Finite Element Analysis of Rockfill Tehri Dam

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Abstract- *Paper deals with the study of method for analyzing the 2-D plane strain behavior of rockfill dam systems using the F.E.M. has been presented. The F.E. concept is utilized to develop a static plane strain analysis technique.*

Keywords - *Rockfill Dam, Theory of Elasticity & F.E.M., FORTRAN-77 FEA Software.*

I. INTRODUCTION

A. General

A Rockfill dam is a type of embankment dam which comprises primarily compacted rock materials. Shaped much like a bank or hill, rockfill dams are effective because the force of the river or reservoir hits the core of the embankment, is exerted in a downward direction, and transferred to the solid foundation of the dam. The proposed project is concern with plain strain2-D analysis. Following are its silent features

1. The objective of the present study is to estimate the displacements & Stresses for single as well as sequential stage analysis of rockfill dam.
2. By considering sequential analysis, the element of idealized system the equilibrium equation are formulated & solved by employing powerful FRONTAL solution technique. The technique is solves by principal of Gauss Elimination. The actual solution is achieved by substituting the boundary condition in formulated equations of equilibrium.
3. The solution in step 2 provides information regarding the displacement suffered by the idealized system & the same in utilized for evaluating strains &stresses at the controlling points of element, which is then transformed into the Nodal Displacements, Elemental Strains & Elemental Stresses. This is achieved directly through assume averaging technique.

Conversional Design of a concrete gravity dam is undertaken through self-weight of dam only.

Plane strain static analyses have been conducted by adopting in 2-D applications. All this stages could be taken care of through plane strain finite element analysis. The Proposed work employees a finite element solution technique for analysis of Tehri rockfill dam. In this specific emphasis is given to 2D static analysis consideration.

In this paper, the finite element methodology for the plane strain analysis is discussed. For this the three elements of 4-nodded plane quadrilateral element are considered. Construction of Tehri Dam- Study of Forces and Geological Aspects as shown in Fig. 1 &Fig.2

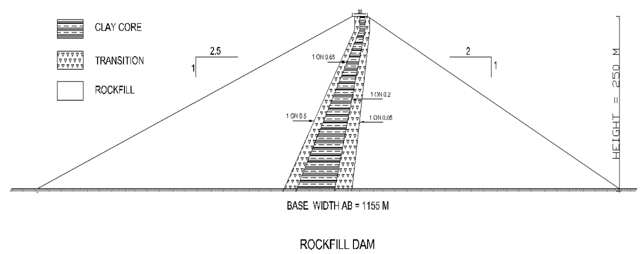


Fig. 1.Cross-section of RockfillTehri Dam (Material & Dimensions)

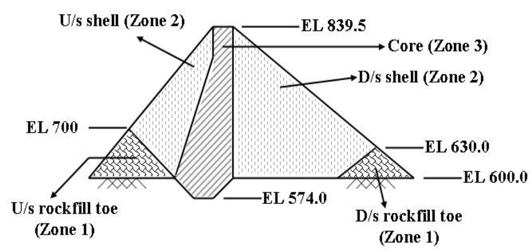


Fig. 2.Cross-section of RockfillTehri Dam (Zone)

II. FINITE ELEMENT METHODOLOGY

Finite element analysis steps:-

1. Finite element idealization of the system being analyzed.
2. Formulation & solution of equation governing equilibrium of the idealized system
3. Evaluation of structural response of idealized system

Element Characteristics:

In this section, we shall discuss the development of $[K_e]$ and $[F_e]$ of the plane quadrilateral element, $[F_e]$ being derived for the body force prevailing over the element.

Parent Element Characteristics:-

For numerical integration of the integrals defining $[K_e]$ and $[F_e]$, we shall employ (2x2) Gauss integration scheme. In this connection, following details are presented.

a) Gauss Point (ξ, η) Co ordinates
b) Values of the interpolation function ($N1$, N_2, N_3&$N4$) at the Gauss Point Locations.
c) Values of the derivatives ($\partial N_i / \partial \xi$, $\partial N_i / \partial \eta$) at the Gauss Point location.

Strain Vectors:

At a point over the element domain, prevail their three components of strain. These are explained in the following:

ε_x = Normal strain in x-direction
ε_y = Normal strain in y-direction
γ_{xy} = Shear strain in (x-y) or (y-x) plane

These components are represented by strain vector [ε]; and the same are related to (u, v) as defined in equation below:

ε_x	$\partial u/\partial x$
ε_y	$\partial v/\partial y$
γ_{xy}	$(\partial u/\partial x) + (\partial v/\partial y)$

$[\varepsilon] = [B]\,[\delta_e]$
Where, [B] is the Element Strain Matrix.

Element Strain Matrix [B]:-

The coefficients (∂Ni/∂x, ∂Ni/∂y) present in the element strain matrix [B] which is cannot be directly evaluated, because Ni's are function of (ξ, η). Hence the chain rule of partial differentiation could be applied for deriving (∂Ni/∂x, ∂Ni/∂y). The details are as follows.

$$\frac{\partial N1}{\partial \xi} = \frac{\partial N1}{\partial x} \cdot \frac{\partial x}{\partial \xi} + \frac{\partial N1}{\partial y} \cdot \frac{\partial y}{\partial \xi}$$

$$\frac{\partial N1}{\partial \eta} = \frac{\partial N1}{\partial x} \cdot \frac{\partial x}{\partial \eta} + \frac{\partial N1}{\partial y} \frac{\partial y}{\partial \eta}$$

Following are the details of the [B] matrix, a sub vector $[B]_i$ is defined as shown below:

$[B]_i$ =Eq. (3.6)

With the [B] matrix is as defined in Eq. (3.7)

$[B]_i$ =Eq.

$[N]_1$	$[N]_2$	$[N]_3$	$[N]_4$

(3.7)

Stress Vectors:

At the point over the element domain prevail their three components of stresses. These are:

σ_x = Normal stress in x-direction
σ_y = Normal stress in y-direction
τ_{xy} = Shear stress in (x-y) or (y-x) plane

These components are represented by stress vectors [σ] as indicated below:

[σ] =

σ_x
σ_y
τ_{xy}

Eq. (3.8)

Assuming the material of the element to be heterogeneous, isotropic and elastic, the vectors [σ] and [ε] are inter-related through Hooke's law, as defined in Eq. below:

$[\sigma]=[C]\,[\varepsilon]$
$[\sigma]=[C]\,[B]\,[\delta_e]$ Eq. (3.9)

Where, [C] is the Elastic Coefficients Matrix, as shown below:

[C] =Eq.

C_1	C_2	0
C_2	C_1	0
0	0	C_3

(3.10)

Let E be the Modulus of Elasticity.
υ be the Poisson's ratio.
G be the Shear Modulus

$$C1 = \frac{E(1-\upsilon)}{(1+\upsilon)(1-2\upsilon)}\ ; C2 = \frac{E\upsilon}{(1+\upsilon)(1-2\upsilon)}\ ; C3 = G = \frac{E}{2(1+\upsilon)} \quad \text{Eq. (3.11)}$$

Element Stiffness Matrix $[K_e]$:

Employing the principles of virtual work, we could prove that:

$$[K_e] = \iint [B]^T\,[C]\,[B]\,dx\,dy$$
$$= \iint J^*\,[B]^T\,[C]\,[B]\,d\xi\,d\eta$$
Eq. (3.12)

Element Load Vector due to body force [F_e]:

Let p_x / unit volume be body force intensity in 'x' direction.
p_y / unit volume be body force intensity in 'y' direction.
The vector [p] defining us body force intensities is as defined in Eq.3.13

$$[Fe] = \int\int [N]\,[P]\,dx\,dy$$
$$[Fe] = \int\int J^*\,[N]^T\,[P]\,dx\,dy$$

$$[p] = \begin{bmatrix} p_x \\ p_y \end{bmatrix} \qquad \text{Eq. (3.13)}$$

$$\begin{bmatrix} u \\ v \end{bmatrix} = [N]\ [\delta_e] \qquad \text{Eq. (3.14)}$$

Where, [N] is the interpolation function matrices as shown in Eq. 3.15

$$[N]_i = \text{Eq.} \begin{bmatrix} [B]_1 & [B]_2 & [B]_3 & [B]_4 \end{bmatrix} \quad (3.15)$$

So that the sub vector [N]i is given by;

$$[N]_i = \begin{bmatrix} N_1 & 0 \\ 0 & N_2 \end{bmatrix} \qquad \text{Eq. (3.16)}$$

The node numbers & nodal coordinated are in the accompanying with a view to demonstrate the complete solution procedure, the single element stage & sequential layered stage is treated as an idealized structure. The solution aims at deriving the complete structural response, against the influence of the self-weight of the element.

III. MODELLING AND ANALYSIS

1. The finite element idealization is achieved by employing 4-nodded quadrilateral element as per requirements. These elements are isoperimetric element having C0-continuity.
2. The cross section of Rockfill (Tehri) Dam is divided into finite element model with 500 elements and 546 nodes, in 25 layers having 10 m elevation of each layer, as shown in fig. 3.

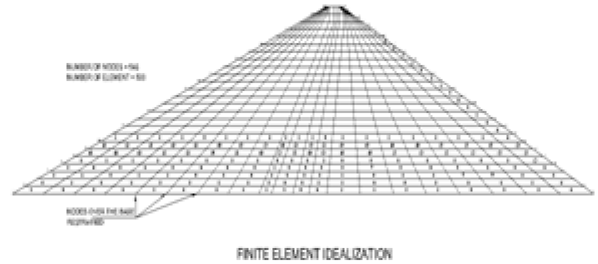


Fig. 3. Idealization of Rockfill Tehri Dam (Zone)

Number of nodes = 546
Number of Elements = 500
Number of layers = 25
Boundary Nodes = 21

Data For Idealizations:

A) Material Property:

No.	ZONE	E (Ton / m^2)	μ	γ_g (Ton / m^3)
1	Core	5000	0.48	1.8
2	Transition	30000	0.43	1.99
3	Rockfill Shell	25000	0.43	1.96

B) Idealization of Rockfill (Tehri) Dam:-

The cross section of Rockfill (Tehri) Dam is divided into finite element model with 500 elements and 546 nodes, in 25 layers having 10 m elevation of each layer, as shown in figure 4.1.

C) Boundary conditions:-

By the way of boundary condition the base nodes i.e. node no. 1 to 21 are restrained in both x and y directions.

U_1=0.00 U_2=0.00…………….. U_{21}=0.00
V_1=0.00 V_2=0.00…………….. V_{21}=0.00

IV.RESULTS

As per the details of the layers given above the sequential analysis is conducted for the layers being taken up 1 to 25.

It is conventional practice to consider in the analysis the dam as whole. Therefore, for the sake of comparison of the response details for such single stage analysis is also conducted.

While reporting the results the single stage analysis is referred to as case 1 and the sequential layered analysis is referred to as case 2.

Nodal Displacements:-

Estimation of permanent displacements of the Tehri dam in the Himalayas due to self-weight of dam for two different cases are shown below:

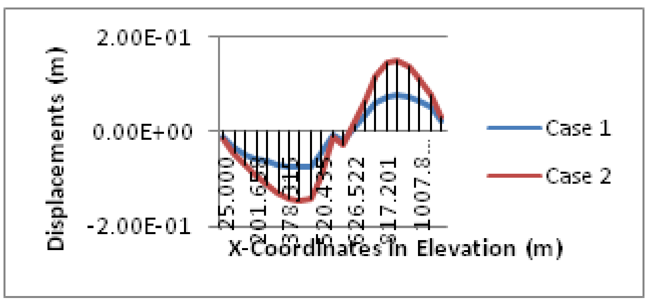
Case 1: Single Stage analysis consider dam as one single body

Case 2: Sequential analysis considers dam constructed as in layer by layer.

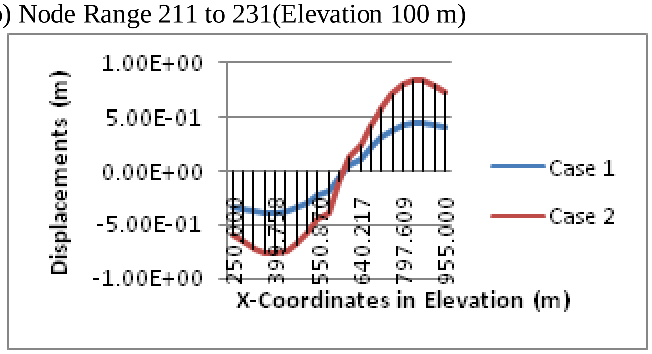
Details of the displacement components (U, V) are presented graphically as shown below:

Comparison for Horizontal Displacements (U) for Case 1 &Case 2:-

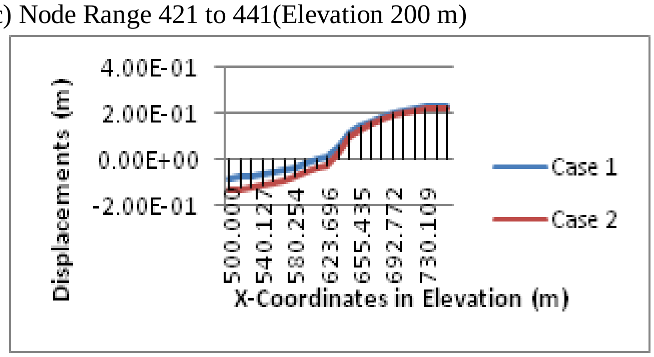
a) Node Range 22 to 42(Elevation 10 m)



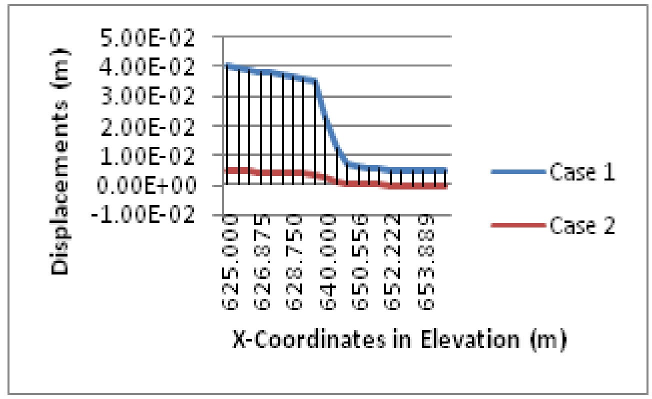
b) Node Range 211 to 231(Elevation 100 m)



c) Node Range 421 to 441(Elevation 200 m)

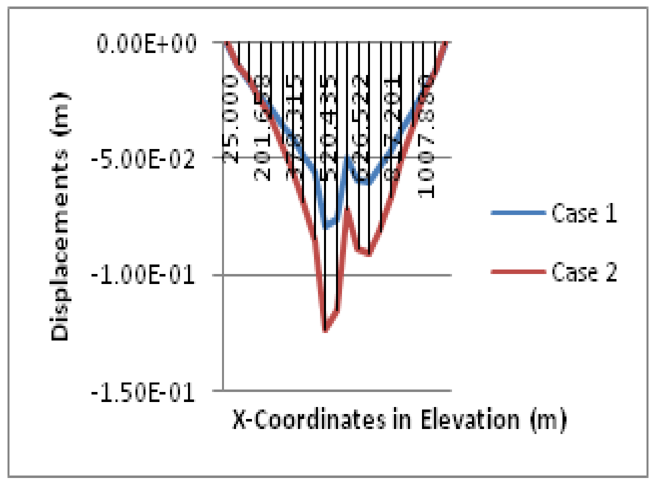


d) Node Range 526 to 546(Elevation 250 m)

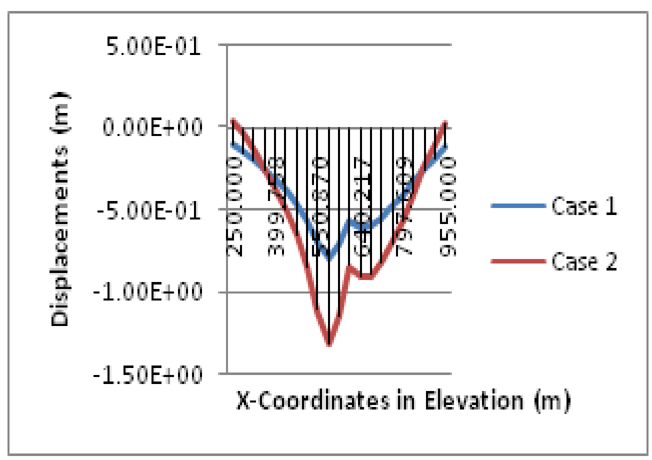


Comparison for Vertical Displacements (V) for Case 1 &Case 2:-

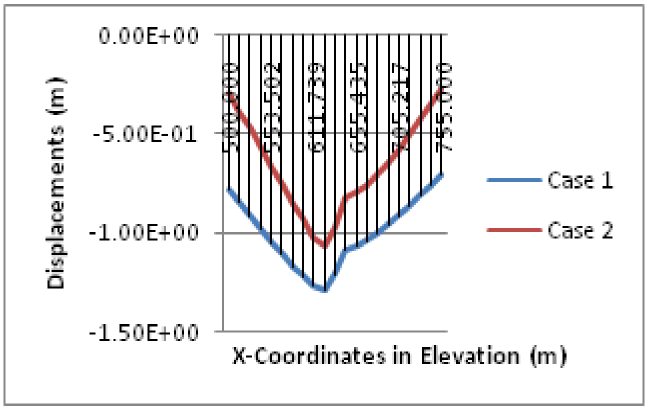
a) Node Range 22 to 42(Elevation 10 m)



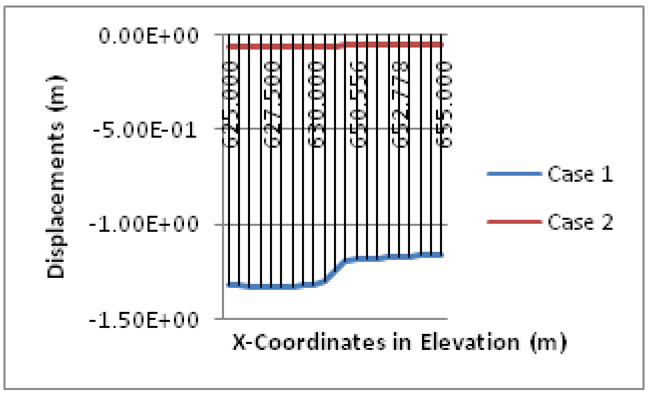
b) Node Range 211 to 231(Elevation 100 m)



c) Node Range 421 to 441(Elevation 200 m)



d) Node Range 526 to 546(Elevation 250 m)



IV. CONCLUSION

It may be observed that up to around 190 m to 200 m height, the displacements for sequential analysis are larger than the once derived for the single stage analysis. Subsequently the trend changes wherein the sequential displacements reduced at a fast rate compare to the once derived for the single stage analysis. In fact at the top of the dam, the vertical displacements are of the order of about 1.37m whereas with the sequential analysis it becomes negligible. In fact this trend is always reported in the published earlier. This important from the practical view point because the sequential response is real response whereby the free-board required by virtue of vertical displacement at the top goes out of consideration.

Element Stresses:-

The results defining element stresses is too massive, hence the same is put over soft copy attach at the end of this dissertation. However, with a view to compare the results of stresses for case 1 and case 2, the critical elements of base layer i.e. layer no. 1 is considered. The details are presented in following table.

Sx = Normal Stress at x-direction
Sy = Normal Stress at y-direction
Sxy = Shear Stress at x-y plane
Smax = Major Principal Stress
Smin = Minor Principal Stress

ELEMENT	NO	1				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-1.35E+01	-4.09E+00	-1.31E+01	-2.27E+01	5.14E+00
CASE 2	1	-1.41E+01	-5.77E+00	-1.61E+01	-2.66E+01	6.68E+00
CASE 1	2	-3.98E+01	-4.09E+00	-2.43E+01	-5.20E+01	8.19E+00
CASE 2	2	-4.20E+01	-5.77E+00	-3.18E+01	-6.05E+01	1.27E+01
CASE 1	3	-4.48E+01	-1.56E+01	-2.06E+01	-5.55E+01	-4.93E+00
CASE 2	3	-5.27E+01	-2.20E+01	-2.64E+01	-6.79E+01	-6.79E+00
CASE 1	4	-1.80E+01	-1.56E+01	-9.25E+00	-2.61E+01	-7.47E+00
CASE 2	4	-2.41E+01	-2.20E+01	-1.04E+01	-3.35E+01	-1.27E+01

ELEMENT	NO	9				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-3.61E+02	1.63E+01	-7.47E+01	-3.75E+02	3.06E+01
CASE 2	1	-5.50E+02	2.73E+01	-1.45E+02	-5.85E+02	6.19E+01
CASE 1	2	-4.50E+02	1.63E+01	-5.65E+01	-4.57E+02	2.31E+01
CASE 2	2	-6.95E+02	2.73E+01	-1.15E+02	-7.13E+02	4.52E+01
CASE 1	3	-3.69E+02	6.18E+01	-6.66E+01	-3.79E+02	7.19E+01
CASE 2	3	-5.61E+02	1.03E+02	-1.32E+02	-5.86E+02	1.29E+02
CASE 1	4	-2.79E+02	6.18E+01	-8.50E+01	-2.99E+02	8.18E+01
CASE 2	4	-4.14E+02	1.03E+02	-1.62E+02	-4.61E+02	1.50E+02

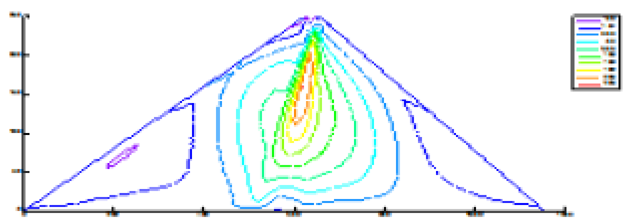
ELEMENT	NO	10				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-3.11E+02	7.74E+00	-6.24E+00	-3.11E+02	7.86E+00
CASE 2	1	-4.76E+02	1.67E+01	-1.32E+01	-4.77E+02	1.71E+01
CASE 1	2	-3.03E+02	7.74E+00	-2.50E+00	-3.03E+02	7.76E+00
CASE 2	2	-4.57E+02	1.67E+01	-5.07E+00	-4.57E+02	1.68E+01
CASE 1	3	-2.80E+02	2.95E+01	-2.79E+00	-2.80E+02	2.96E+01
CASE 2	3	-4.08E+02	6.38E+01	-5.70E+00	-4.08E+02	6.39E+01
CASE 1	4	-2.88E+02	2.95E+01	-6.62E+00	-2.88E+02	2.97E+01
CASE 2	4	-4.27E+02	6.38E+01	-1.40E+01	-4.28E+02	6.42E+01

ELEMENT	NO	20				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-5.72E+01	-5.30E+00	4.02E+01	-7.91E+01	1.66E+01
CASE 2	1	-6.31E+01	-8.27E+00	5.75E+01	-9.94E+01	2.81E+01
CASE 1	2	-2.08E+01	-5.30E+00	2.46E+01	-3.88E+01	1.27E+01
CASE 2	2	-2.34E+01	-8.27E+00	3.32E+01	-4.99E+01	1.82E+01
CASE 1	3	-2.96E+01	-2.03E+01	2.07E+01	-4.62E+01	-3.64E+00
CASE 2	3	-4.23E+01	-3.16E+01	2.68E+01	-6.43E+01	-9.63E+00
CASE 1	4	-6.69E+01	-2.03E+01	3.67E+01	-8.71E+01	-4.87E-02
CASE 2	4	-8.30E+01	-3.16E+01	5.18E+01	-1.15E+02	4.92E-01

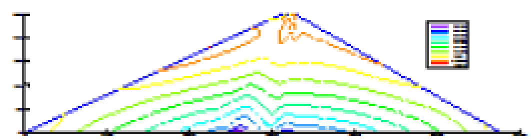
The maximum stresses for the dam are bound to occur at the base of the dam. With this in view, the details in the table above for the critical elements of each material are presented. It is clearly seen that stresses due to sequential considerations are higher than those due to single stage analysis. Because the stresses define the nature of equilibrium, the sequential analysis would govern the design. This means for the rational practical design the sequential analysis is clearly warranted.

The results defining element stresses is put over contours of the results of stresses for case 1 and case 2 for the critical elements. The details are presented in following contours.

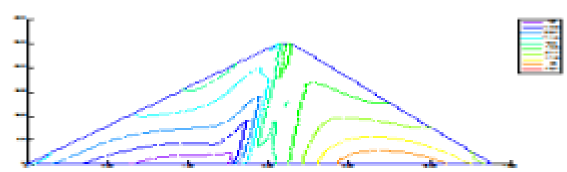
A) Contours of Major Principal Stress (KN /sq. m) (+ denotes tension, - denotes compression)



B) Contours of Minor Principal Stress(KN/sq. m)(+ denotes tension, - denotes compression)



C) Shear (KN)



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