by Alberta, and other provinces are currently drafting regulations.

Where legislation has been enacted such as in the United States, dam inspections have revealed many unsafe structures, and very often spillways are found to be inadequate. In this session we will discuss the process of design reviews, how to increase dam crest levels and modifications required to increase spill capacity.

DESIGN REVIEWS

From a dam owner's standpoint, the review of a dam should be simple matter. After all, the structure has probably been there for many years, and if built with fill, is now an almost indistinguishable part of the landscape, with the downstream slope covered with grass, shrubs and even the occasional tree. An expert could come out, walk over the dam, take a few photos, and write a short report giving the structure a clean bill of health. On rare occasions this will happen. The more common scenario is for the expert to start asking questions such as:-

- Where are the drawings, are they up-to-date, and do they show the "as built" condition?
- Where are the construction records, what is the strength of the materials?
- Where are the logs of drill holes, test pit analysis in borrow areas?

Given such data, the expert can then determine the dam slope stability and factors of safety. If the data is not available, a geotechnical program will be required to obtain data, and this can be very expensive. An idea of the work required can be obtained from the following two cases, for a concrete dam, and for an embankment dam.

Concrete Dam Stability Analysis

The forces acting on a concrete dam, which affect stability include:-

Upstream Water Pressure - from the retained water. The only force which can be calculated with precision, knowing the maximum water level.

Ice Pressure - Usually taken as 150 kN/m acting 0.3 m below the surface (10 kips per foot, one foot below water level), but which can range up to 200 or 300 kN/m. (1)

Silt Pressure - This is highly variable, being a function of depth, density and pressure coefficient. (2) In northern Canadian experience, sometimes it can be neglected, but is often present at an old dam.

Uplift - Water pressure acting from below, which can vary from 100% to less than 25% a few meters in from the dam face. It is a function of the foundation material, foundation preparation (grout, cut-off, blanket) and the drain system. It is one of the major variables, and optimistic assumptions (low uplift) will have to be confirmed with site tests. (3)

Seismic loads - These affect the other loads acting on the dam, and are a function of earthquake intensity. They are usually given as a percentage, varying from 3% to 30%, of horizontal loads and about half of this on vertical loads, for two earthquake conditions, the operating basis earthquake (OBE) and the maximum credible earthquake, (MCE) (4). There should be no damage with the OBE; and some damage, but not failure, would be acceptable with the MCE.

Dead loads - Due to weight of the existing structure, can be determined accurately if structure geometry and material weight are known.

As will be noted from the foregoing, the loads on a structure can vary, but also the load combination can vary to include:-

Normal loads - Reservoir full or empty, with normal uplift.

Unusual loads - Reservoirs at extreme flood level, with normal uplift, and with high uplift due to blocked drains.

Extreme loads - Reservoir full, normal uplift, with OBE and MCE earthquake loads.

Having determined all loads, the next step is to calculate the factors of safety against sliding and overturning, and determine whether these are within acceptable limits. The procedure is well known (5), and results in a table giving the safety factors for the six load conditions.

In many cases the structure may fail to meet one of the load conditions. The work must then be extended to determine more precisely such factors as the friction coefficient, cohesion and actual uplift.

Embankment Dam Stability Analysis

The same forces which act on a gravity dam, also act on an embankment dam, However, due to the heterogeneous nature of the material, and the variety of materials used from impervious fill to large rock, the dead load cannot be determined accurately. Furthermore, the stability analysis is far more complex, and requires knowledge of the geotechnical properties of the dam material, along with the location of the phreatic line within the dam. Tests to determine these parameters can be expensive, and will include site drilling for samples, the installation of piezometers, monitoring over a reservoir drawdown cycle, and extensive laboratory testing of materials.

Once the design parameters are known, stability analysis is usually carried out using a recognized computer program such as SLOPE 2, which determines the factor of safety for the upstream and downstream dam slopes.

Other Safety Factors

In addition to sliding and slope stability, two other factors have to be evaluated, namely:- wave run-up during a major storm, and spillway capacity.

Both of these affect the freeboard available above normal reservoir full supply level, and above the extreme flood level. If the dam is more than about 20 years old, chances are that storms will have already revealed any weakness in the rip-nap, or lack of freeboard, and the deficiency will have been rectified. More recent dams will have benefited from modern techniques used to determine wave height (6), hence freeboard is usually adequate.

On the other hand, spillways are often inadequate, and have to be enlarged. In the process, dam crests may have to be raised to increase spill capacity.

RAISING EMBANKMENT DAM CRESTS

The most common method used to increase the crest level of an embankment dam, is to place pervious material on the downstream face, and add a sloping impervious core, tied into the existing core as at Corani (7) illustrated in Figure 1. Here 4.5 m was added to the dam crest, to increase the reservoir capacity.

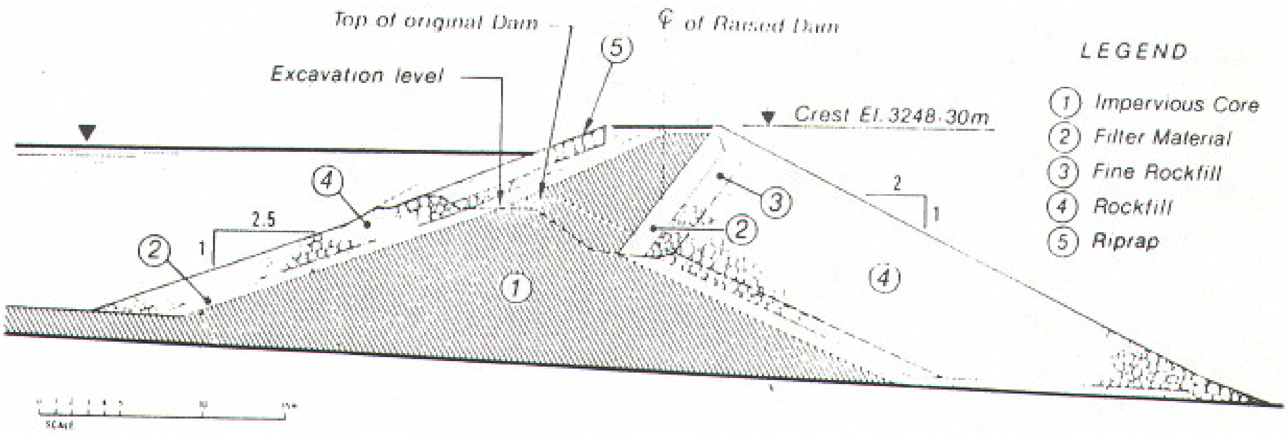


FIGURE 1 - TYPICAL SECTION CORANI DAM

A variation of this method is to steepen the slopes and build on top of the dam (Figure 2) as proposed for a dam in Newfoundland where the crest will be raised by 5 m (16.4 ft).

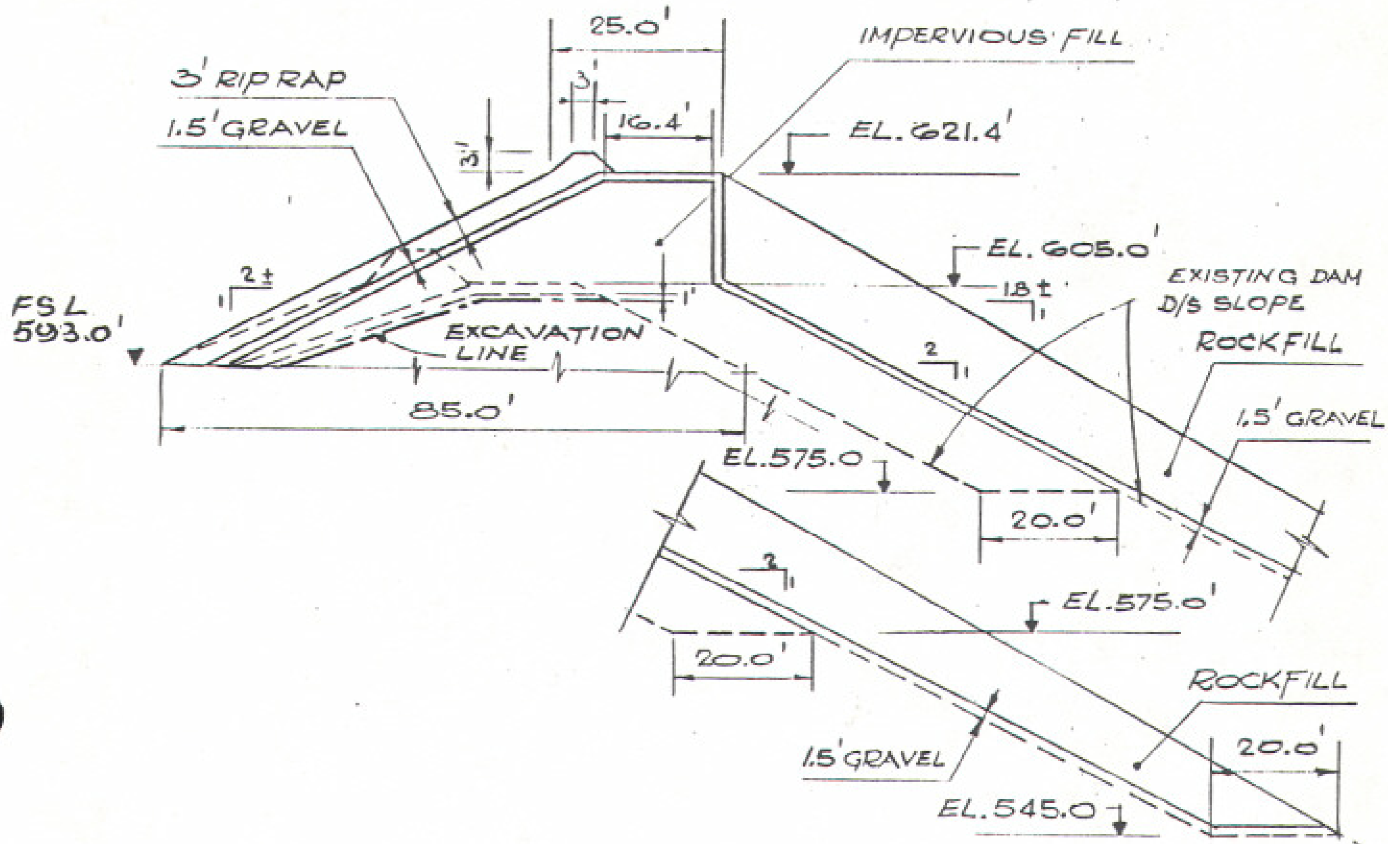


FIGURE 2 - TYPICAL SECTION NORTH DAM

Factors which must be considered in the embankment dam design include:-

Core Contact - This should be achieved below the frost affected zone

Freeboard - Scheduling the work during a period of low reservoir level, or operating the reservoir at a lower level during construction, will be necessary in order to maintain a safe freeboard during the construction work.

Blanket - Where the dam has a blanket, its effective length/head ratio will be reduced with the higher dam. Seepage will have to be estimated for the higher head. Natural sedimentation will usually have reduced the seepage, and records of seepage will improve the evaluation.

Abutment Treatment - Additional grouting may be necessary to resist the higher head.

A more common situation which can arise with dam crests, is a requirement to increase the water barrier up to crest level. This is due to the concept of allowing the reservoir water level to rise to crest level during a PMF, which is often above the level of the dam core.

Frost action on the core - unless it is very silty and lacking in fines - usually requires the core to be covered with about one meter of sand and gravel. If not, the core cracks, and produces a longitudinal crack in the dam crest, which with time will eventually widen to split the crest. A low-cost solution is to add an impervious plastic membrane by excavating a trench in the crest, and about 0.5 m into the core, placing the membrane and back filling with core material topped with sand and gravel as shown in Figure 3.

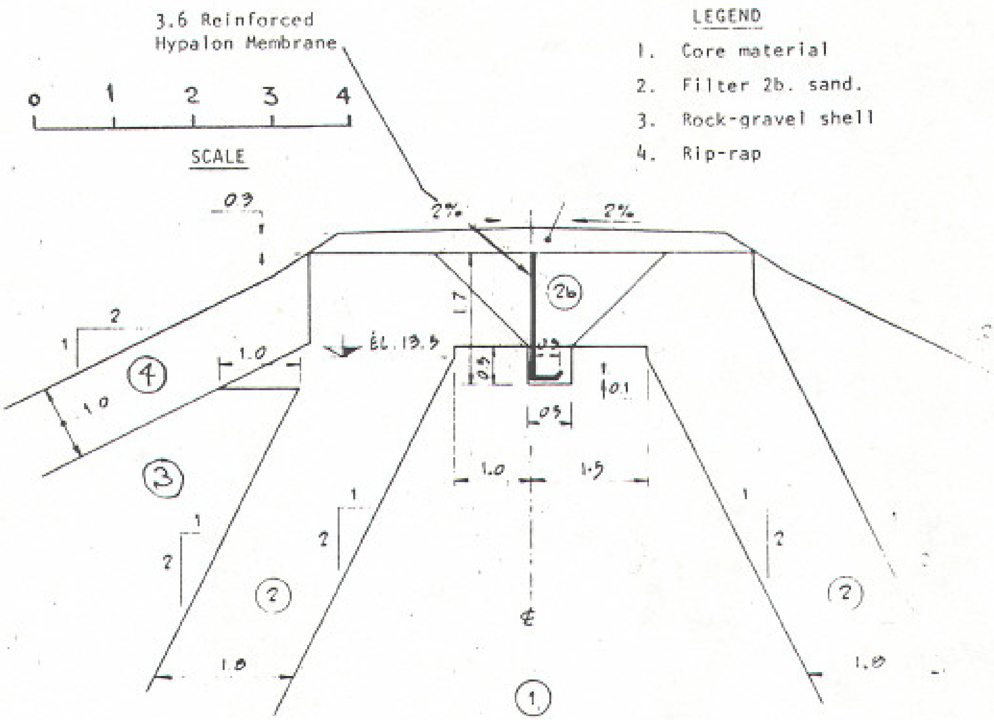
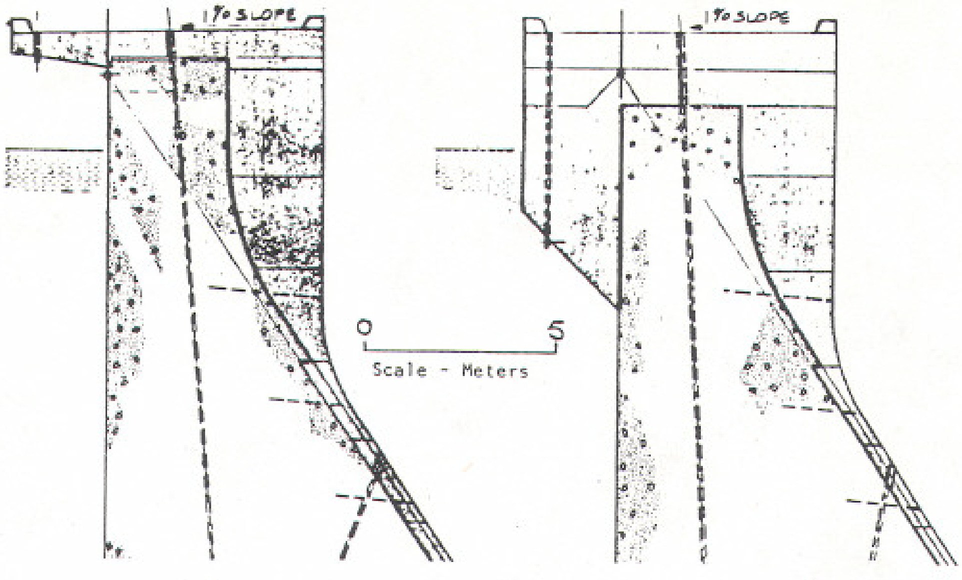


FIGURE 3 - CREST DETAIL, LACHUTE DAM

RAISING CONCRETE DAM CRESTS

Adding concrete to the crest of an existing dam is a more simple procedure than with an embankment dam. A typical solution is shown in Figure 4 which shows work currently underway at the Ghost Dam on the Bow River in Alberta. Here two problems had to be solved. For the transition section between the spillway-powerplant and the side embankment dams, the crest level varies, dropping to a lower level at the main concrete section. In this section the crest is being raised and the road widened as shown in Section A on Figure 4.

Concrete is being added on the downstream face to improve stability, and to provide a more weather-resistant facing. At the same time the crest is being widened to improve access. Due to the variable geometry of the dam, each concrete monolith was checked for stability under the new load conditions, and the addition of concrete required to stabilize each monolith was optimized. All monoliths require concrete on the downstream face, but some monoliths also require additional concrete added to the upstream face to improve stability, as shown in Section B, Figure 4.



A

Typical section where crest raised and widened.

B

Typical section where crest raised, widened, and additional concrete added for stability.

FIGURE 4 - GHOST DAM CREST MODIFICATIONS

Where larger increases in crest level are required, then additional mass concrete will be needed on the downstream face. If a large increase in crest level is required, as compared with the existing height of the dam, it may be necessary to encase the original dam within the new structure, as at the Corani spillway (7), shown on Figure 5.

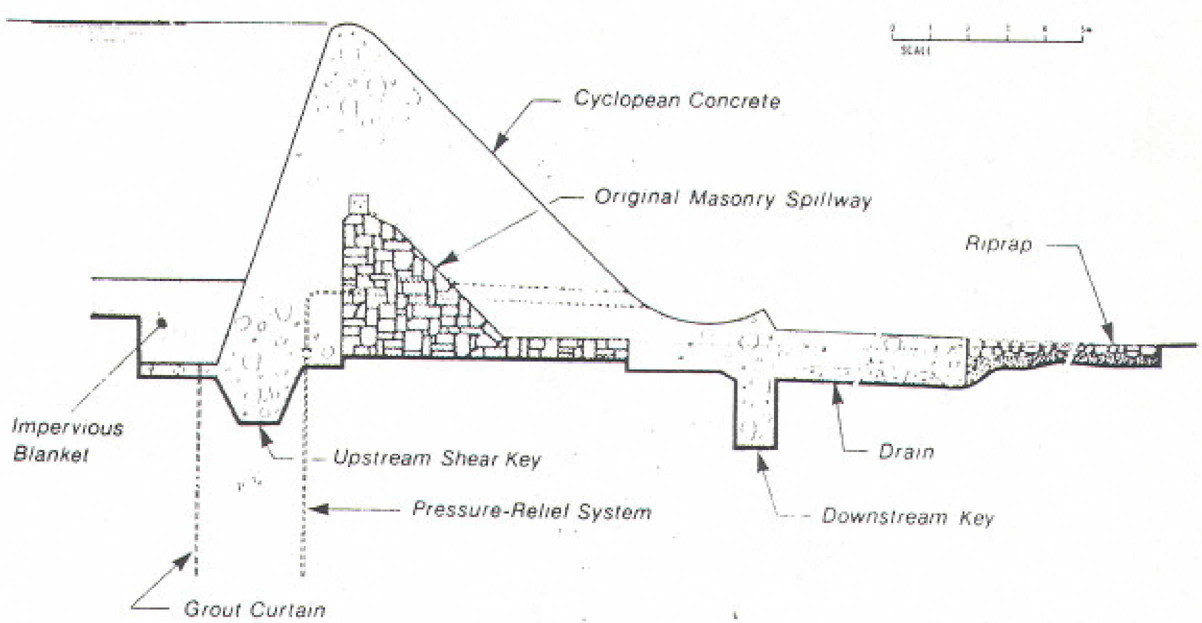


FIGURE 5 - SECTION THROUGH CORANI SPILLWAY

When adding concrete to existing structures it is necessary to ensure:-

Bonding of new concrete to old is such that the structure will act as one unit. This can be accomplished with dowels and removal of the surface weathered concrete. A bonding agent should be avoided - it is expensive, and will form a waterproof membrane behind which moisture will accumulate, and in freezing may break the bond.

Drainage. Very often the old concrete is more pervious than the new concrete shell being added on the downstream face. Box drains at the interface, and drains through the new concrete are needed to prevent the new concrete being jacked off the face. Also there may be seepage or even leakage through construction joints. These have to be intercepted and drained, preferably to a drainage gallery within the dam.

STRUCTURE MODIFICATIONS FOR OVERTOPPING

A concrete dam will withstand overtopping, hence no modifications are required, except perhaps at the abutments. If these are of any material other than rock, they constitute the weak link in the dam, and will have to be reinforced. The extent and method of reinforcement will depend on the depth of overflow for which the structure has to be designed. If less than about one meter, then heavy rip-rap should be adequate, placed on the abutment to about 2 m above the dam crest, and in a wedge-shaped section downstream. The entire mass should then be filled with slush concrete to anchor the rocks in place.

For larger flow depths, the abutments will have to be reinforced with a concrete facing, designed and shaped to handle the flow.

At a spillway, larger flows due to a larger surcharge on the reservoir will have three effects. (a)- The stability of the structure will have to be checked, and if necessary improved with rock anchors; (b)- The gates will have to be lifted higher to clear the water surface. This can be accomplished by simply raising the gate towers and installing longer wire ropes or screw stems as was necessary at Bearspaw (8); (c)- The stilling basin may have to be reinforced and enlarged. (Figure 6.)

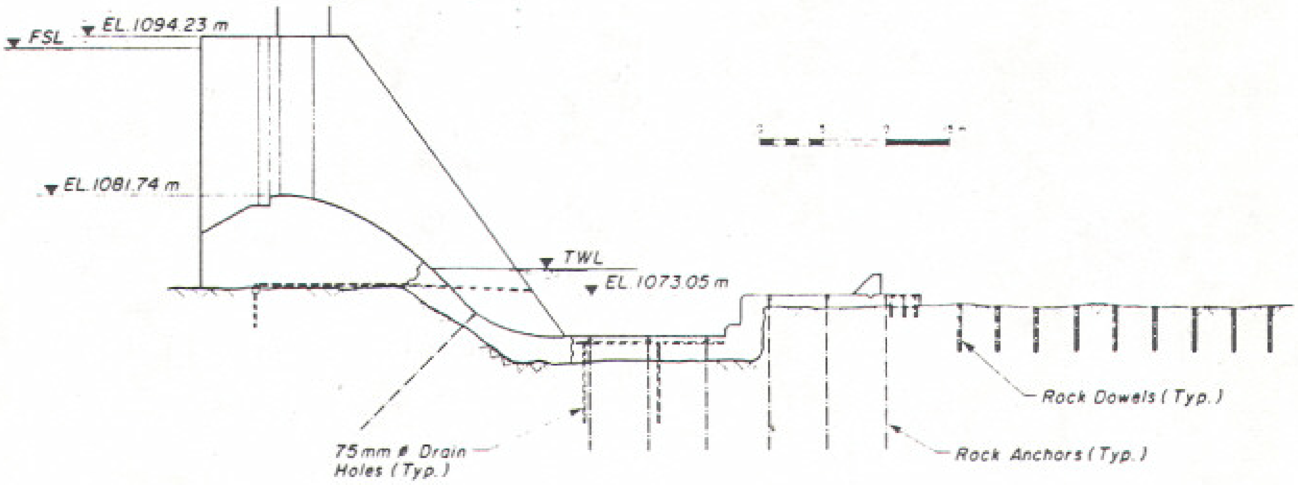


FIGURE 6 - SECTION THOUGH MODIFIED BEARSPAW SPILLWAY

Embankment dams present a far more serious challenge, and it is generally recognized that they cannot withstand any overtopping. However modifications can be made to install a "fuse plug" in a section of the dam. This is simply a short section where the crest is about 1.5 m lower (Figure 7) which will wash out before the flood overtops the main dam crest. The location is selected to minimize downstream damage, since the washout will be rapid, and could cause a major flood wave.

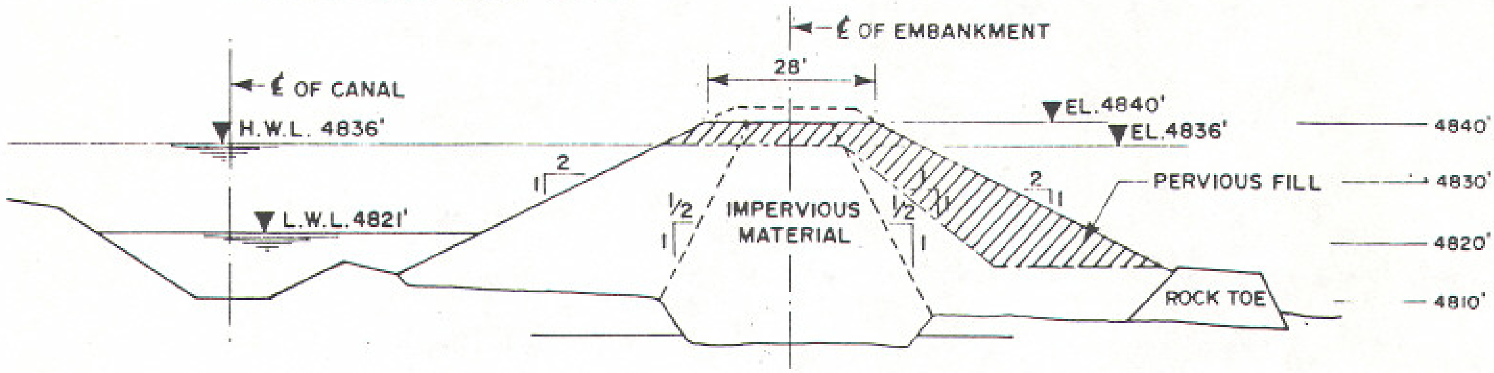


FIGURE 7 - SECTION THROUGH CASCADE FUSE PLUG

For small dams, where there is a relatively flat downstream slope, a cobble lined drop structure chute spillway can be installed as at Mount Pleasant (Figure 8). The spillway crest should be reinforced with a timber or sheet steel pile cut-off wall to prevent erosion.

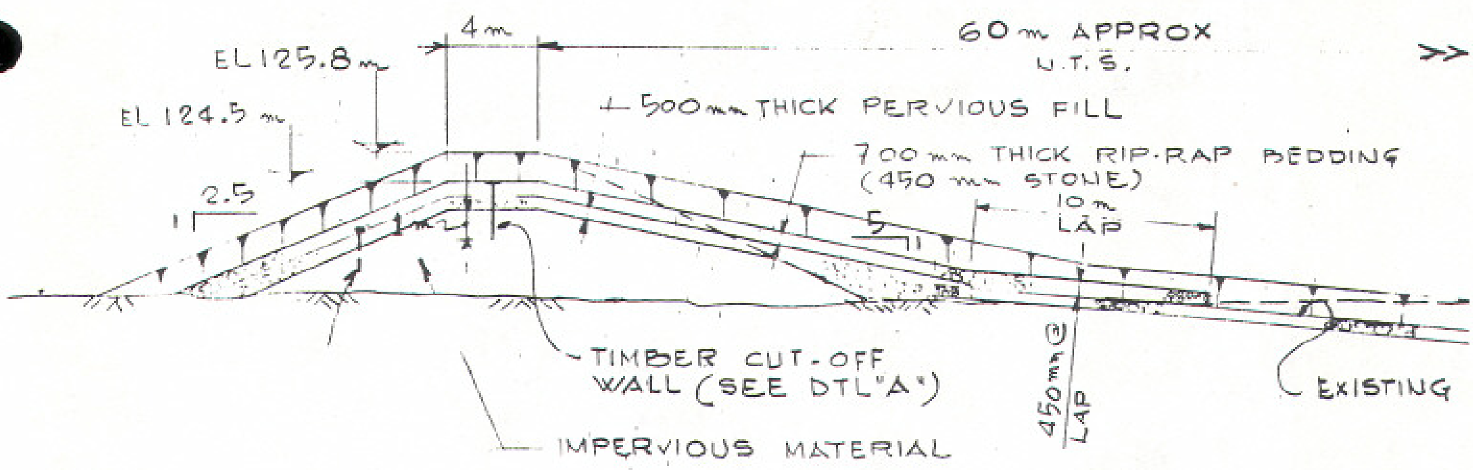


FIGURE 8 - MOUNT PLEASANT SPILLWAY

There are two important details which should be watched when building a small rock-lined chute spillw-v:-

Cut-off -- This must penetrate the impervious layer, and must also be continued up the spillway flanks to above maximum water level, to prevent erosion around the ends -- the most common cause for failure

Rock size -- In the chute, there is a very definite relationship between slope, depth of flow and rock stability (9). Any attempt to reduce the required rock size will result in failure.

ADDING STRUCTURES TO INCREASE SPILL CAPACITY

This can be accomplished in many ways, but the selection will depend entirely on the configuration of the existing development and the local topography. The methods which should be considered include:-

- Adding a new gated spillway.
- Adding a new weir spillway
- Enlarging an existing spillway by cutting down the ogee
- Enlarging an existing spillway by raising the flood level.
- Adding a fuse plug spillway
- Adding a glory hole spillway onto an abandoned diversion tunnel.

Examples of new gated and new weir spillways are at Ghost and Bearspaw dams on the Bow River in Alberta.

New Ghost Spillway

At Ghost, the existing stoplog controlled spillway with a capacity of 1075 m^3/s (38,000 cfs), is being demolished and replaced with a gated spillway having a capacity of 4737 m^3/s (167,400 cfs).

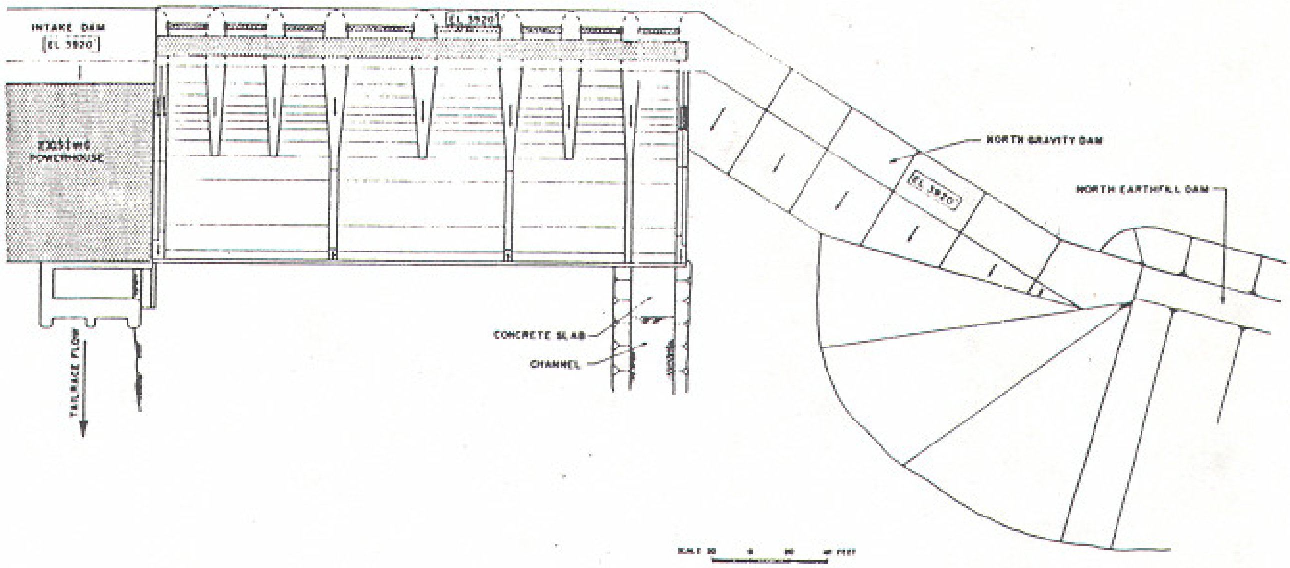


FIGURE 9 - PLAN,NEW GHOST SPILLWAY

The new spillway will have 8 gates, six with a span of 6.12 m, and two with a span of 9.75 m, in order to avoid placing the new spillway piers over existing construction joints.

The dam will be cut down 11 m, with the last 2 m being removed behind steel bulkhead cofferdams, in order to keep the reservoir at a level which will permit the generating units to remain on line. A typical spillway section is shown in Figure 10.

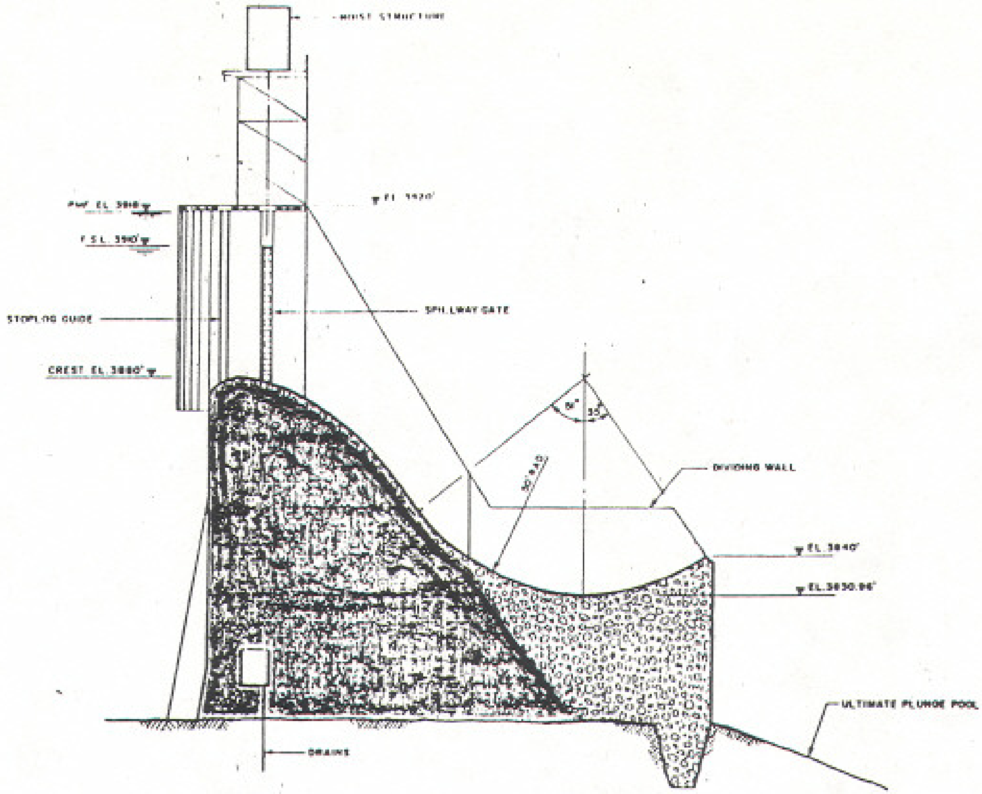


FIGURE 10 - GHOST SPILLWAY SECTION

The shape of the flip bucket was determined from hydraulic model studies, wherein it was found that operation was improved with a 35° flip on the three northern gate buckets, with the rest being at 45°.

New Bearspaw Spillway

At Bearspaw the spillway capacity has been increased from 2832 m^3/s to 6145 m^3/s by adding a side channel weir spillway of 1897 m^3/s capacity, and increasing the reservoir flood level by 3 m. The increased flood level will increase the flows in the main spillway to 4248 m^3/s, necessitating extension and reinforcement of the stilling basin as shown in Figure 6. In addition, the screw stem spillway gate operating mechanism had to be raised by 2.5 m to keep the gates above the new flood level. This was accomplished by raising the hoist platform with hydraulic jacks and adding a section to the steel columns. At the same time the opportunity was taken to install fabric sleeves around the greased screw stems as dust protectors.

No pier strengthening was required, since the high water levels will only occur when the spillway gates are fully open.

This arrangement was selected as being the most economic solution from several alternatives, which included adding gated spillways and cutting down the existing ogees - as mentioned previously, the existing layout and local topography will dictate the most economic and practical method of adding spill capacity. A general layout of the development is shown in Figure 11.

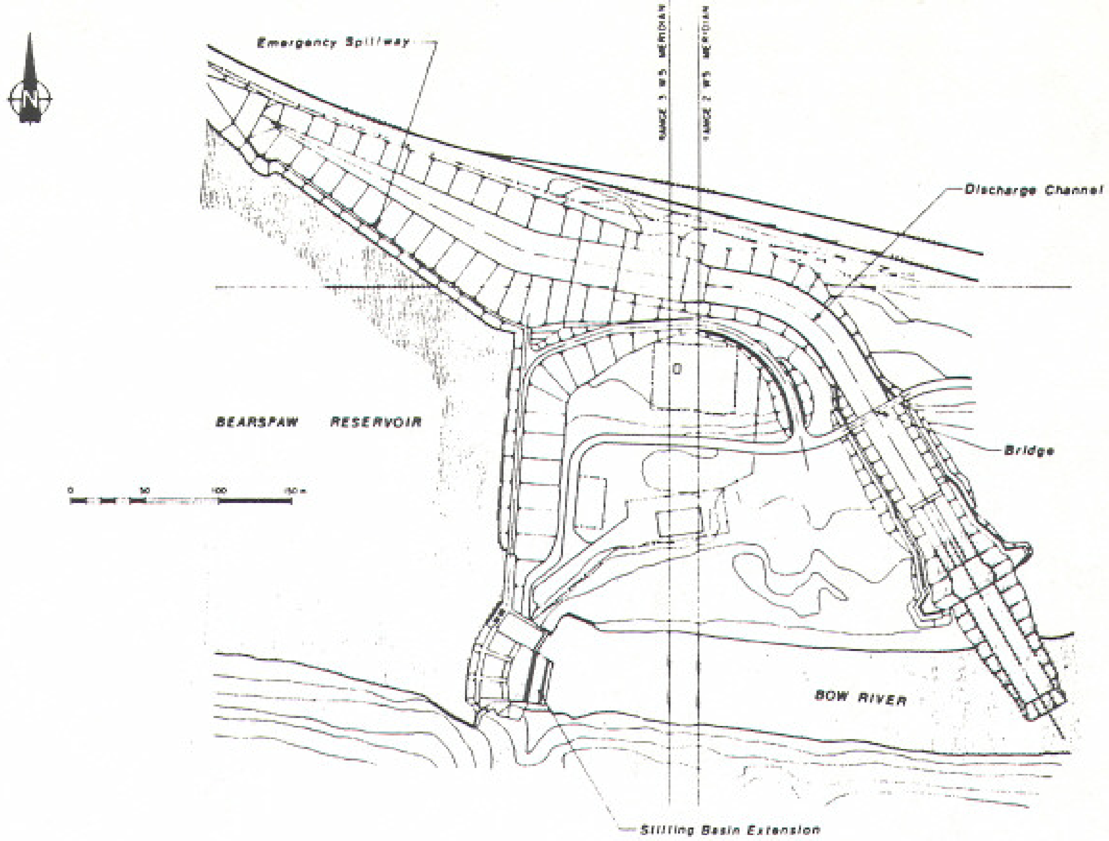


FIGURE 11 - BEARSPAW - GENERAL LAYOUT

The emergency side channel weir spillway is concrete lined to just below the dam, and was hydraulic model tested at a scale of 1:35. The weir was built on top of an embankment dam with the core joined to the concrete weir by an impervious polyethylene membrane 2 mm thick. The channel was lined with concrete cast in squares having a length of about 15 m, joined with waterstops. An extensive drainage system counteracts any uplift and draws off all groundwater. A section is shown in Figure 12.

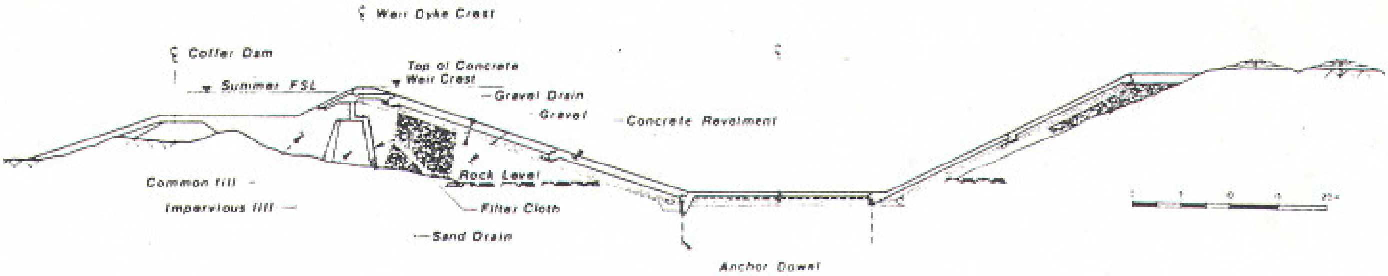


FIGURE 12 - SECTION - BEARSPAW EMERGENCY SPILLWAY

Stoplog Release Mechanism

In Canada there are many spillways controlled by stoplogs. These structures were built when low-cost labour was available, and plants were manually controlled. Powerplants have now been automated, and labour is expensive. Thus stoplog operation is expensive, time consuming, and difficult to arrange on short notice. On plants with small headponds an intense rainstorm can cause a rapid rise in the headpond water level, sometimes at a rate which cannot be countered by removal of stoplogs, due to the time required to arrange for, and remove the logs.

Such was the case at a dam in Lachute, Quebec, where the left abutment was washed out when 0.6 m of water overtopped the concrete dam. In such cases it would be prudent to equip one of the stoplog bays with a mechanism to rapidly release the logs in the spillway bay. This can be accomplished by installing a steel column in the middle of the bay, with the bottom prevented from moving downstream by a steel stop, and the top retained by a pin which can be pulled out with a hydraulic jack. Such a system was installed at the St Marguerite Dam (10), and a similar system was installed at the Lachute Dam. A section through the mechanism is shown on Figure 13.

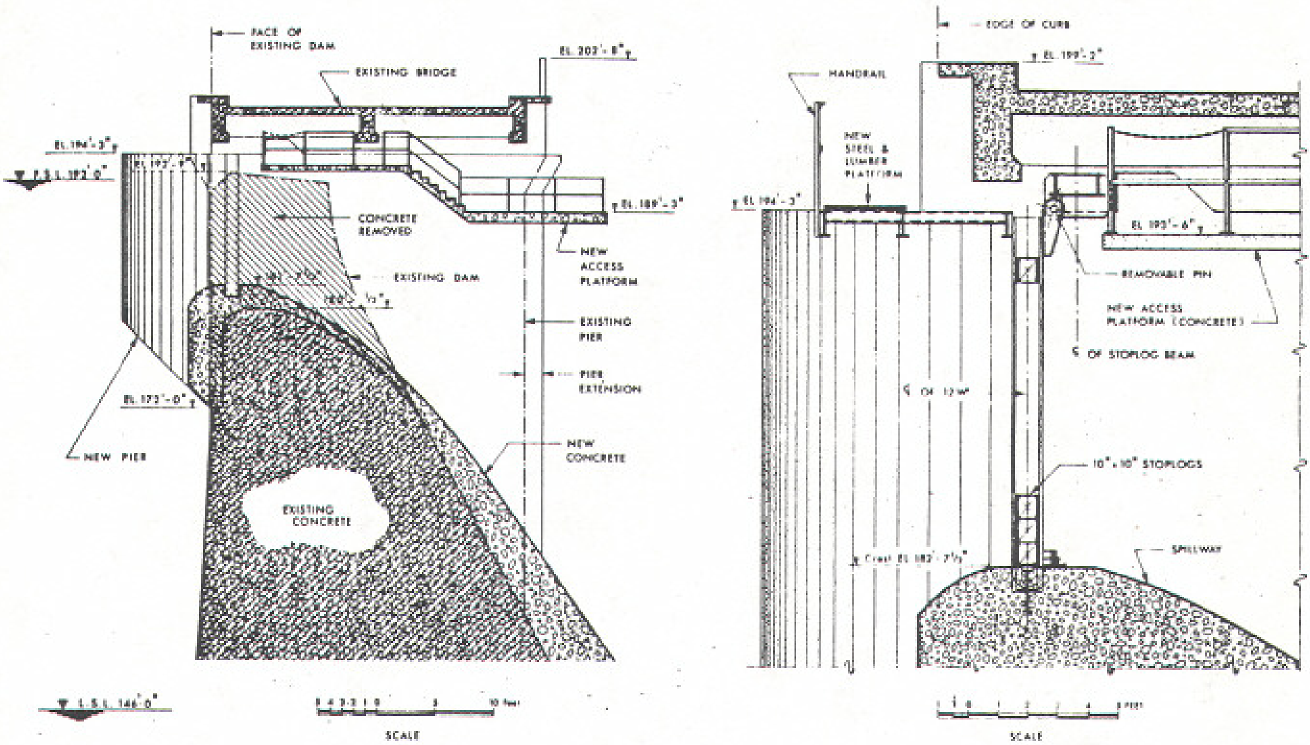


FIGURE 13 - SECTIONS, STOPLOG RELEASE MECHANISM

At St. Marguerite six new rapid-release stoplog bays were added to an existing dam to increase the spill capacity. At Lachute the mechanism is being built into an existing bay, to provide quick spill capacity. The only detractions to the system are the loss of the steel column and logs; and the inability to close the opening under flowing water.

CONCLUDING REMARKS

Based on the foregoing, it is evident that there are many ways to upgrade an existing dike or dam. Other methods which have not been discussed include post tensioned rock anchors - which can be used to improve stability. However, they should be regarded as a second option, to be used only when other methods are too expensive, since the question of anchor deterioration from long term corrosion has not been positively resolved. Another method is to bury a deteriorated concreted dam within a rock fill embankment, using the concrete section as the dam core. This will stop deterioration of the concrete from freeze - thaw, and may be more economic than trying to repair the concrete. This was the case at Gull Pond in Newfoundland, where the concrete spillway was also buried, and a new spillway channel was excavated in the left rock abutment (11).

Finally, it is hoped that the ideas and designs outlined in this presentation will be of use to the reader. Further details can be obtained from the references.

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