# CHALLENGES IN EXECUTION OF CONCRETE FACE ROCK-FILL DAMS IN EMERGING ECONOMIES

**S.C. MITTAL, IMRAN SAYEED, U.V. HEGDE AND SENTHIL RAJA**
*DMR Hydroengineering and Infrastructure Works, Faridabad, India*

## ABSTRACT

*It is strongly believed that Concrete Face Rockfill Dams are proposed when the bed rock is not available at reasonable depth for placement of concrete dam. However, this is not the actual case. CFRDs offer economic solutions for suitable dams for power generation, irrigation or water supply in cases where there is a dearth of natural construction material either for concrete aggregates or for impervious core. Placement of CFRDs across rivers with thick RBM is definitely an added advantage particularly in Himalayas.*

*In India the first CFRD was constructed as a part of Dhauliganga Stage I hydroelectric power project in Uttarakhand, India. This 56m high dam was completed with a plinth on river deposits of 70m thickness and on bedrock on the banks.*

*DMR has carried out design and engineering for 60m high CFRD for 1200 MW Teesta III hydroelectric power project in Sikkim, India. In this case an innovative layout for spillway on both the banks and spillway tunnel on right bank were proposed.*

*Small dams have been developed for irrigation purpose in Nepal and Cambodia. The Dhap dam in Nepal has been completed with central spillway as bed rock of gneiss was available at a shallow depth. In case of Stung Tasal CFRD in Cambodia the 21m high dam also comprised central spillway as the sound rock was available at shallow depth below the weathered granite. At this project suitable impervious core material was not available for the earthen dam earlier contemplated. The paper discusses the advantages as well as challenges posed by CFRDs as a viable solution.*

## 1. INTRODUCTION

Concrete face rock-fill dams have an old history contrary to the popular belief that the concept is new. However it is a fact that modern period of CFRD from 1970s saw emergence of this type of dam as a viable alternative and a number of dams over 80m height were constructed. Since then, however, the technique has come of age and examples of very high CFRDs over 200 m are now available and have been successfully commissioned. In fact, after 2000 onwards a number of CFRDs over 140m have been constructed. Shuibuya dam in China at 233m is the highest commissioned CFRD in the world. In the pipeline the 315m high Rumia dam in Tibet Region, China is also proposed to come under construction.

The first CFRD can be traced to Sierra Naveda, California in 1850s. The segregated and dumped rock-fill as used earlier had a high compressibility and therefore affected the stability of concrete face as well. The damages to concrete face and consequent leakages make this type of dam unpopular. Subsequently in 1950s with the advancement of vibratory roller to compact the rock-fill, CFRD gained ground.

Clearly CFRDs have some advantages in the use of locally available material, good adaptability to site conditions and in economic considerations. Prior to 2000, empirical approach was used for design. Problems such as cracks in face slab and cushion layer, separation of face slab in cushion layer, concrete rupture along vertical joints, between face slabs and excessive leakage have been experienced in CFRDs. Later design approaches considered all aspects such as compressibility of foundation material as well as that of embankment material and many problems have been resolved.

The practicability and cost aspects with regards to CFRDs particularly in areas where there is heavy rainfall or in places where impervious clay core material is not available make such structures as sought after particularly in emerging economies.

## 2. FOUNDATION CONSIDERATIONS

In ICOLD Bulletin No 141 (2010) concepts for Design and Construction have been discussed in great detail. It is widely believed that CFRD can be placed in any type of foundation which can be alluvium also. While it is true that many CFRDs have been built when bedrock is not available in the river bed, ideally plinth should be resting on bedrock foundation. Alternatively if bed rock is not available in the river bed it should be either exposed on either banks or available at a shallow depth. In case rock is not available both in the river bed and also in banks the plinth will neither be resting on rock nor could be tied to the abutments effectively. Moreover, seepage control below the dam as well as on the banks shall be a big challenge and such site shall not be technically or economically feasible.

It also pertinent to bring out here that a high CFRD say above 150m height is not desirable on weak foundation. However, if geotechnical parameters are known well in advance a higher consolidation effort shall be required to raise the safety factor and accordingly a higher construction period shall be necessary. It should be appreciated that for CFRDs constructed on bedrock, only the settlement of rock-fill affects the plinth, concrete face slab, joints etc whereas in alluvial foundation, the situation is more complex as the settlement at the crest is the result of settlement of rock-fill plus compression of foundation material.

The plinth is normally founded on hard, non-erodible fresh rock that can be treated by grouting. With treatment, weathered jointed rock is also acceptable. Joints need to be cleaned before pouring of foundation concrete for plinth and also it is necessary to prepare the geological map of foundation for construction record just as done for concrete gravity dam foundation. Other measures such as backfilling of cracks etc are also required. Plinths have been constructed on alluvial soils also in several projects. The height of such dams varies from 28 to 106m. It needs to be ensured in alluvial foundation that materials are stable under all loading conditions and deformations in foundation are small such that resultant moments in joints in the plinth or cracking of concrete face will not lead to excessive seepage (ICOLD 2010). Materials should have low compressibility and be stable under seismic loadings. It may be noted that the plinth connects the foundation with concrete slab and should be stable.

It has been advocated (Materon 2002) for ascertaining the width requirement of plinth RMR system (Bieniawski 1982) shall be used. In this manner external and internal plinth combined width can be devised.

## 3. EMBANKMENT MATERIAL

The availability of suitable material plays an important role in selection of type of dam. Economic considerations are important as this is the main portion of dam and if transport distances are large the dam itself could become unviable. The CFRD accommodates to the maximum extent locally available material.

Earlier in CFRDs a thin zone of dry masonry which was placed by crane constituted the support base for concrete face. Later with the advent of compaction equipment for rock-fill this practice was abandoned.

The table given below has been developed based on in principle main zones for concrete faced rock-fill dams (ICOLD 2010). Various countries have their variations also.

**Table 1** : Typical Embankment Zones for CFRD

| Zone | Material | Placement | Purpose |
|---|---|---|---|
| 1A | Fine grained cohesion-less silt and fine sand with isolated gravel & cobble sized rock particles up to 150 mm | Placed in 200-300 mm layers and lightly compacted | Source material if required can migrate through cracks |
| 1B | Random mix of silt, clays, sand, gravel and cobbles | Placed in 200-300 mm layers and compacted | Protection to Zone 1A |
| 2A | Sand and gravel filter located within 2-3 meters of perimeter joint. Material quality is nearly equal to concrete aggregates | Placed in 200-400mm layers and well compacted by vibratory compactors | Filter material, secondary defence against leakage |
| 2B | Sand and gravel size particles horizontal width varies from 2m to 4m depending on height of the dam. Material quality is nearly equal to concrete aggregates | Placed in 400 mm horizontal layers compacted with 4 passes of 10 ton smoothdrum vibratory roller | Provides support to concrete face |
| 3A | Rock-fill with size 400 mm or less. Horizontal width varies from 2m to 4m depending on height of dam<br>Rock-fill obtained from quarry or from crusher minus 300-400 mm size | Placed in 400 mm layers with 4 passes 10 ton heavy roller | Transition between Zone 2B and 3B. |
| 3B | Rock-fill with maximum size 1000 mm | Placed in 1000 mm thick layers | |

The above table has been developed from the ICOLD Bull. 141 and should serve as a guideline for embankment zones. Some countries have however developed their own standards and there could also be variations depending upon height of the dam and local availability of materials.

The CFRD therefore has a great adaptability for site conditions and material availability. Nevertheless certain basic criteria need to be ensured particularly when the height of dam increases.

Some examples below give the analysis for selection of CFRD dams and their importance as solutions for difficult sites in India, Cambodia and Nepal with which the authors have been associated:

## 4. DHAULIGANGA HYDROELECTRIC PROJECT STAGE I, UTTARANCHAL, INDIA

Dhauliganga hydroelectric power project stage I is located in Pithoragrh District of Uttaranchal State close to India's border with Nepal. It is 500 km north-east of New Delhi and comprises of India's first 56m high Concrete Face Rock-fill Dam besides 5.6 km long head race tunnel and an underground power station having installed capacity of 280 MW. The dam is built across Dhauliganga River near Chirkila village and the power station discharges tail water in a stream close to Kali or Sharada River flowing on Indo-Nepal border. The construction was started in the year 2000 and the project was completed in 2005 highlighting one of the timely commissioning of hydropower plant in arduous Himalayas.

Geologically the project is located in Lesser Himalayas within a single rock formation locally known as Chiplakot Crystalline bounded by two thrust faults. The main central thrust is also 7 km upstream of the dam site. The bed rock at the dam site is biotite gneiss and schist as exposed on both the banks. In fact the left bank rises steeply after a small rocky spur that has been used to accommodate the left bank spillway. The river bed was extensively explored by six drill holes and other techniques in the investigation stage and it was found that bed rock is almost 70m below the existing river bed.

Alternative dam sites were also investigated in the vicinity but there was no indication of shallower bed rock profile. In fact the valley span also increased at other sites. The options were to excavate deep into the river bed for a concrete gravity dam or to have rock-fill dam. However there was lack of impervious clay deposits in the vicinity of dam site and it was difficult to transport the only clay deposit from about 50 km due lack of proper access road. Moreover the average annual rainfall in Pithoragarh district is 1500 mm out of which 80-85% falls during the monsoon season between June and September. The intensity of rainfall may also be particularly more severe during any period in monsoon as was later seen in 2013 floods when during a week in August more 230% above normal precipitation occurred. All these factors added uncertainty as well as additional costs in favour of a conventional rock-fill or a concrete dam. As such, it was decided after careful consideration to design and construct a Concrete Face Rock-fill Dam at Dhauliganga

### 4.1 Concrete Face Rock-fill Dam

The CFRD at Dhauliganga Stage I power plant is 56m high and 270m long at crest level excluding the spillway which comprises of two bays 10m high and 5m wide. The spillway is designed for a flood discharge of 3210 cumecs with flip bucket for energy dissipation. It was proposed as low level type for the combined function of flood release and flushing during monsoons of sediment accumulated in the reservoir during monsoons.

On the right bank where the spillway has been located on a rock pedestal, 500m long spillway tunnel also caters to the flood discharge (Figure 1)

**Figure 1** : Dhauliganga Hydroelectric Project Stage I: Layout of CFRD

The catchment area is 1360 km$^2$ with diversion tunnel catering to 1:30 year flood for 1335 cumecs discharge. This arrangement ensured smooth construction of the dam without any flood related problems. The dam top is at El 1351m, and FRL at 1345m thus leaving a free board of 6m. Besides this 1m high parapet wall is also constructed,

The dam section is provided with 1.5H:1V both upstream and d/s slopes. As seen in Figure 2 more gentler slope 2.5H:1V is provided at the u/s as well as d/s toe. The different zones along with the thickness of placement of layers in the main dam 3B and 3C of 80cm and 120 cm respectively are indicated in the cross section. The rock-fill material for this dam came from the locally available biotite gneiss rock.

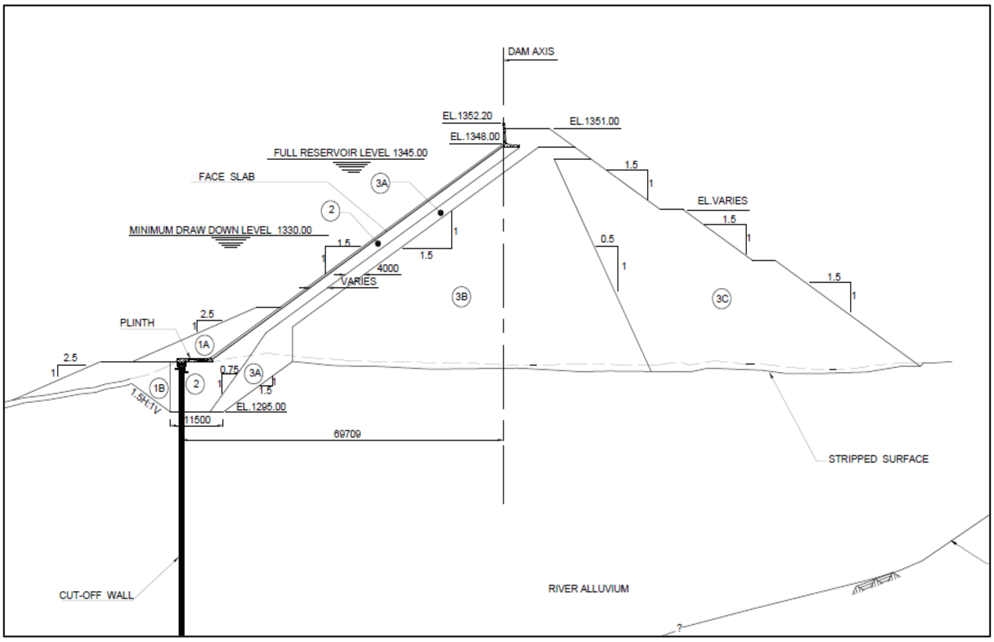

**Figure 2** : Dhauliganga Project: CFRD Section

The plinth in the river bed portion is connected to bed rock by means of plastic concrete diaphragm wall of 1m thickness thus precluding any possibility of seepage below the dam foundation which is placed on river alluvium. The river-fill material consisted of large sized boulders embedded in silty and sandy matrix having a permeability of 10-4 to 10-5 cm/sec. The alluvium fill extended down to a depth of 60m below the bed level of the river and consists of a upper layer of sand and gravel with pebbles and boulders, a central layer of sand lens upto 20m thick, and underlying zone again of sand and gravel with pebbles and boulders. Boulders of size of 2 to 3 m diameter embedded in the sand gravel layer exist in the river alluvium. Standard penetration tests were conducted for assessment of liquefaction potential and same was ruled out after detailed studies.

The plinth on the left bank continued and abutted into bed rock whereas on the right bank spillway was present and thus on the right flank the CFRD abutted against the spillway concrete pier wall. There were apprehensions regarding placement of plinth on river borne alluvium. However, examples such as Campo Moro dam in Italy, Kekeya and Tongjiezi dams in China, Chakoukane dam in Morocco, Santa Juana and Puclaro dams in Chile were studied and looking at the clear advantages of CFRD the decision was taken.

It was resolved that with careful design details of plinth and plinth cut off connection, it was possible to use river alluvium with boulders as foundation for the CFRD. The performance of Dhauliganga was severely tested during flood of 2013. Although there were damages to the spillway glacis due to heavy bed load the CFRD remained intact barring minor damages.

The specifications of the concrete face are as follows:

- Thickness of concrete face slab varied from 30 cm at top and 45 cm at the bottom
- Strength of concrete 25 N/mm2 at 28 days, 40 mm aggregate and 100 mm slump
- Reinforcement in each direction was specified as 0.35% of the concrete

## 5. TEESTA III HYDROELECTRIC PROJECT, SIKKIM, INDIA

Teesta III hydroelectric power project is located near Chungthang village in North district of Sikkim and harnesses the water from Teesta River to generate 1200 MWs of power. The site is located in Great Himalayas upstream of Main Central Thrust in Central crystalline consisting of hard gneiss with schist layers.

Teesta is the most important drainage system of Sikkim. The river rises at El 5280 m in the glaciated and snow bound Himalayas and actually forms by joining of two main tributaries the Lachen Chu and Lachaung Chu just 400 m upstream of dam site. The catchment area up to dam site is 2787 km$^2$ out of which 70% is snow bound. The diversion discharge is 1028 cumecs and flood discharge is 7000 cumecs.

During the feasibility stage a concrete gravity dam was proposed with huge excavation down to a depth of 50m. This quantity of 18 lac cum of excavation for the dam pit and associated structures and combined with 8 lac cum of concrete neither suited the site technically nor construction wise it could be economically scheduled and executed without major hiccups. Thus on techno economic considerations once again CFRD proved to be an appropriate choice where instead of deep excavation the foundation could be laid on river-fill material for the 60 m high dam. As done in Dhauliganga, plastic concrete diaphragm wall was provided for a maximum depth of 50m to socket into largely symmetrically underground bed rock profile.

## 5.1 Concrete Face Rock-fill Dam

The CFRD at Teesta III is 60m high with 1.5H:1V slope on either side. The spillway consists of two spillway tunnels of 10 m dia and 1.0 km length on left bank and two gated bays of 11x14m each as well. It also has an innovative 1 km long silt flushing tunnel of 5m dia on right bank close to the power tunnel intakes. The spillway bays, tunnels on left bank and SFT on right bank are designed to pass 7000 cumecs discharge. In Teesta III the diversion tunnel is not plugged and is also used a spillway tunnel. For plan and section of Teesta III CFRD Figures 3 and 4 may be referred.

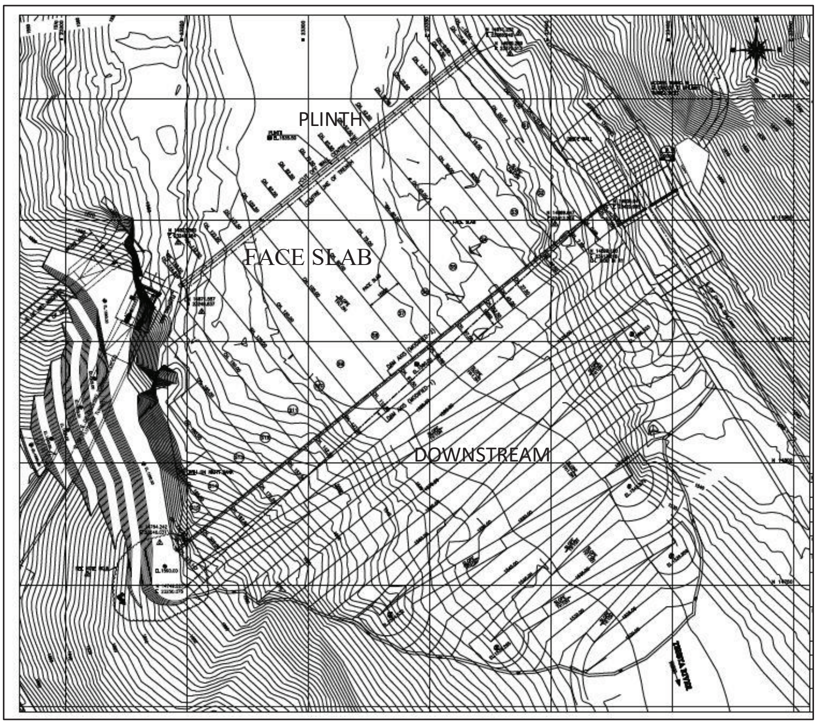

**Figure 3** : Teesta Hydropower Project Stage III : Layout of CFRD

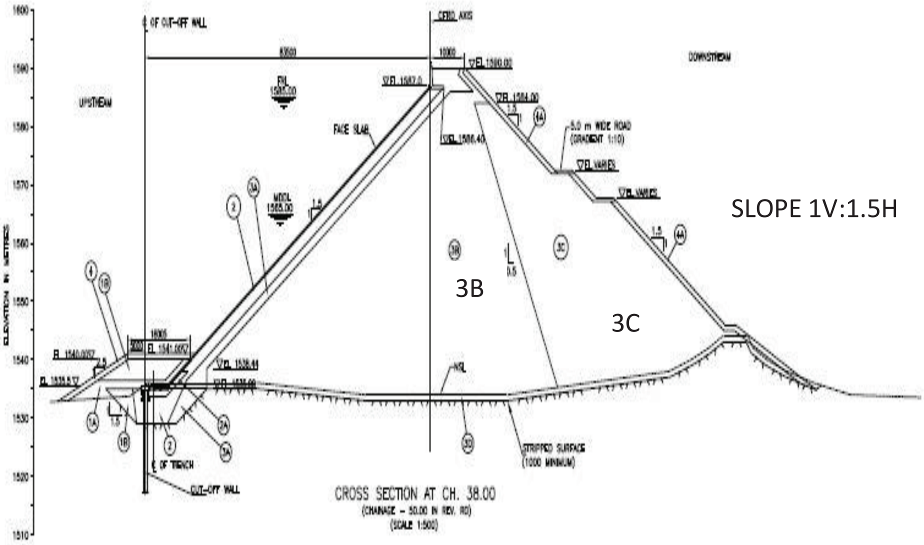

**Figure 4** : Teesta Project Stage III: CFRD Section

## 6. DHAP WATER SUPPLY PROJECT, NEPAL

Dhap Dam site is located near the famous tourist spot Chishapani about 40 km north of Kathmandu. It can be accessed by 20 km long all weather Kathmandu Sundarijal road and then by 21 km un-metalled road. The dam site is in Shivpuri hills at higher elevation and is in Shivpuri Nagarjuna national park. On the eastern side Sindhupalchok is present and on North Western side Nuwakotis present. Earlier a low dam was constructed by SNNP which is 350 m u/s of the dam site. A suitable site dam exists in lower reaches of Dhap valley where it narrows down. There is falter ground about 50m wide at the dam side with shallow streams flowing on either side near the banks.

Overall the proposed dam site is located within strongly metamorphosed basement rocks of the Higher Himalayan Tectonic Zone. Gneiss and schist are the two main rock types. Referring to "Engineering and Environmental Geological Map of the Kathmandu Valley", in scale 1:50000 published by DMG, Nepal at the dam site Precambrian Shivapuri Gneiss Formation is present.

The Main Central Thrust (MCT) is present 5km north to the dam site at Patibhanjyang saddle. The Chishpani region was impacted by 2015 earthquake which indicated that the area is seismically sensitive.

At the dam site the Pre-Cambrian Shivpuri Gneiss formation is manifesting with mica gneiss, banded gneiss and biotite schist rocks with intrusions of muscovite granite. The weathering effect is pronounced in the rock. The top layer of bed rock below the organic soil had developed into residual soil due to long effect of weathering.

The purpose of construction of Dhap dam is to boost water supply in Bagmati river and eventually to Kathmandu in dry season. The project is being constructed by Department of Water Resources and Engineering, Bagmati river basin, Nepal through Guangzhou-Lama-Raman JV for which design was carried out. The scheme consists of main CFRD dam at the mouth of the valley and a saddle dam at the north east corner.

### 6.1 Concrete Face Rock-fill Dam

The 24m high and 190 m long dam with crest elevation at 2090.14 m would impound a small stream having a catchment area of 0.8 km$^2$ and reservoir storage of 1 MCM of water. The u/s and d/s slope of dam are kept as 1V:1.7H and width at crest being 8m and free board of 3m. The dam volume is 1,04,758 m$^3$. The discharge being very small diversion was achieved through a pipe. The plan showing layout of dam is given in Figure 5.

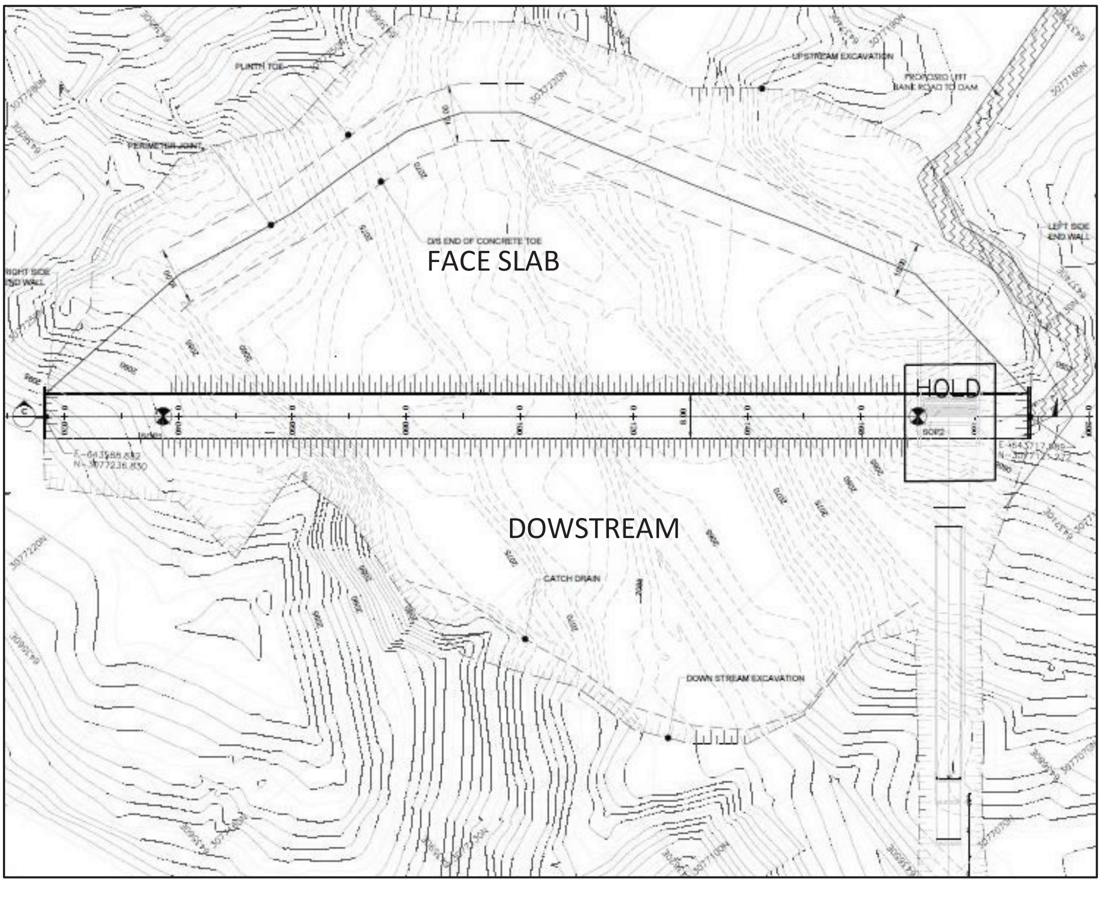

**Figure 5** : Dhap Water Supply Project: Layout of CFRD

The plinth has been kept on bed rock on the banks and is secured by anchors.

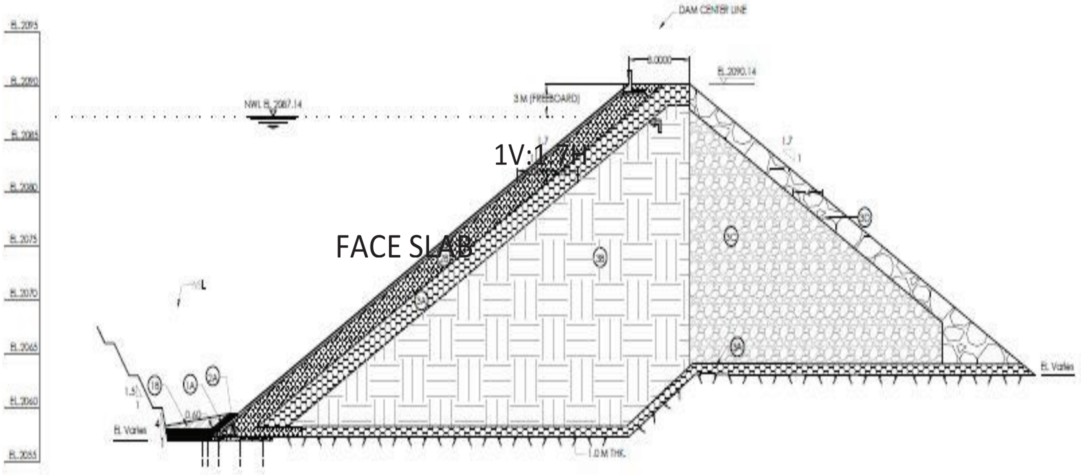

**Figure 6** : Dhap Project: CFRD Section

## 7. STUNG TASAL CFRD, CAMBODIA

Stung Tasal Dam is located in Aoral district in Kampong Sepu Province in Cambodia. It is included in overall development of Irrigation and drainage system and rehabilitation plan undertaken by Royal Government of Cambodia (RGC). Quite an extensive and detailed report on "Preparatory Survey for Irrigation and Drainage System Rehabilitation and Improvement Project in Kingdom of Cambodia" has been prepared by Japan International Cooperation Agency (JPIC) Nippon Koei Co Ltd for Ministry of Water Resources and Meteorology, RGC, The Kingdom of Cambodia. The climate and metrology, drainages, water availability in different basins and utilization through water resource projects for drinking, irrigation, tourism, fisheries and hydropower generation are discussed. In the southern central portion of the country the Stung Tasal dam is a part of 'The study on comprehensive agricultural development of PrekThnnot River Basin (Master Plan Study) 2005-08'. The site is in upper reaches on a Stung Tasal tributary of Prek Thnnot River. There are several projects in Prek Thnnot River basin out of which the Stung Tasal project was given high priority. It is being funded by Government of India for construction.

An agreement was signed in between MOWRAN, WAPCOS and Angelique International Limited (AIL) in Jan 2012.

As per feasibility report it was proposed to construct 21m high and 650m long rockfill dam across the Stung Tasal river to provide irrigation for an area of 10,000 ha. Besides, a hydropower station with an installed capacity of 750 KW at 60% load factor would be constructed about 70m d/s of the dam. The spillway was un-gated with a length of 90.5 m on the left bank, the inlet for irrigation sluices located on 20m long non overflow concrete section of right side of spillway and on left side of spillway power intake for penstocks would be housed on another 20m length of non-overflow concrete section. Benefits out of the scheme were (a) Irrigation for 10,000 ha, (b) electrical energy 4.0 million units and (c) flood moderation.

### 7.1 Concrete Face Rock-fill Dam

In the feasibility, a rock fill dam was envisaged but the investigations and testing revealed that suitable material for construction of rockfill dam was not available. The soil condition was found to be dispersive in the region due to which a concrete face rock fill dam was proposed. Finally the 21m high and 720m long CFRD was proposed and designed with two spillways and the same was completed in 2015 (Figure 7). The dam impounds water storage of 140 MCM. The project will immensely boost rice cultivation and fisheries in the region and would irrigate 10000 ha of area. It has been constructed with a line of credit of USD 30 million by Government of India.

The 720 m CFRD includes two spillways one in the middle of the river which is 45m wide with 3 bays and 3 under-sluices for irrigation discharges. The top of dam is at elevation 110.2m and the FRL is 108.2m. Another un-gated auxiliary spillway has been constructed on the left bank and the same is 30.5m wide with three bays and crest elevation of 108.2m.

The river valley at the dam site is U-shaped and wide but with well-defined banks. The river catchment up to the dam site is 465 sq km with an annual rainfall of raging from 3500 mm in the west to 1250mm in the east. The bed rocks at the dam site are quite heterogeneous with igneous, sedimentary and metamorphic rocks existing together. The strike of rocks is east-west with steep dips of 70 degrees. Some fractures are present within the formations but the left bank exhibited stronger rock conditions when compared to right bank. A shear zone was passing on the right bank.

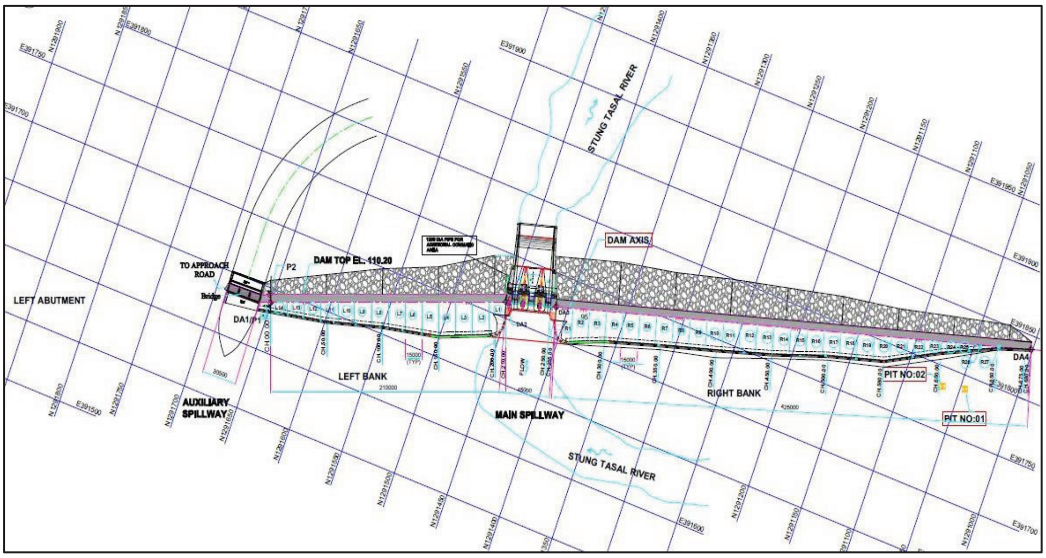

**Figure 7** : Stung Tasal Project: Plan of CFRD

The weaker bed rock conditions on the right bank were indicated by exploratory holes and found in the percussion drill holes carried out for grouting as well as in the excavation for plinth foundation on the right bank. At the upstream plinth, single row grout curtain has been placed extending down to 10m below the foundation level.

The main reason for the switch over to CFRD from conventional rockfill dam was that the material for clay core was not available. The impervious soil in the area was highly dispersive thus unsuitable for use in the impervious core.

Quartzite rock was used as rockfill and filter material which met the required specifications.

The face slab and plinth are of M25 grade concrete with the face slab being 250mm thick and underlain by 50mm thick M10 levelling concrete. The width of face slab panel is 15m.

A section of CFRD is given in Figure 8.

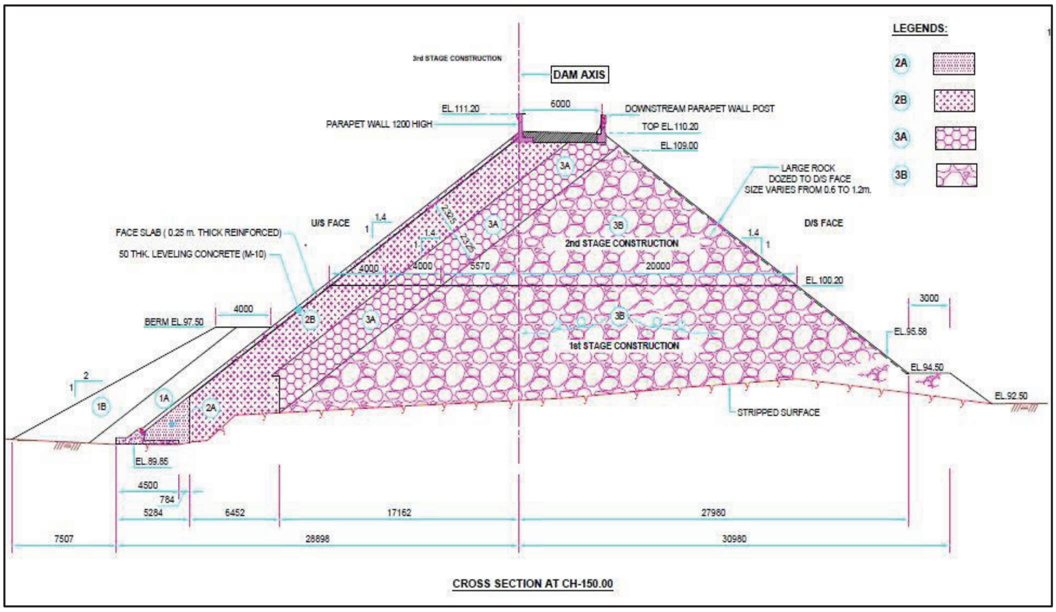

**Figure 8** : Stung Tasal Project: CFRD Section

## 8. CONCLUSIONS

The CFRD dams in spite of being so adaptable to site conditions and materials for use in construction are not so popular amongst the water resource projects. World over out of 25 tallest dams only two are concrete face rock-fill/embankment dams and out of 50 tallest dams five are CFRD. Nonetheless, under construction category out of all major dams over 150m height 23.1 % are CFRD, 34.6% Embankment type, 30.8% are Concrete gravity and 11.5% are Concrete arch dams. Therefore, the engineering community appears to be growing in confidence about utility of CFRD structures.

In India all the CFRDs viz Dhauliganga Stage I, Teesta Stage III and Kishanganga belong to hydropower sector and fourth Pakal Dul which is 167m high is also in hydropower sector. There seems to be a lack of confidence about CFRDs in the irrigation sector. They could become a popular choice in irrigation and water supply also provided some of the challenges are overcome.

Out of the four cases discussed above in growing economies there were some common difficulties such as expertise in slip form shuttering for face concrete. As Dhauliganga stage I was the first CFRD in India it took a long time for adapting this type of design and gain acceptability from the evaluating agencies. The CFRD here offered solutions for the non-availability of impervious core material for rockfill dam, and also for deep bedrock in the river bed. The CFRD dam concreting for face slab and plinth is a specialized work and the same was overcome by going for international bidding and experienced agency. In projects like Dhap and Stung Tasal the availability of skilled agencies was a problem. The slip form for concreting of face slab and plinth concreting even though a small activity remains a challenge area as many construction agencies are not comfortable with the same as they have not executed such type of projects. As the concrete face is executed in panels the joints with copper stops gain significance. By international competitive bidding these problems can be overcome. A certain amount of caution is required for placing the foundation of tall CFRDs on overburden. Higher dams above 120m or so have not been placed on overburden. In any case loose gravel material or soil should be removed even for CFRDs also.

In Teesta III and Dhauliganga Stage I transport of hydrofrase cutter for execution of cut-off wall was an issue due to arduous terrain, narrow roads, sharp curves and inadequate bridges. The compaction of the rockfill material also remains an issue along with intricate design details of plinth etc. In developing countries facilities for specialized testing are not available with result that evaluations of rockfill or gravel material for construction are based on concrete aggregate tests. Consequently, many technical people believe that suitable material is not available which may not be the case for CFRD construction material. Another challenge is suitable place for finding the spillway especially when large discharge capacities are necessary.

Even though the above difficulties are there, CFRDs are having certain advantages such as placement of foundation either in overburden or on bed rock. This however is subject to height of dam and local conditions. Speed of construction and use of locally available materials is another big advantage that makes them attractive and economic. More awareness regarding design and quality testing aspects is necessary to make them acceptable and popular.

All the four cases discussed in the paper have resulted in not only technical solutions but have been cost effective also. It is suggested that they should be adopted more in irrigation and water supply projects as well.

## REFERENCES

Asia Development Bank (2013): Bagmati River Basin Improvement Project: Drilling Works for Feasibility Study at the Dhap Dam Site. Initial Environmental Examination March 2013. https://www.adb.org/projects/documents/bagmati-river-basin-improvement- project-drilling-works-dhap-dam-iee.

Clarke, I.D. and Sen S.P. (1998) Preparing for Civil Works. Water Power and Dam Construction. https://www.waterpowermagazine.com.

Cruz, Paulo T. de, Materon Bayardo, Freitas Jr, Manoel De S. (2010): Concrete Face rockfill Dams: Taylor & Francis 406 pages.

Dandekar M.M. and Sharma K.N. (2013): Water Power Engineering, 2nd Edition. Vikas Publishing House, Noida, India.

Gupta R.K., and Agrawal R.K. (2016-17) Stung Tasal Dam Project Cambodia for Irrigation and Flood Management. India Water Week. https://indiawaterweek. thewaternetwork.com / document-XAs/ stung-tasal-dam-project-cambodia

ICOLD (2010), Concrete Face Rockfill Dams: Concepts for design and construction, Bulletin 141, International Commission on Large Dams, Paris.

ICOLD (2018) Cut offs for Dams, Bulletin No 150, International Commission on Large Dams, Paris.

Ingram, Elizabeth (2017): India commissions 1200 MW Teesta stage III hydropower project in Sikkim. https://www.hydroreview.com.

Japan International Cooperative Agency : Nippon Koei Co. Ltd., (2012); Preparatory Survey for Irrigation and Drainage System Rehabilitation and Improvement Project in Kingdom of Cambodia. https://www.jica.go.jp

Ojha, B K (2014): Teesta III Cut Off Wall. International Journal for Technological Research in Engineering. Vol. 1 (8) April 2014.

Poyry (1999): Dhauliganga Hydroelectric Scheme, Uttarakhand, India. https://www.poyry.com.

ICOLD (2018) Cut offs for Dams, Bulletin No 150, International Commission on Large Dams, Paris.