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Finite Element Analysis of Rockfill (Tehri) Dam

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***Abstract*— A Rock-Fill dam represents a complex two dimensional continuum, comprising an assembly of rock material, core & shell cushion material. These components interact & share the applied water pressure load & self-weight of the dam. Rational understanding of the phenomenon of interaction would go a long way towards realistic rating analysis; for which two dimensional finite element analysis serves the purpose admirable. For this two dimensional Finite Element Analysis employing solid C0 Continuum element would conduct. This project deals with a case study, in which he following aspects is covered.**

1. ***Application of the two dimensional plane strain finite element analysis software for rating of the rock-fill dam located at on the Bhagirathi River near Tehri in Uttarakhand, India.***
2. ***Application of two dimensional Finite Element Analysis software for design in respect of the rehabilitation details for the Rock-Fill Dam.***

***Keywords*— Rock-Fill Dam, Theory of Elasticity, Finite Element Method and FORTRAN-77 FEA Software.**

I. INTRODUCTION

This project is focus on the development of a suitable deformations modelling and analysis method for the prediction and study of idealizations of behaviour in rockfill dams, and consequently, for the evaluation of dam safety against deformation & stability. The research is limited to the two-dimensional (2-D) static sequential analysis of rockfill dams.

The prediction of the future displacements of individual observation points could also be accomplished by means of a statistical or finite element model. However, such a nonphysical model would not provide any physical insight into the deformation processes occurring in the dam. In contrast, a finite element model has the advantage that the mechanism of the deformation of the whole dam can be simulated based on measurements made at observation points located on its exterior surface. Following points shows the objective of this case study.

1. To analyze the displacements for monitoring the dam behavior in the rock fill dam.
2. To develop a more accurate stress-strain softening relation and to calibrate the parameters
3. To develop a numerical program specially for implementing the constitutive model in order to carry analysis of rockfill dams under self-weight loading condition and static sequential analysis.

II. METHODOLOGY

This case study was designed to investigate the application of the two dimensional plane strain finite element analysis software for rating of the rock-fill dam and for design in respect of the rehabilitation details for the Rock-Fill Dam located at on the Bhagirathi River near Tehri in Uttarakhand, India.

Tehri dam built in U.P on river Bhagirathi is a rock fill dam comprising a central core, transition zone & rock fill shells. Bases on the publish data properties of material employed in various zone of dam be finite element analysis of the dam is undertaken.

Following steps are conducted for finite element analysis,

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

This case study is concern with Plane Strain two dimensional analysis. Following are its silent features

1. The finite element idealization is achieved by employing three nodded triangular elements, four nodded quadrilateral element as per requirements. These elements are isoperimetric element having C0 continuity.
2. By considering sequentially the element of idealized system the equilibrium equation are formulated & solved by employing powerful FORTRON-77 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 stress, stresses at the controlling points of element, which is then transformed into the nodal stress & strain. This is achieved directly through direct averaging technique.

III. CASE STUDY ANALYSIS

A Finite element analysis for the proposed dam section with consideration being given to Nonlinear elastic static effects. The analysis of this kind is recommended for under taking the design where seismicity of the site not of very high orders.

A Finite element analysis for the proposed dam section with consideration being given to static effects. The analysis of this kind is recommended for under taking the design where deformation of the earth structure of very high orders. The rock fill dam Tehri at Jharkhand resting on hard strata could thus be analyzed in this manner because significant static activity for unknown. In figure 4.1 the section detail and material properties of the section being consider are shown.
Number of nodes = 546, Number of Elements = 500, Number of layers = 25, Boundary Nodes = 21

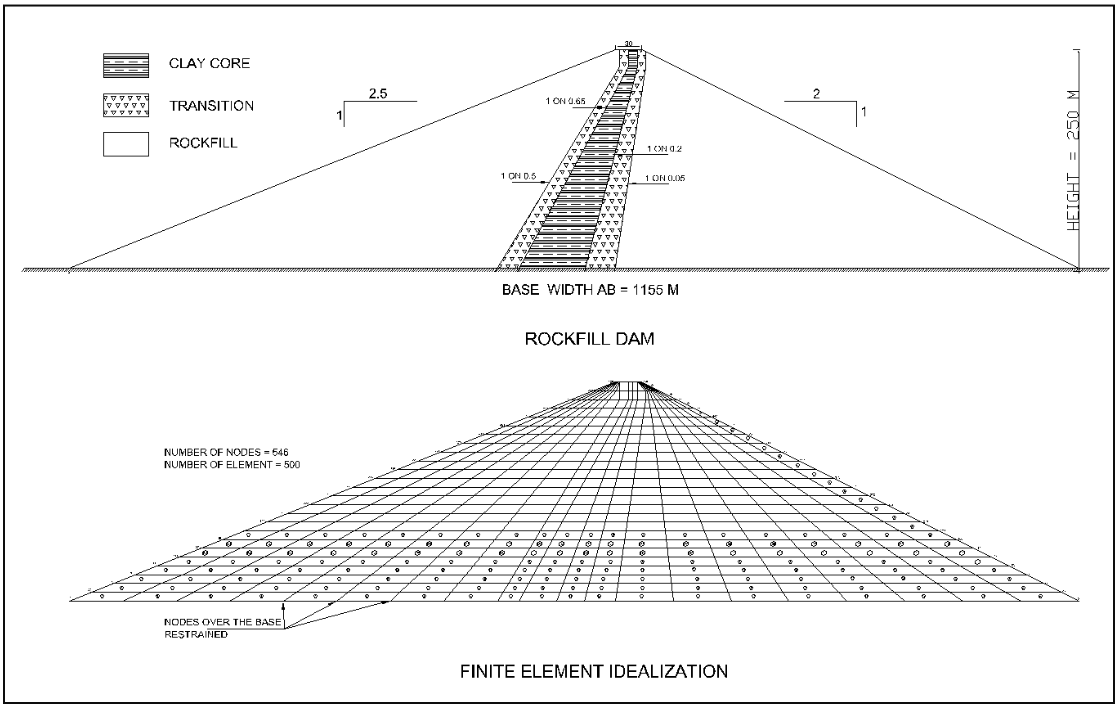


Fig. 4.1: Finite Element Idealization of Rockfill Tehri Dam (Courtesy: AutoCAD Draft)

IV. THEORTICAL SOFTWARE CONTENTS

The analysis program has the general purpose constitution with applicability for 2 nodded line element and 3 or 4 nodded plate elements. In view of this we can call it justifiable analysis software. The software comprises a main programme and several subroutine linked with the main program.

V. PRESENTATION AND DISCUSSIONS OF RESULTS

Analysis- 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 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:

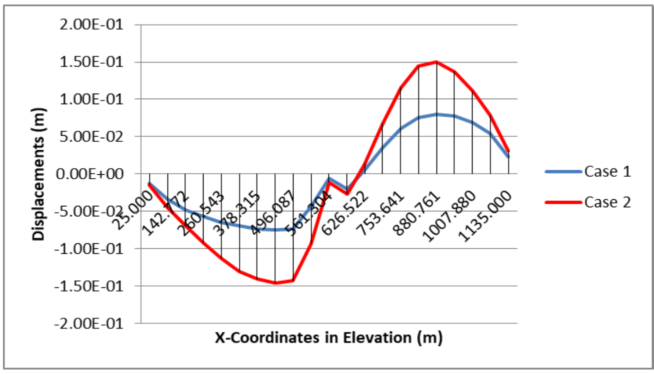
Case 1: Single Stage analysis consider dam as one single body

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

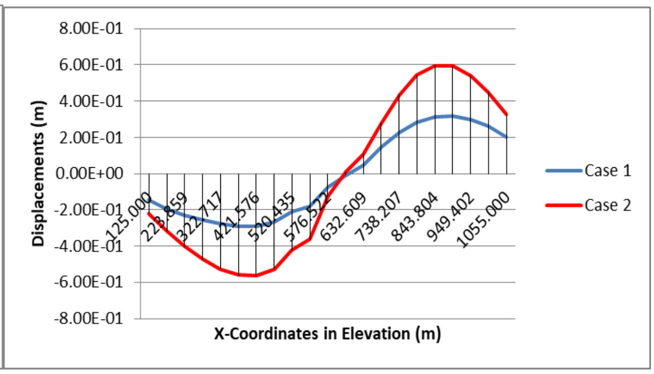
Details of the displacement components (U, V) are presented graphically as shown below:

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

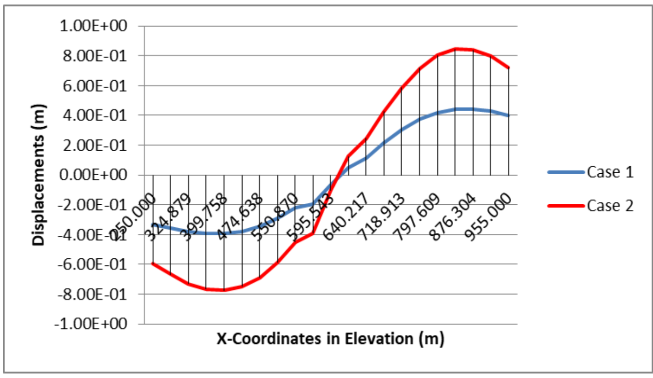
a) Node Range 22 to 42(Elevation 10 m)



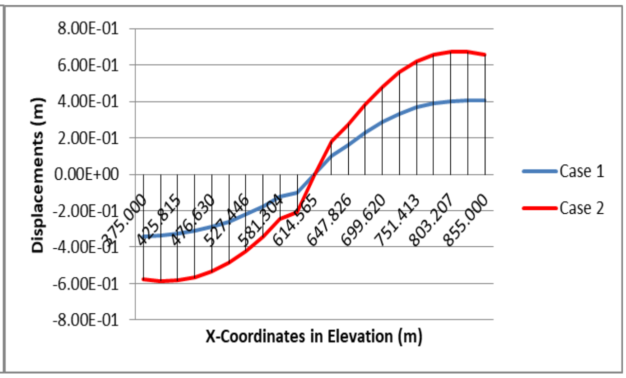
b) Node Range 106 to 126(Elevation 50 m)



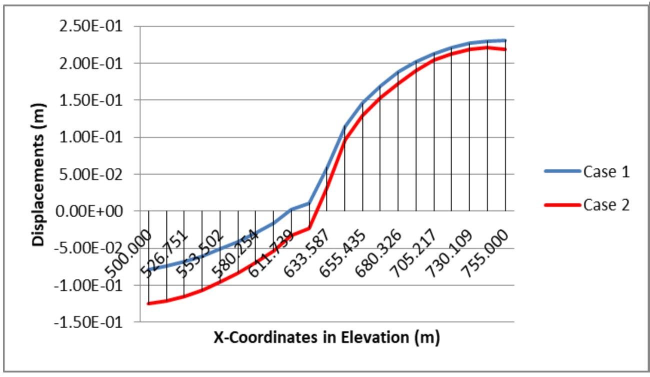
c) Node Range 211 to 231(Elevation 100 m)



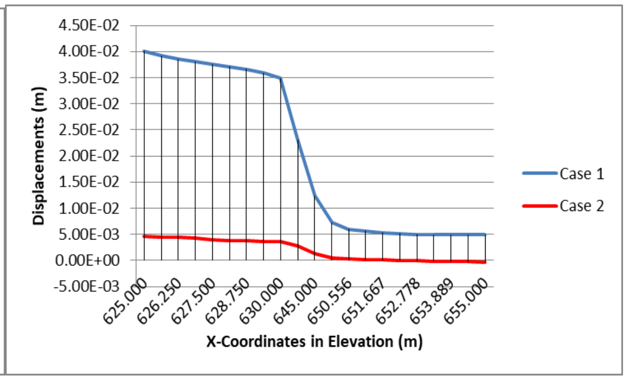
d) Node Range 316 to 336(Elevation 150 m)



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

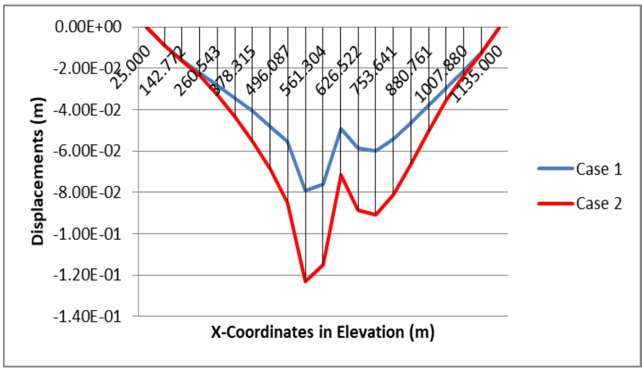


f) Node Range 526 to 546(Elevation 250 m)

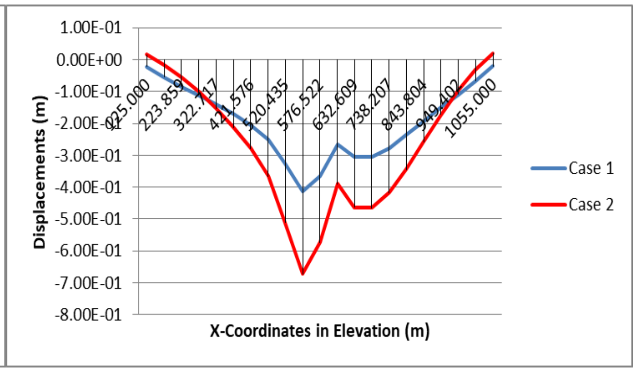


Comparison for Vertical Displacements (V) for Case 1&Case 2:-

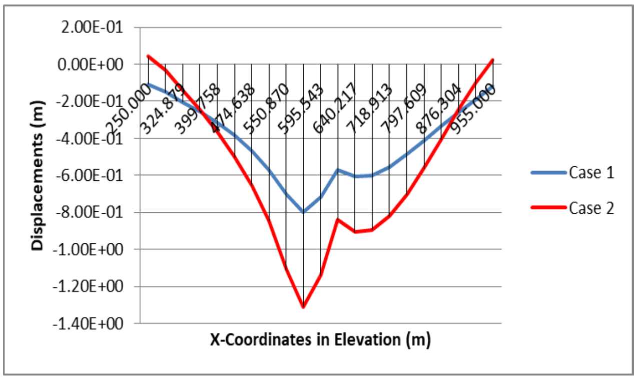
a) Node Range 22 to 42(Elevation 10 m)



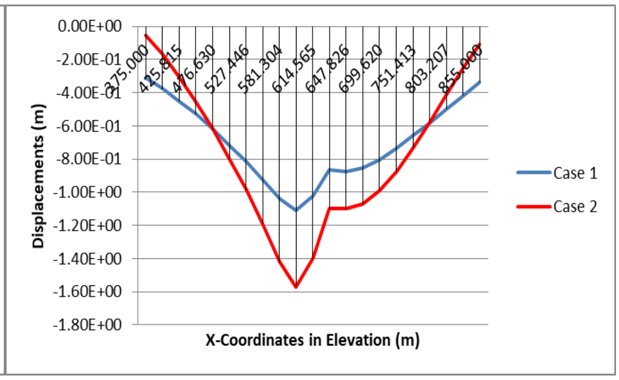
b) Node Range 106 to 126(Elevation 50 m)



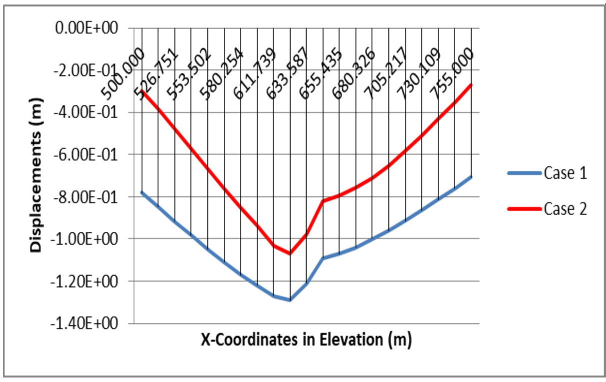
c) Node Range 211 to 231(Elevation 100 m)



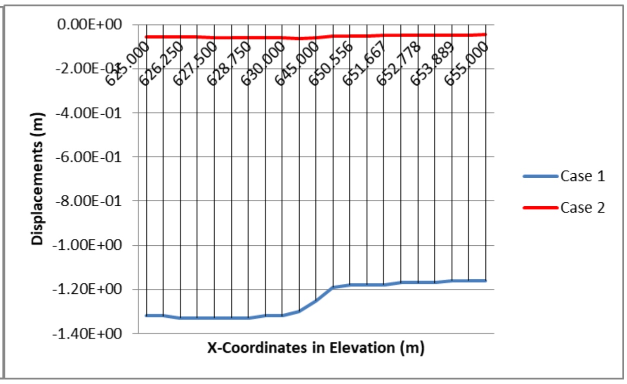
d) Node Range 316 to 336(Elevation 150 m)



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



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



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 (N/mm2)
Sy = Normal Stress at y-direction (N/mm2)
Sxy = Shear Stress at x-y plane (N/mm2)
Smin = Major Principal Stress (N/mm2)
Smax = Minor Principal Stress (N/mm2)

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	8				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-2.66E+02	2.14E-01	-6.57E+01	-2.81E+02	1.55E+01
CASE 2	1	-3.84E+02	4.50E-01	-1.28E+02	-4.23E+02	3.89E+01
CASE 1	2	-2.89E+02	2.14E-01	-6.51E+01	-3.03E+02	1.42E+01
CASE 2	2	-4.35E+02	4.50E-01	-1.26E+02	-4.69E+02	3.45E+01
CASE 1	3	-2.86E+02	8.19E-01	-6.58E+01	-3.00E+02	1.52E+01
CASE 2	3	-4.27E+02	1.72E+00	-1.28E+02	-4.63E+02	3.69E+01
CASE 1	4	-2.62E+02	8.19E-01	-6.64E+01	-2.78E+02	1.66E+01
CASE 2	4	-3.76E+02	1.72E+00	-1.29E+02	-4.16E+02	4.16E+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

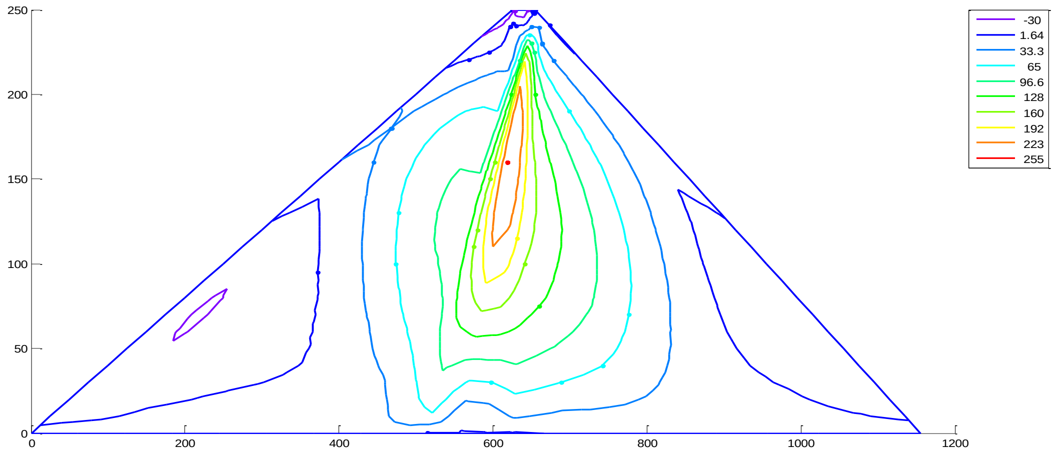
ELEMENT	NO	10				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-3.11E+02	7.74E+00	-6.24E+00	-3.11E+02	7.86E+00
CASE 2	1	-4.76E+02	1.67E+01	-1.32E+01	-4.77E+02	1.71E+01
CASE 1	2	-3.03E+02	7.74E+00	-2.50E+00	-3.03E+02	7.76E+00
CASE 2	2	-4.57E+02	1.67E+01	-5.07E+00	-4.57E+02	1.68E+01
CASE 1	3	-2.80E+02	2.95E+01	-2.79E+00	-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	11				
	GP	SX	SY	SXY	SMIN	SMAX
CASE 1	1	-2.92E+02	-3.72E+00	-1.18E+00	-2.92E+02	-3.71E+00
CASE 2	1	-4.39E+02	-4.02E+00	-1.91E+00	-4.39E+02	-4.01E+00
CASE 1	2	-2.29E+02	-3.72E+00	-2.56E+00	-2.29E+02	-3.69E+00
CASE 2	2	-3.36E+02	-4.02E+00	-3.40E+00	-3.36E+02	-3.99E+00
CASE 1	3	-2.46E+02	-1.42E+01	-1.61E+00	-2.46E+02	-1.42E+01
CASE 2	3	-3.58E+02	-1.53E+01	-1.90E+00	-3.58E+02	-1.53E+01
CASE 1	4	-3.10E+02	-1.42E+01	-1.99E-01	-3.10E+02	-1.42E+01
CASE 2	4	-4.63E+02	-1.53E+01	-3.84E-01	-4.63E+02	-1.53E+01

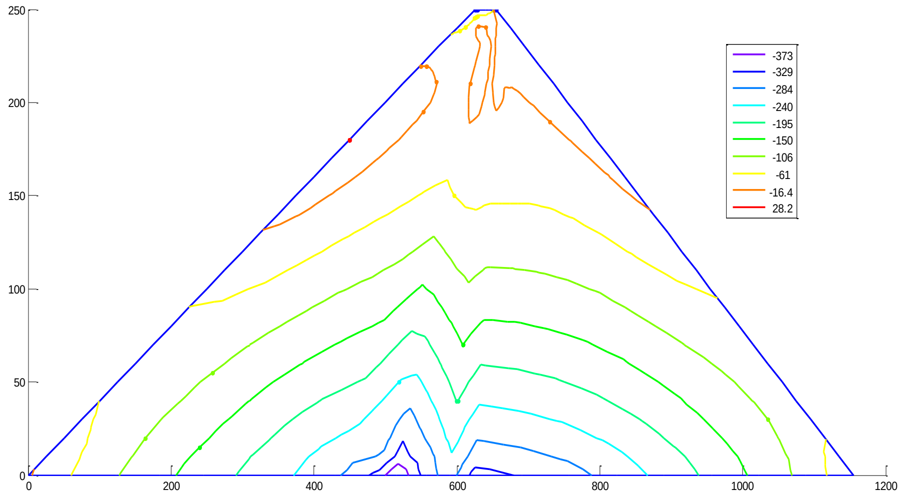
The maximum stresses for the dam are bound to occur at the base of the dam. With this in view, the details in the table above for the critical elements of each material are presented. It is clearly seen that stresses due to sequential considerations are higher than those due to single stage analysis. 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.

Contours of Structural Response- 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.

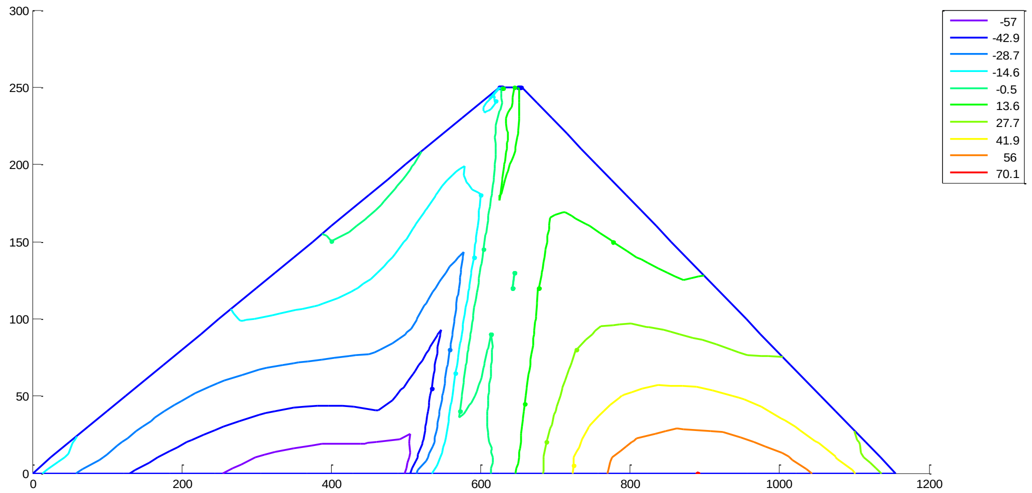
A) Contours of Major Principal Stress (KN /sq. m) (+ denotes tension, - denotes compression)



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



C) Contours of Shear Forces (KN)



VI CONCLUSION

It follows from the details presented above that both for the considerations to the free-board requirement and development of the stresses the sequential analysis offers realistic response. Hence, the same should always be adopted for practical designs.

VII FUTURE SCOPE OF WORK

In case of the dam with large heights, the mechanical constants such as the Elasticity Modulus and Poisson's ratio would be functions of the stresses and strains developed. The literature provides the information in this regard. In the sequential analysis this aspect is to be introduced while considering a layer through the iterations govern by *"Newton-Rafson technique"*. Therefore, the software needs to be modified accordingly so that realistic design developed.

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