EVOLUTION OF ZONING FOR THE CONCRETE FACE ROCKFILL DAMS (CFRD’S) RELATED TO THE EXISTANCE OF LOCAL MATERIALS.

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ABSTRACT

During the past 30 years many Rockfill Dams, of the type concrete faced, have been designed and constructed using existing local materials of inferior quality, for practical and economical reasons. In this paper the authors review some of the variations from the original conception of CFRD’s zoning, presented by others in 1985, and describe new elements introduced in the dam zoning for economical construction of new projects.

Some of these projects, where the authors have participated, are briefly described indicating the performance during construction and operation of the structures.

1 INTRODUCTION

During the technical discussions at the annual meeting of the American Society of Civil Engineers (ASCE), held in Detroit in October 1984, was defined the International nomenclature for the Concrete Face Rockfill Dams’s (CFRD’s) as presented at the zoning shown on Figure 1.

Zones 1 were designated for soils and impervious materials. The 1A material located on the face slab was specified as impervious material while zone 1B was a material, Rondon type, for confining 1A material against face slab.

Zone 2 called as cushion material is a transition zone with a maximum size of 3” – 4”, containing 40% of sand and a maximum content of fines of 8%.

Zone 3 were designated as rockfills. 3A zone located between zone 2 and the main rockfill (3B) is a transition which is placed simultaneously with zone 2 material in layers of 0.40 – 0.50m thick.

3B and 3C were designated as rockfills, with a maximum size of 1m (3B) placed in layers of 1m.
Zone 3C was specified with maximum size as 2m thick. Zone 4 was designated as over sizes material placed on the downstream slope.

![Diagram showing CFRD zones with labels](image)

**Figure 1.** International Nomenclature for CFRD’s as defined on Detroit, 1984.

## 2 Extruded Curb

After zoning proposed in 1984 the use of an extruded concrete curb was introduced. This extruded curb was used for the first time at the ITÁ, 125m, Brazil in 1999. The purpose of the extruded curb was to confine the 2B material avoiding compaction on the upstream slope and protecting the surface from heavy rains causing important erosions as observed in other CFRD dams.

![Extruded curb construction](image)

**Figure 2.** Extruded curb construction

![Itá CFRD. Upstream face with extruded curb protection](image)

**Figure 3.** Itá CFRD. Upstream face with extruded curb protection
3 NEW ZONING

In the period 1984 to date, a new concept of zoning has been used in several projects adding elements that complement the original zoning as shown on Figure 4, taking into account that some dams have been constructed or are planned in seismic areas\(^3\).

![Figure 4. New zoning with zone 2A, extruded curb, vertical drain and downstream slope variations](image)

1A zone is specified as a silt or fine sand with low plasticity index IP < 8.
Zone 2 has been divided in 2 areas, a filter located under the perimetric joint called 2A, whose function is to contain and clog the perimetric joint with silt 1A when a failure of the water stops is presented. 2A is a filter material of 1A placed on the face slab.
2B remains identical as specified at the original zoning.

- **Vertical Drain**

It has been built a vertical drain in the center of the dam connected to a horizontal drain at the bottom of the dam that protects downstream eventual saturation during operation of the Project or in the event of an earthquake.
It also allows the placing of local granular materials, of inferior quality, downstream of the central drain.
Additionally, the new zoning requires that the 25-30%H of the top of the dam be built with the best material (3B) and the downstream slope with flatter slopes (1.5-1.6H:1V) as shown on Figure 4. Flatter slopes were used at Zipingpu CFRD, China, resisting and earthquake of magnitude 8 with adequate performance.
3B and 3C zones have been specified with layers of thin thickness, compacted with vibratory rollers, 20t minimum and addition of water.
Zone T, located at the dam center, has been built with local materials, of inferior quality and layers lower than used for 3B and 3C zones.
4 ESTABILITY

The inclusion of local materials of inferior quality, located downstream the drain, does not affect the stability, since the wedge shear zone is located on 3B material which has the best strength parameter (Angle $\phi$).

A stability analysis methodology is discussed in Reference$^4$, including acceleration parameters applicable on seismic areas. Figure 5.

![Figure 5. (CORREGIR ESTA FIGURA)](image)

5 CONSTRUCTION PLANNING

An important aspect to be taken into account with the new zoning is the construction planning of the CFRD. It is important to give priority at the construction of the plinth. The plinth excavation should be done simultaneously with the excavation of the diversion tunnels, so that after diversion the only excavation lacking is the river bed area and the portion covered by the river on both banks. In places where the abutments are steep, planning and construction of the plinth can be executed during placement of rockfill$^5$.

The volume of plinth excavation and concrete placing are relatively small. There is a tendency on the part of contractors to leave these activities after diversion, causing delays that affect the execution of the work in general.

6 BEHAVIOR OF NEW CFRD’s

Following is described some aspects of modern dams where have applied, partially or completely, the concept of the new zoning$^6$.

- El Cajón, 188m, México. Rockfill: Ignimbrite.

El Cajón Project was built by the COMISIÓN FEDERAL OF MÉXICO – CFE, with modern criteria, compacting thin rockfill layers ($3B = 0.60$) and $(T=1.00m)$ with heavy compactor rollers, 20 t, with generous application of water, > 200 l/m$^3$.

The maxim rockfill deformation, at the center of the dam before reservoir filling, was 0.75m which represents to only 0.40% H.
During construction of the slabs was observed that the back pressure from water accumulated at the lowest point of the plinth, produced displacements of the slab which were corrected by drilling holes to relieve pressure.

Figure 6. El Cajón Dam. Rockfill deformation before reservoir filling.

The behavior of the dam has been excellent.

- **Reventazón, 130m, Costa Rica** – Fill: Riverbed gravels, conglomerates, consolidated breccias.
Dam Reventazón CFRD is being built by the INSTITUTO COSTARRICENSE DE ELECTRICIDAD, ICE, using riverbed gravels and mixtures with conglomerates and consolidated breccias, of inferior quality, to obtain the required volume for the dam. Fill 3B is riverbed material placed in 0.60m layers. Zone T is a mixture of gravels and consolidated breccias in the ratio 2:1. 3C material is the product of alluvial gravels mixed with conglomerates in the ratio 3:1. The materials located downstream of the dam axis, are protected by a vertical drain located at the center of the dam connected to a horizontal drain at the dam bottom. Figure 9.

An interesting aspect of this dam is that processed materials as the drain and transitions rockfill (2B and 3A) were placed efficiently with metallic molds as illustrated in Figure 10.

The observed deformations of the fill are consistent with the predictions of the Project.

- **Porce III, 150m, Colombia. Rockfill: Igneous and schists**

The Porce III CFRdam was built by EMPRESAS PÚBLICAS DE MEDELLÍN - EPM, with material from the structures excavation (underground and spillway) mainly
igneous and metamorphic schists from the spillway excavation. The processed materials including (2B and 3A) the vertical drain were produced by crushing underground igneous material of good quality. Main rockfill was built with schists presenting high values of Los Angeles Abrasion closed to 60%.

Material was well compacted in thin layers (0.60m – 0.80m) with Heavy Compactor rollers and water application. Central maximum deformation was lower than 1.0%H. During construction of the lower face slabs was not presented back pressure, because the vertical and horizontal drains worked well drawing the compaction water downstream.

The dam has an adequate behavior according to the design premises.

- **Mazar, 166m, Ecuador. Rockfill: quartztitic, cloritic and sericitic schists**

Mazar Dam was built by CORPORACIÓN ELECTRICA DEL ECUADOR – CELEC E.P. with schistose materials in thin layers of 3B (0.50m) and 3C (0.80m) with 6 passes
of a heavy compactor vibratory roller and water addition of 300 l/m³. A central drain, slightly inclined downstream, was placed to protect downstream material 3C against saturation.

Figure 14. Typical zoning of Mazar CFRD

Figura 15. Mazar – Downstream view

COMPLEMENTAR TEXTO (FREITAS)
• **Chaglla, 211m, Peru. Rockfill: gravels and limestone rockfill**

Chaglla dam is being built by EMPRESA DE GENERACIÓN HUALLAGA S.A., using the Huallaga river gravels and deposits of calcareous material (limestone) close to the dam site. The specifications follow the selection of modern thin layers, addiction of water and heavy vibratory compactors with a weight of 20 t minimum. The design incorporates a central vertical drain and a zone T of granular material of inferior quality with fines close to 15% passing the No. 200 sieve. However, during the exploitation of this source a substantial reduction of fines have been noted to values close to 5% as a maximum. 3B materials (gravels or limestone) are compacted in 0.60m layers. The Chaglla narrow valley has required the design of special waterstops to offset potential high perimetric joint movements.

![Figure 16. Chaglla Dam cross section](image)

![Figure 17. Face slab construction](image)
New projects such as Coca Codo Sinclair in Ecuador and in Patagonia on the Santa Cruz river, Argentina, are considering the new zoning using a vertical drain and local materials compacted in thin layers.

7 CONCLUSIONS

A new zoning of CFRDs, has been used to complement the original zoning of Detroit 1984. New zoning incorporates modifications as follows:

- Dam layers are thinner than original ones. They are compacted by heavier rollers generating high modulus of compressibility.
- A central vertical drain has permitted to use rockfills of inferior quality downstream of the central drain. This drain prevents saturation of downstream material making the dam stable even during seismic events.
- Upper downstream slope has been designed flatter to give better capacity of stability in seismic zones.
- Special water stops have been designed to provide more capacity to resist greater movements in very narrow valleys.

These improvements have allowed building higher CFRDs with excellent performance from a technical and economical stand point.

REFERENCES


