STRENGTHENING AND OPTIMIZATION OF GRAVITY DAMS

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This to certify that the thesis entitled " STRENGTHENING AND OPTIMISATION OF GRAVITY DAMS" being submitted by Mr.P.C. JOSE to Indian Institute of Tecnhology, Delhi, for the award of the degree of DOCTOR OF PHILOSOPHY is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the standard fulfilling the requirements for the award of the degree of Doctor of Philosophy. The research report and the results presented in the thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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(P.C. JOSE)

ABSTRACT

Because of the ever increasing demand for water, food and energy, the number and size of dams are growing. Many more dams are under planning especially in large mountainous regions of India. Gravity dam remains a very common type of dam since the earlier times of dam construction. Gravity dams are also indicated in various statistical studies as producing the smallest rate of failure incidents the world over. This is perhaps proof of the fact that among other factors, quality of design and construction of dams have considerably improved as also their ability to manage floods during construction and operation.

An important aspect in the design of gravity dams is its foundation. With the rapid pace of development for harnessing water resources for irrigation and generation of power, the ideally tailored sites have been virtually exhausted and using somewhat less favourable foundations has become inevitable. In India a number of dams are being constructed in Himalayan region and the Himalayan geology is still in a stage of transformation, with the result the foundation rock mass contains weaknesses such as joints, seams and layered strata with varying material properties. The complexity of rock mass is not a deterrant in building

dams at such sites, but the design and construction are conducted with suitable remedial measures for strengthening such foundation.

In this background, investigations were directed towards finding an economical solution for the problem of strengthening of gravity dams by studying the significance of certain inherent structural elements, that are present as part of the dam for certain other functional requirements and research work was started in that direction. Certain preliminary findings of this investigation (Jose et al 1989) had confirmed the practicability of the solution for strengthening of dams on weak foundations. The preliminary study showed that a concrete strut at the downstream toe of the dam improves the stress distribution at the base of the dam and also improves the stability factor along seams in the foundation.

The purpose of the present work was to examine the suitability of a concrete strut either at the upstream heel or at the downstream toe of the dam, as a strengthening element. In some of the dam designs, the strut is a natural element at the downstream toe as in the case of spillway blocks, power dam blocks supporting the penstocks etc. There are some other situations when the dam is constructed on a hillock to reduce rock excavations and the upstream and downstream face of the hillock are provided with concrete claddings to reduce foundation seepages.

For examining the suitability of concrete strut as strengthening element, dam-foundation system is analysed using Finite Element Method. For this purpose, a two dimensional FEM Computer Program FEDAM has been written. Serendipity quadratic eight noded rectangular elements have been used for stress analysis. Following loading conditions have been considered.

1. Self weight of dam
2. Hydrostatic pressure of water
3. Weight of Water
4. Uplift pressure
5. Silt pressure
6. Hydrodynamic pressure of water
7. Earthquake

Dynamic forces are however taken as quasistatic forces. These forces are simulated strictly using USBR and ISI codes of practice.

Considering the variability of rock mass properties, investigations are conducted for foundation rock condition such as homogeneous rock, stratified rock and jointed rock. In order to compare the results and to draw relative conclusions, same dam profile on dip slope rock foundation is considered for all these studies.

For dams founded on homogeneous rocks of varying elasticity, studies were done for three different type of materials for the rock. First with the rock modulus as 10% of concrete and second with the modulus of rock as 30% of the modulus of concrete and third with modulus of rock 500% of modulus of concrete. Effect of the strut was studied by considering the strut in four cases (i) without concrete strut (ii) concrete strut of 5m width on the downstream side (iii) concrete strut at the upstream heel (iv) concrete strut both at upstream and downstream side. The results show that the strut is very helpful as strengthening element if modulus of rock is low.

For dams founded on stratified foundation studies were done for three & four layer systems of rock stratification with a value of rock modulus increasing or decreasing from top to bottom strata. The elastic modulus of rock in all strata were kept at different values proportional to the elastic modulus of concrete. The results show that when top of the rock strata is of low modulus the introduction of strut at the toe of the dam is quite effective and it decreases the tension at the heel.

For dams founded on jointed rocks, studies were done for different locations and orientations of seams. For these studies rock modulus is considered as 30% of concrete modulus. Modulus of seam material was varied from 10% to 30% of that of rock. The orientation of seam was assumed as (i) horizontal (ii) inclined downstream. In general, it can be concluded that the concrete strut on the downstream toe of the dam is very effective in strengthening the dam founded on jointed rock, both from strength consideration and sliding factor considerations and weaker the material the more effective the concrete strut.

The present work has contributed to the identification of the concrete strut primarily at the toe of the dam (in some cases it could be at the heel also) in strengthening of concrete gravity dams founded on weak rocks. The effect is more pronounced for dipslope rock foundations.

After finding an economical solution for the problem of strengthening of gravity dams, a need was felt to find an economical profile of the gravity dam and to optimize the shape of the strut also. The classical method of dam design is mainly semi-empirical and has become a matter of practice over the years in many countries. The initial design of the dam is currently based on the USBR code of practice which stipulates the sliding safety of dam and also allowable stresses in the body of dam and foundation.

Optimal shape design using FEM is an emerging area. Now-a-days, finite element technique is not merely used as an analysis tool but it is used to optimize the shapes as well. The existing techniques for shape optimizations are good for small engineering structures but do not yield very good results for large engineering structures.

In the present thesis, a technique is proposed for the optimal shape designs of concrete gravity dams. This technique is quite simple to apply and yields accurate results. It can evolve the optimal shapes from the primitive rectangular or cylindrical blocks. So it is not merely a shape optimization technique which can modify the existing shapes but it can evolve the optimal shapes also. The technique is not restricted only to move inner or outer boundaries but it can create holes within the body and can subsequently optimize them. The program has the facility to delete the material as well as to add the material. For all shape optimal design studies bi-linear four noded rectangular element are used. For iterative solutions these elements take quite less computer time. For nodal recovery of stresses latest block technique has been used.

Optimization of solid gravity dams is done by optimizing the downstream profile of the dam for different height to width ratios of 1.0, 1.25, 1.43 and 1.66 and also for rigid foundations and weak foundations with a downstream dipslope. Optimization of the downstream profile was done consistent with safety factors and also subject to geometrical constraints. The effect of the concrete fillet at the upstream heel and downstream toe were also studied. The profile of the dam resting on downstream dipslope rock foundation is also optimized. Later on a strut is introduced at the toe and its profile is optimized.

Shape optimization of a hollow gravity dam is done by (i) optimizing the upstream and down-stream profiles (ii) by creating a hole in the low stress regions in the body of the dam and subsequently optimizing its boundary. Shape optimization was done for dams founded on rigid rocks and also for dams founded on weak rocks with a downstream dipslope. A fillet at the toe of the dam is created by the program by adding the material. Similarly, the shape of the strut at toe is also optimized.

From those studies it is concluded that the proposed technique for evolving the optimal shape designs is quite simple and accurate and can be applied to real engineering structures.

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