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Prestressed Aluminium Arch Dam

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Abstract

Arch dams provide elegant and economic solutions for dam sites where the valley contracts in plan and where the banks are composed of strong monolithic rock. To provide for a more economical structure and one which could be constructed much faster, a new design has been proposed called the Prestressed Aluminium Arch Dam.

The original concept developed from the fact that arch dams carry their load in compression though ideally, the more logical way of containing any liquid is by tension members. However, since rock is generally weak in tension, it was decided to use a structural system that would take advantage of the tensile membrane action, yet load the foundation in an optional manner in compression for the hydrostatic load. This was hoped to be achieved by constructing the wall from material having high tensile strength and high resistance to corrosion and then prestressing it so that stresses opposite to those originating from hydrostatic load are produced .

The new design presented comprises of a wall composed of horizontally curved multicellular box sections fabricated from structural aluminium alloy and prestressed with high tensile bolts. The bolts and wall section are anchored to anchorage blocks embedded in the banks.

The resulting approach led to a parabolic profile being chosen for the dam with the rise of the arch at the crest level kept at one fourth of the span length and with the wall axis being kept vertical. The principal loading criteria included: a) design of wall as a tensile arch in the reservoir empty condition and prestressed with a force that would produce half the equivalent water load, the stresses induced being predominantly tensile; b) in the final stage when reservoir is full the arch is designed as a conventional arch and the stresses are predominantly compressive. Thus at any stage the structure is effectively designed for only half the water load.

The more important steps in the design process included: fitting of parabolic arch profile to dam site; selecting suitable sections for the wall, foundations and anchorage's; making rigorous stress analysis both for static and dynamic load conditions; and making a model analysis.

The construction aspects briefly describe the various stages of construction viz. diverting of river; laying out the dam; excavation of foundations; construction of foundation/anchorage's; fabrication of aluminium alloy box girders; erecting, welding and prestressing them; installing service facilities; and instrumenting the dam.

As a practical design application an example is given of a 54.5 m high Prestressed Aluminium Arch Dam, for a site where the valley width at crest level is 66.67 m and base width is 12.12 m. The wall forming the body of the dam is made up of aluminium alloy box girders having depth at crest of 1.8 m and gradually increasing to 3.4 m at base. The height between horizontal diaphragms is 2 m and the vertical diaphragms are spaced at 4 m centres. Analysis is carried out for a typical 2 m high box girder at mid height having a parabolic profile of span length 47.92 m and rise of 8.05 m. The principal loading conditions considered are; as a tensile arch under prestressing load to produce an equivalent uniform load of half the hydrostatic load; and as a conventional arch under full hydrostatic load with a temperature variation of 8°C. The analysis is made using the simplified edge perturbation method of shell theory. For the various loading conditions, values of moment, hoop force and shear are evaluated. Based on these forces, the stresses in the various elements of the box girder are calculated. The structural aluminium alloy used is of grade 6061-T6 having an ultimate tensile strength of 294 MN/m^2. The allowable stress considered take into account the buckling factor and an assumed factor of safety of 1.85. For the sections selected, all stresses are shown to be within allowable limits. Based on the prestressing force, the number of high tensile bolts are calculated using steel having ultimate tensile strength of 1500 MN/m^2.

A design is given for a typical wedge shaped anchor block having maximum width of 6 m and embedded 5.25 m into hard granite rock. An analysis based on the failure of the rock wedge due to the prestressing force is made and the anchorage is shown to have an adequate factor of safety against the pull out force.

A preliminary idea of the economics of the new design is obtained by comparing its cost with that for a conventional concrete arch gravity dam using the same parameters of the site as indicated in the example. The main features of the dam are height 54.5 m, radii at top of crest 35.4 m; central angle 150°, thickness at crest 2.6 m and at base 10.13. The major quantities used for comparison are excavation, concrete, aluminim alloy and HT bolts. Based on the prevailing rates a cost advantage is clearly shown.

Other advantages indicated for the new design include: a) the use of aluminium alloy and HT bolts offers a much higher strength to weight ratio leading to significant advantages in transportation, handling, structural design and load bearing capacity; b) prestressing of aluminium wall permits balancing of water load leading to a more economical design; c) repetition of multi cellular boxes forming the body of the dam leads to optimal saving in construction cost and time; d) the wall is free from corrosion and hence maintenance cost are greatly reduced; e) the hollow passages within the dam, lead to better conditions of heat release, creating favourable thermal conditions; f) savings in substructure cost because of substantial reduction of dead weight; g) modern welding processes permit leaking joints to be more easily repaired; h) the cavities in the multi-cellular box construction serve as excellent inspection galleries, permitting the entire face of the dam to be monitored; i) the parabolic arch profile permits of a more gentle arch abutment conjugation and j) the dam has exceptional grace and beauty and neatly expresses its function.

It is concluded that innovative design and modern materials of construction can be used to create a dam type that will be a viable alternative to concrete arch dams.