Paper No. 128, Bulletin I. S. E. T., Vol. 9, No. 4, December 1972, pp. 129-140

BEHAVIOUR OF CYLINDRICAL ARCH DAMS WITH VARYING GEOMETRICAL PARAMETERS

A. R. CHANDRASEKARAN* AND R. K. GUPTA**

INTRODUCTION

Arch dams are increasingly being constructed as better techniques are now available for their analysis and design. Arch dams are built in seismic zones as well as in valleys having not very good abutments.

For the purpose of analysis, the dam has been treated as an assemblage of flat finite elements(1). The stresses obtained would be somewhat approximate as compared to the use of more refined finite elements(2) but the analysis would be adequate for a relative comparison of the influence of various parameters.

In moderate seismic zone, it is conventional to check the design for a horizotal seismic acceleration of the order of 0.10g. Stresses due to these equivalent lateral load have been obtained and compared with static stresses. It is seen that these dynamic stresses are small compared to that of static stresses.

Though V shaped valley is ideal for arch dams, they can be constructed in other shapes including the extreme case of U shaped valleys. Stresses have been obtained for different ratios of crest length to base width.

The radius of the cylindrical arch influences the stresses. This has been varied. The thickness of the dam were varied both in the vertical as well as the horizontal direction.

DESCRIPTION OF DATA

The geometric details of a typical singly curved cylindrical arch dam was as follows : height 99 ft., thickness 10ft., radius 150 feet, central angle 106°, crest length 264 ft., and base width 114 feet. These dimensions nearly correspond to that of an actual profile of a dam(1). The geometrical parameters have been varied in the range of the above values as given below.

Variation of Base Width to Crest Length Ratio

Three different ratios have been considered keeping the other parameters constant. The details of different parmeters are given below.

(i)	Type of dam	—Singly curved. constant thickness. cylindrical arch.
(ii)	Height	—99 ft.
(iii)	Thickness	—10 ft.
(iv)	Radius	—150 ft.
(v)	Central Angle	—106°
(vi)	Crest length	—264 ft.
(vii)	Base width to crest length ratio	—(a) 0.432 (b) 0.379 (c) 0.333

---

* Professor } School of Research and Training in Earthquake Engineering, University of
** Lecturer } Roorkee, Roorkee.

Variation of Central Angle

Three different central angles with constant crest length have been considered. Details of parameters are given below:

(i) Type of Dam —Single curved. constant thickness. cylindrical arch.
(ii) Height —99 ft.
(iii) Thickness —10 ft.
(iv) Crest length —264 ft.
(v) Base width —114 ft.
(vi) Radius —(a) 150 ft.
  (b) 175 ft.
  (c) 200 ft.
(vii) Corresponding central angle —(a) 106°
  (b) 92°
  (c) 80°

Variation of Height

Three different cases have been considered with the following parameters:

(i) Type of Dam —Single curved. constant thickness. cylindrical arch.
(ii) Thickness —10 ft.
(iii) Radius —150 ft.
(iv) Crest length —264 ft.
(v) Base width —114 ft.
(vi) Central angle —106°
(vii) Height —(a) 99 ft.
  (b) 120 ft.
  (c) 135 ft.

Variation of Thickness in Horizontal Direction

Three cases with different thicknesses in horizontal direction have been considered. The details of parameters are given below.

(i) Type of dam —Singly curved. cylindrical arch.
(ii) Height — 99 ft.
(iii) Radius —150 ft.
(iv) Central Angle —106°
(v) Crest length —264 ft.
(vi) Base width —114 ft.
(vii) Thickness —(a) Constant thickness throughout.
  (b) Thickness increases gradually towards abutments with 1 : 20 slope.
  (c) Thickness increases gradually towards abutments with 1 : 15 slope.

Variation of Thickness in Vertical Direction

Three cases have been considered with different thicknesses in vertical direction. The details of parameters are given below:

(i) Type of Dam	—Singly curved cylindrical Arch
(ii) Height	— 99 ft.
(iii) Radius	—150 ft.
(iv) Central Angle	—106°
(v) Crest length	—264 ft.
(vi) Base width	—114 ft.
(vii) Thickness	—(a) Constant thickness throughout. (b) Thickness increases gradually towards base with 1 : 16.5 slope keeping water face vertical. (c) Thickness increases gradually towards base with 1 : 11 slope keeping water face vertical.

The other assumptions regarding the material and loads are as follows:—Modulus of elasticity of the material $=2.6\times10^6$ psi, Poisson's ratio—0.2, unit weight—62 4 lbs/cft. Density—144 lbs/cft. The level of water in the reservoir is assumed to be at the top of the dam. For determination of static stresses, load due to self weight and hydro-static load has been considered. Earthquake loads have been assumed to be represented by an equivalent horizontal acceleration of 0.10g applied on the mass of the dam in the direction upstream to downstream.

RESULTS

The dam has been idealised as an assemblage of flat rectangular elements. Two networks—one coarse and the other fine as shown in fig. 1(a) and 1(b) have been used in the analysis. The details of the stiffness matrix, mass matrix, stress matrix and the technique adopted for the solution are given in reference 3.

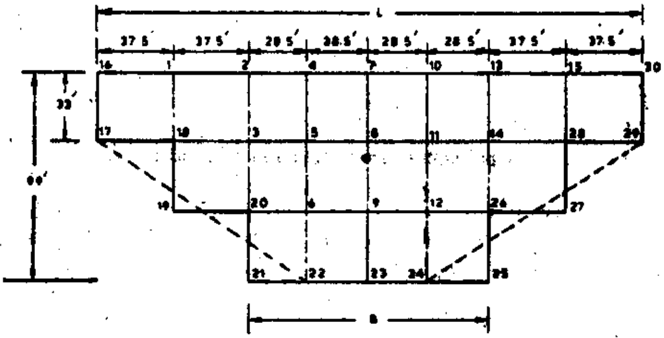

Fig. 1a.

In the region of the sloping valley sides, a stepped boundary has been used (as shown in fig. 1) in the developed surface of the air face of the dam with the real valley profile shown by dashed line. In the case where the thickness varies horizontally, vertically or in both directions, it has been assumed that the dam is an assemblage of finite elements of various thickness and the thickness for each element is taken as the mean thickness of the element.

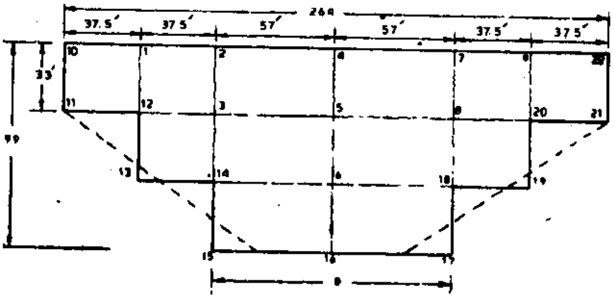

Fig. 1b.

Figure 2 shows a comparison between the results of a coarse and fine mesh. The two cases nearly give same values for deflection whereas stresses are somewhat different. The finer mesh results would be more close to actual values.

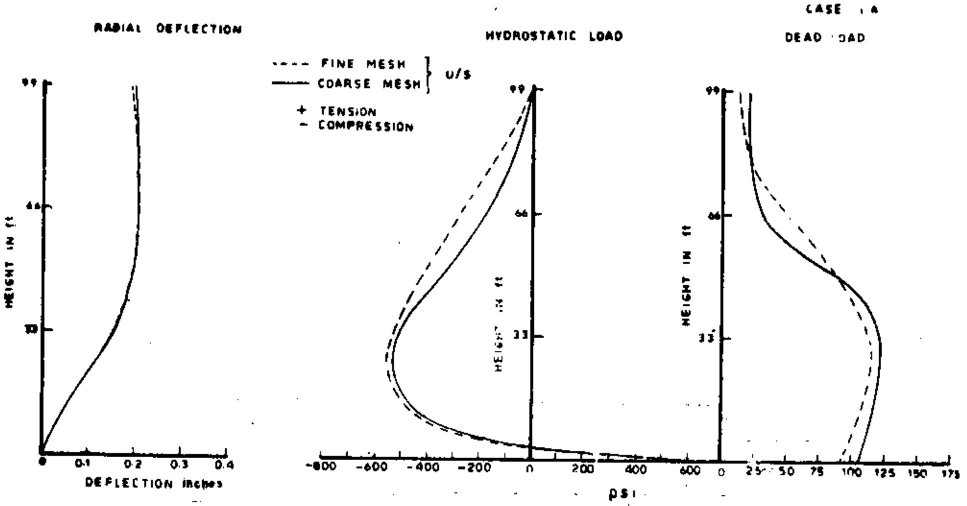

Fig. 2. Comparision of Deflection and Vertical Stresses

Figure 3 shows the total stresses due to dead load, hydrostatic load and a lateral seismic type load. It is seen that the increment in stresses over static stresses due to a uniform seismic coefficient of 0.10g is rather small. This is mainly due to the mass of the dam being small in arch dams as compared to gravity dams. In moderate seismic zones with good foundations, earthquakes would not pose a problem in the design of arch dams.

STATIC ANALYSIS

Deflections

Figure 4 shows the radial deflections of central cantilever due to hydro-static load for different cases. The following conclusions can be made.

(a) As the base width to crest length ratio decreases, the maximum deflections which occur near about 0.6 height, decrease.

(b) As the radius increases or central angle decreases, the deflections increase.

(c) As the height increases without any change in the thickness, the deflections increase.

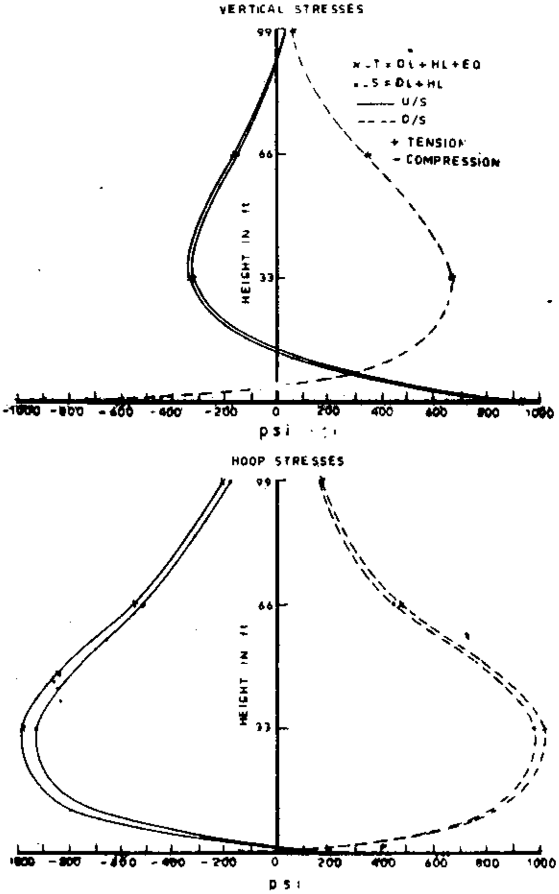

Fig. 3. Combined Stresses

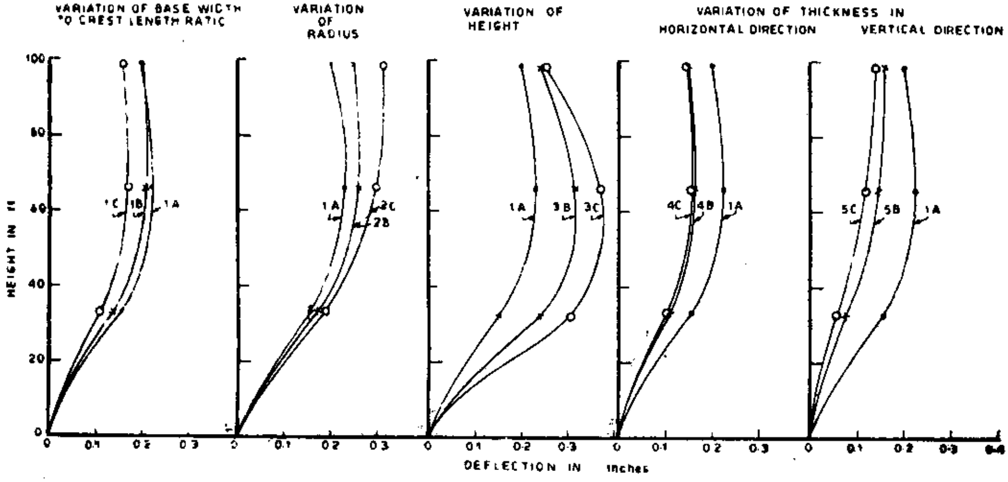

Fig. 4. Radial Deflecton of Central Cantilever due to Hydrostatic Load

(d) As thickness increases horizontally from the centre towards the abutments, the deflections decrease.

(e) As the thickness increases vertically towards base, the deflection decreases.

Vertical Stresses due to Hydrostatic Load

Figure 5 shows the vertical stress distribution due to hydrostatic load on the central cantilever on upstream and downstream sides for the different cases. The following conclusions can be made.

(a) As the base width to crest length ratio decreases, the compressive and tensile stresses on both the faces go on reducing.

(b) As the radius of the dam increases, the compressive and tensile stress on both the faces increases.

(c) As the height of the dam increases, the compressive and tensile stress on both the faces increases.

(d) As the thickness of the dam increases horizontally towards the abutments, the compressive and tensile stress on both sides increases.

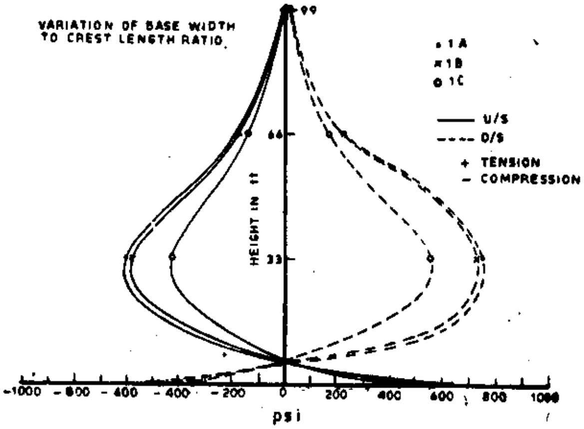

Fig. 5a.

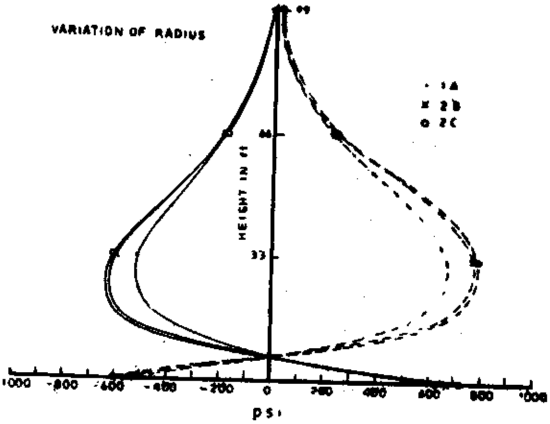

Fig. 5b. Vertical Stresses due to Water Load

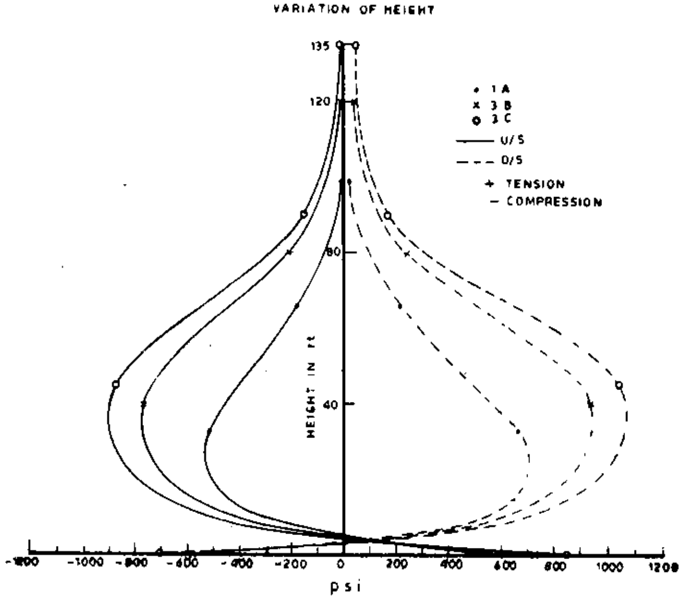

Fig. 5c. Vertical Stresses due to Water Load

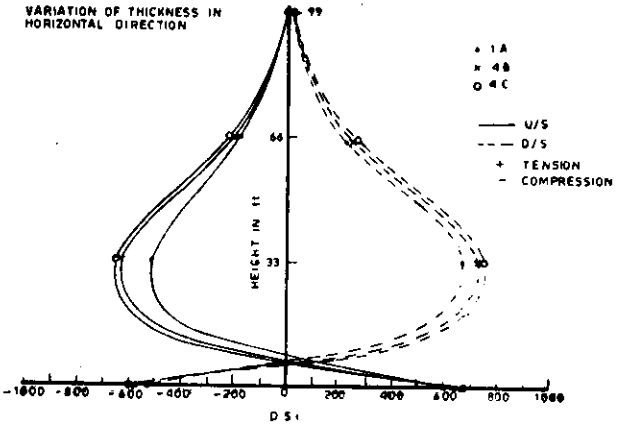

Fig. 5d.

(e) As the thickness of the dam increases vertically towards the base, on upstream face the tensile stress increases and compressive stress reduces while on downstream face the compressive stress increases and tensile stress reduces.

Hoop-Stresses due to Hydrostatic Load

Figure 6 shows the distribution of hoop stresses due to hydrostatic load on the central cantilever on upstream face for different cases. From the results it has been concluded that the hoop stresses go on increasing in all the five cases considered.

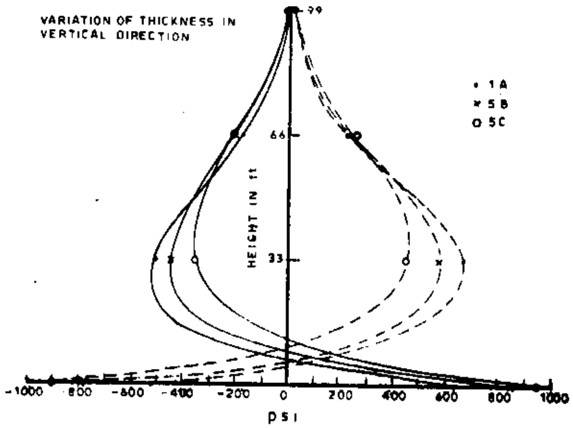

Fig. 5e. Vertical Stresses due to water Load

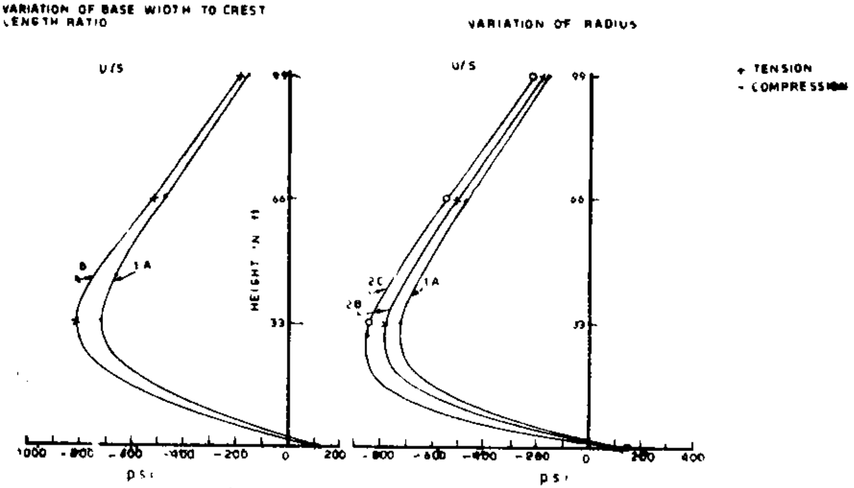

Fig. 6a. Hoop Stresses due to water Load

Vertical Stresses due to Dead Load

Figure 7 shows the vertical stress distribution due to dead load on the central cantilever on the upstream and downstream sides for the different cases. The following conclusions can be made.

(a) As the base width to crest length ratio decreases, the stresses go on reducing on both the faces.

(b) As the radius increases, there is no marked variation of stresses on upstream side while on downstream side the stresses go on reducing slowly.

(c) As the height increases, the stresses on both the faces go on increasing.

(d) As the thickness increases horizontally or vertically, the stress on both faces reduces.

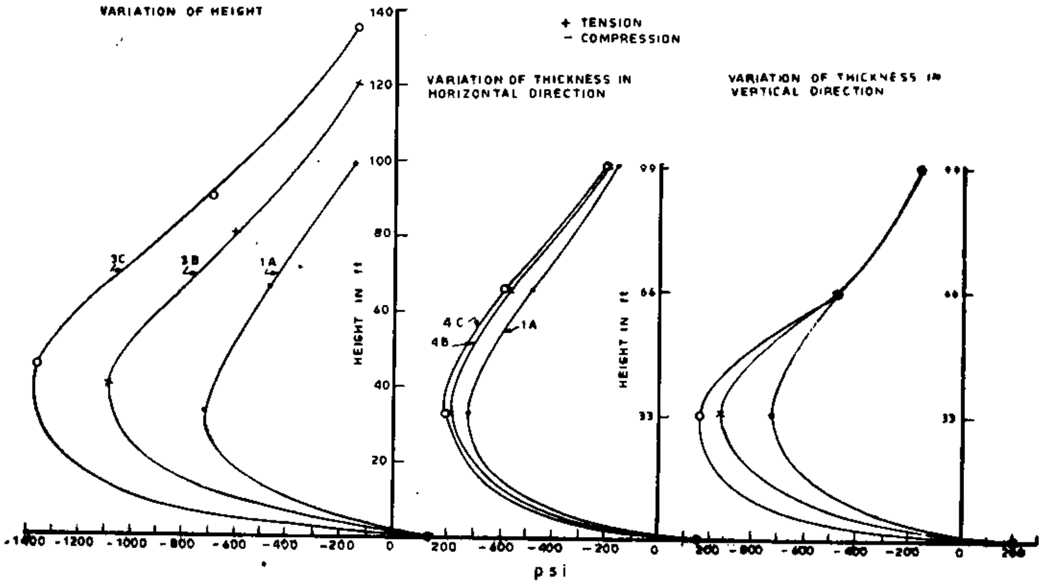

Fig. 6b. Hoop Stresses due to Water Load

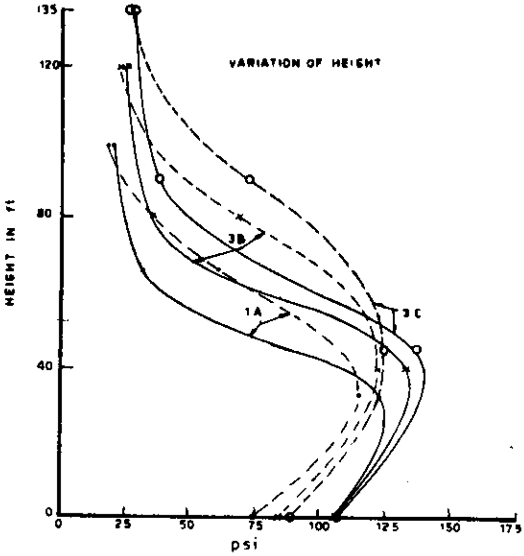

Fig. 7a. Vertical Stresses Due to Dead Load

Hoop-Stresses due to Dead Load

Figure 8 shows the hoop stress variation for different cases on upstream and downstream sides on central cantilever. The following can be concluded.

(a) As the base width to crest length ratio decreases,

  (i) On the upstream face the tensile stress in the lower third region increases slightly.

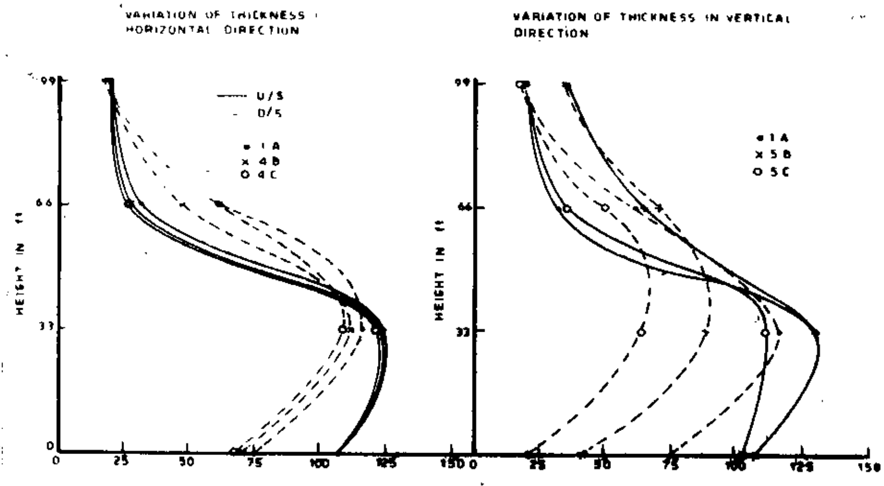

Fig. 7b. Vertical Stresses Due to Dead Load

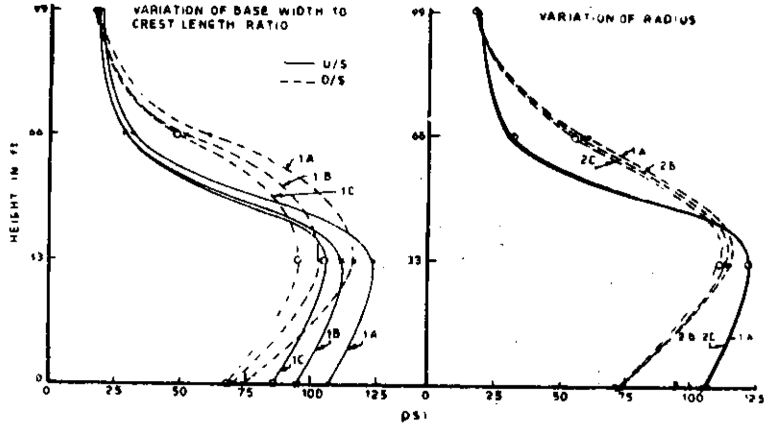

Fig. 7c.

(ii) The compressive stress in the middle third region increases, and

(iii) The compressive stress in the top third region decreases, while on the downstream face the tensile stresses occur and go on decreasing.

(b) As the radius increases the stresses go on reducing slowly on both the faces.

(c) As the height increases, the maximum stresses go on increasing on both faces.

(d) As thickness increases in horizontal direction, the stresses go on increasing on both faces.

(e) As the thickness of the dam increases vertically, the maximum stress reduces on both the sides.

ACKNOWLEDGEMENT

The authors are thankful to Dr. S. S. Saini for useful discussions.

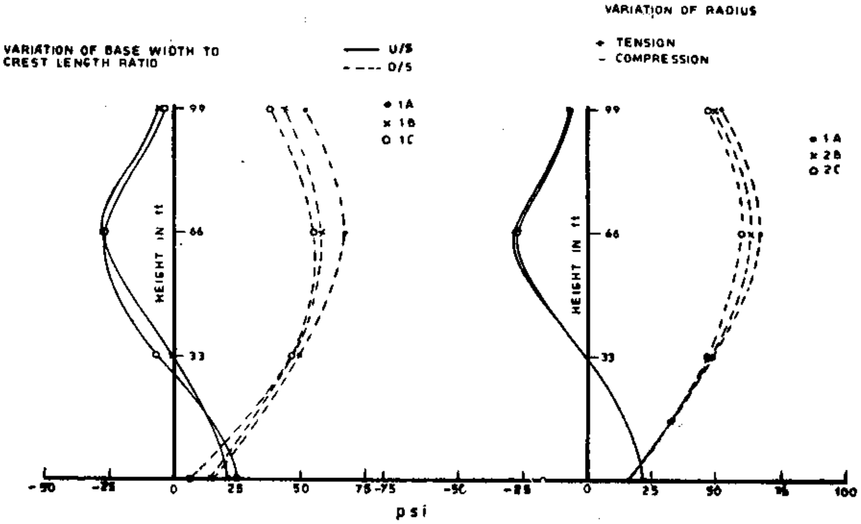

Fig. 8a. Hoop Stresses Due to Dead Load

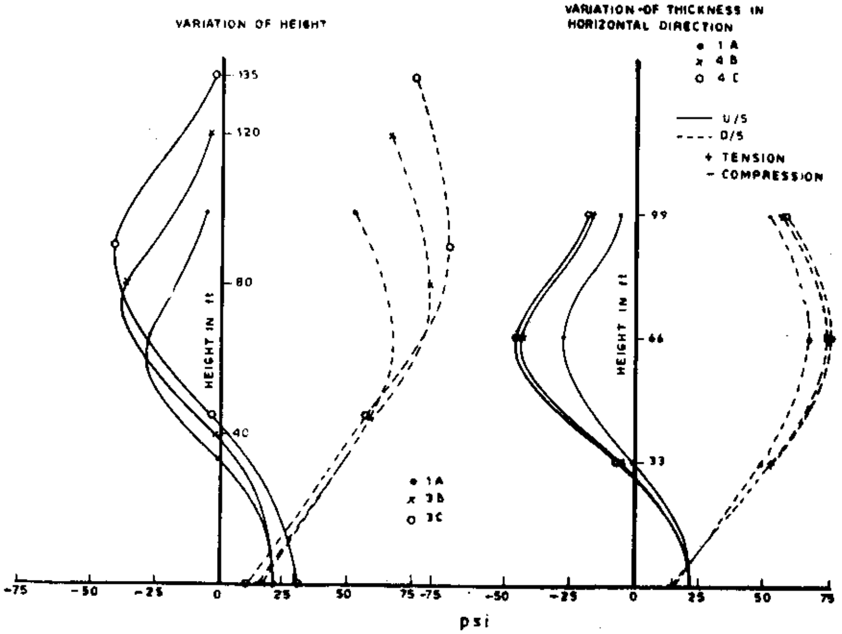

Fig. 8b. Hoop Stresses Due to Dead Load

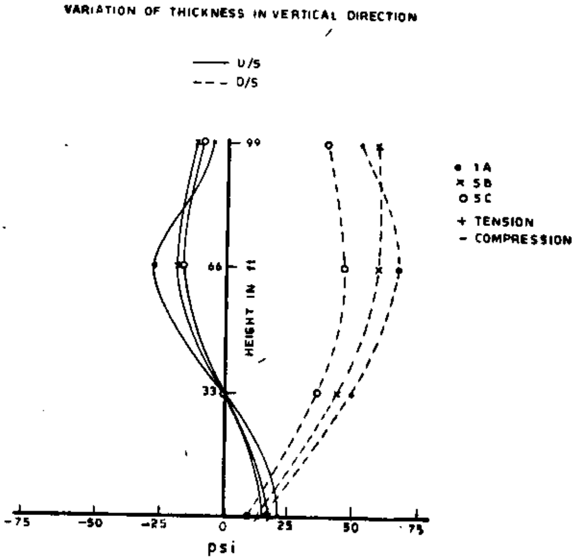

Fig. 8c. Hoop Stresses Due to Dead Load

REFERENCES

1 Rydzewski, J. R., "Theory of Arch Dams", The International Symposium held at Southampton University, April 1964.

2. Ahmed S, "Curved finite Elements in the Analysis of Solid Shell and Plate Structures", Ph. D. Thesis, Division of Civil Engineering, University College of Swansea, Wales, April, 1969.

3. Gupta, R. K., "Behaviour of Arch Dams Under Static and Dynamic Loads", M. E. Thesis, University of Roorkee, Roorkee, Sept., 1972.