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Effect of Soil Structure Interaction on Gravity Dam

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Abstract— In the proposed study, the effect on gravity dam has been examined using finite element analysis software ANSYS 14. The gravity dam is completely resting on soil media and surrounded by soil media. The relevant amount of soil around and bottom of the gravity dam has been modeled to simulate the in-situ conditions. The gravity dam has been analyzed using static load. Analysis of the gravity dam has been carried out and the influence of soil properties has been studied at the region of transverse sections, which exhibited the response in terms of stress and deformation with significant difference.
Keywords - gravity dam, finite element method, static analysis, soil structure interaction, Natural Frequency and Mode Shapes

I. INTRODUCTION

1.1 Soil Structure Interaction

Soil-Structure Interaction is a challenging multi disciplinary subject which covers several areas of Civil Engineering. Virtually every construction is connected to the ground and the interaction between the artifact and the foundation medium may affect considerably both the superstructure and the foundation soil. The Soil-Structure Interaction problem has become an important feature of Structural Engineering with the advent of massive constructions on soft soils such as nuclear power plants, concrete and earth dams. Buildings, bridges, tunnels and underground structures may also require particular attention to be given to the problems of Soil-Structure Interaction.

We have seen earlier that considering the soil as a deformable elastic medium the stiffness of soil gets coupled to the stiffness of the structure and changes it elastic property. Based on this the characteristic response of the system also gets modified. This we can consider as the local effect of soil. On the other hand consider a case of a structure resting on a deep layer of soft soil underlain by rock. It will be observed that its response is completely different than the same system when it is located on soft soil which is of much shallow depth or resting directly on rock. Moreover the nature of foundation, (isolated pad, raft, pile), if the foundation is resting or embedded in soil, layering of soil, type of structure etc. has profound influence on the overall dynamic response of the system. The complexity of the problem, due also to its multidisciplinary nature and to the fact of having to consider bounded and unbounded media of different mechanical characteristics, requires a numerical treatment for any application of engineering significance. The Finite Element Method appears to be well suited to solve problems of Soil-Structure Interaction through its ability to discretized only the boundaries of complex and often unbounded geometries.

1.2 Aim of the Study

The aim of work is twofold. First includes working on the analysis of gravity dam section neglecting soil structure interaction. Second includes working on the correct modeling of structures considering soil structure interaction. Some of the procedures currently practiced by structural designers for this are studied and a modeling procedure is selected. Based on this procedure a model is generated for future work.

The second part includes different parameters of different height of dam, changing modulus of elasticity of soil and different soil model dimensions and their result obtained by check the displacement and stresses.

II. FORMULATION OF PROBLEM

In a gravity dam the force of the water is held back by the self-weight of the dam, with some assistance from shearing resistance and bond. Analysis of structure with soil structure interaction effect is done by FEM. The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. In this method all the complexities of the problems like varying shape, boundary conditions and loads are maintained as they are but the solution obtained are approximate. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering. A number of popular brand of finite element analysis packages are available commercially. Here ANSYS 14 is used for the analysis of the gravity dam section.

2.1 Data for the Gravity Dam

The gravity dam is approximately triangular in shape. Inner surface of the gravity dam is vertical and the outer surface of the gravity dam is sloping linearly with respect to depth. The slope of surface is 2H: 3V. Width of the gravity dam is varying (decreasing) linearly from bottom to top as the depth of water is increasing. The base of dam is considered as fixed. Gravity dam is triangular in geometry and loading about x and y axis.

Details of data of Gravity dam (Solid Gravity Dam)

- Height of Dam = 84 m Maximum water level = 80 m
- Width of base = 56 m Tail water depth = 6 m
- Top of width = 6 m Assume unit length of dam.

Table 1: Materials properties of gravity dam & soil model

Properties of Concrete	Density	2300 kg/m3
	Modulus of elasticity of the concrete	30000 N/mm2
	Poisson's ratio of body	0.18
Properties of soil	Density	1900 kg/m3
	Modulus of elasticity of the soil	161.464 N/mm2
	Poisson's ratio of soil	0.3

The various forces and their moments about the toe are then calculated. We have forces,

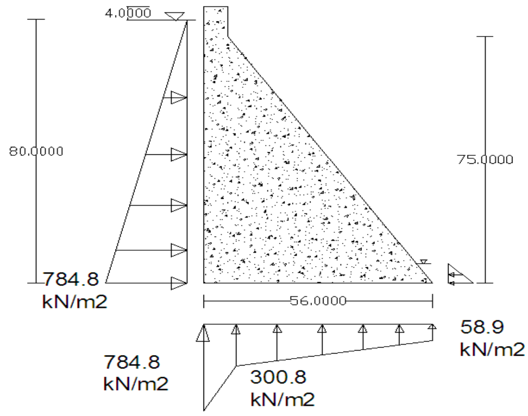


Figure 1. Various forces acting on gravity dam

2.2 FEM in Structural Analysis (Basic Steps)

In engineering problems there are some basic unknowns, from which behavior of entire structure can be predicted. These variables are displacement in solid mechanics. In a continuum these unknowns are infinite. The finite element procedure reduces such unknowns to a finite element number by dividing the solution region into parts called elements. The material properties and governing relationships are considered over these element corners. An assembly process, duly considering the loading and constraints, results in a set of equations. Solution of these equations gives us approximate behavior of continuum.

Steps:

- Divide the structure into pieces (elements with nodes)
- Evaluation of element stiffness
- Connect (assemble) the elements at nodes to form an approximate system of equations for whole structure, i.e., assemblage of element stiffness matrices for the system.
- Introduction of boundary conditions.
- Solve system of equations involving unknown quantities at nodes (e.g., displacements).
- Calculate desired quantities (e.g., strains and stresses) at selected elements

2.3 Problem Solution by Software

Gravity dam section is modeled as ax symmetric problem. Analysis of the Gravity dam neglecting and considering soil structure interaction effect is done by Finite Element Method. Finite Element Method based software ANSYS is used for the analysis.

Result for gravity dam

1. Results for gravity dam section considering fixed base
2. Results for gravity dam section considering soil structure interaction effect.
3. Comparison of results with ANSYS modeling.

2.4 Finite Element Analysis

Finite element analysis (FEA) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry. Numerical solutions to even very complicated stress problems can now be obtained routinely using FEA.

Ray Clough was the first to use the Finite Element procedure. From the time remarkable advances have been made in the last many years both on the mathematical foundations and generalization of method to solve field problems in various areas of engineering analysis.

III. VALIDATION OF PROBLEM

This presents brief introduction of ANSYS 14 software for modeling the formulated problem. Analysis of the gravity dam section can be done by ANSYS 14 software considering and neglecting soil structure interaction effect. ANSYS is the finite element based software. General steps used in the modeling and analysis of the structure in ANSYS 14 are described below.

3.1 Finite Element Analysis Using ANSYS Software

In the dissertation work finite element analysis is done using ANSYS 14 version software in ANSYS workbench. ANSYS Workbench combines the strength of CPU with the project management tools necessary to manage the project workflow. In ANSYS Workbench, analyses are built as systems, which can be combined into a project. The project is driven by a schematic workflow that manages the connections between the systems. From the schematic, you can interact with applications that are native to ANSYS Workbench (called workspaces) and that display within the ANSYS Workbench interface and you can launch applications that are data-integrated with ANSYS Workbench, meaning the interface remains separate, but the data from the application communicates with the native ANSYS Workbench data.

3.2 Static Structural Analysis of the Gravity dam section

3.2.1 Analysis of the Gravity dam (Without Soil Structure Interaction Effect)

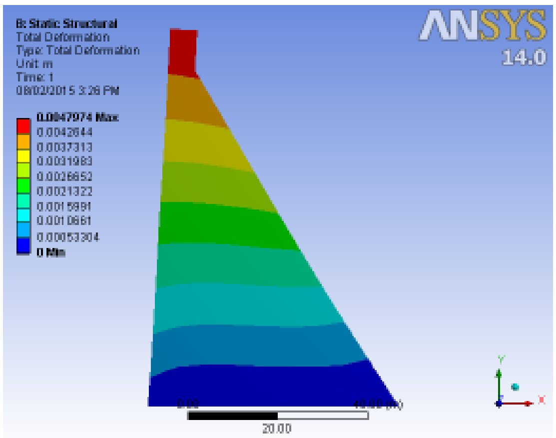
Here the gravity dam section is modeled as 2-D plain strain model. Analysis is done neglecting soil structure interaction effect, so the base of the gravity dam section is considered as a fixed base. After completion of solution we can specify the solution from one analysis as input conditions to another analysis.

3.2.1. Results of validation: The Results cell indicates the availability and status of the analysis results (commonly referred to as post processing). From the Results cell, you cannot share data with any other system.

3.2.2 Comparison of stress results in ANSYS with stability analysis

Stresses in Gravity dam without considering soil structure interaction effect:

- By ANSYS 14 solution,
  Maximum stress at toe = 2.033 N/m²
  Max Shear Stress at toe = 0.926 N/m²
- By analytically stability analysis ,
  Maximum stress at toe = 2.288 N/m²
  Max Shear Stress at toe = 1.05614 N/ m²



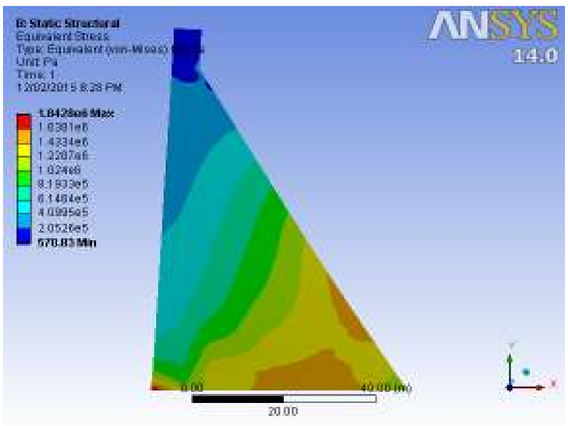


Figure 2. Equivalent stress & total deformation in in static analysis of dam without soil structural interaction

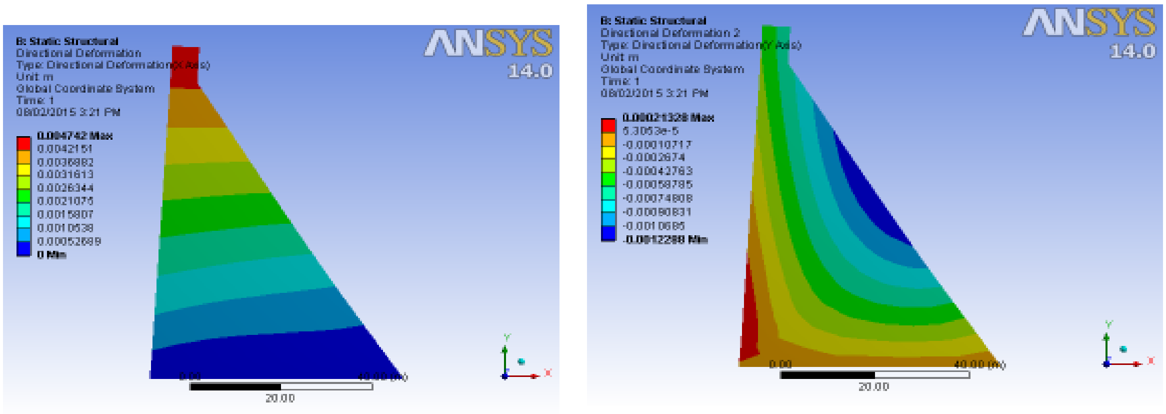


Figure 3. X & Y- deformation in static analysis of dam without soil structural interaction

3.3. Analysis of the gravity dam section in ANSYS (With Soil Structure Interaction Effect)

Here the gravity dam section is modeled as 2-D plain strain model. Analysis is done considering soil structure interaction effect, so the base of the gravity dam section is not considered as a fixed base. Here the modeling of soil is done in addition to the structural modeling. As the soil is also modeled, effect of soil stiffness on the structure can be evaluated. As the soil stiffness is attached to the structure change in stress and displacement result of the structure can be evaluated.

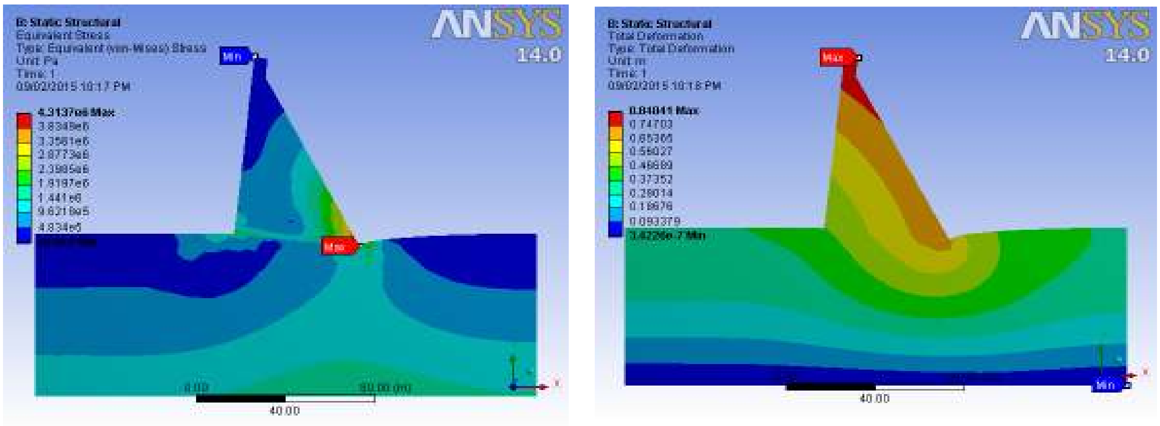


Figure 4. Equivalent stress & total deformation in static analysis of dam with soil structural interaction

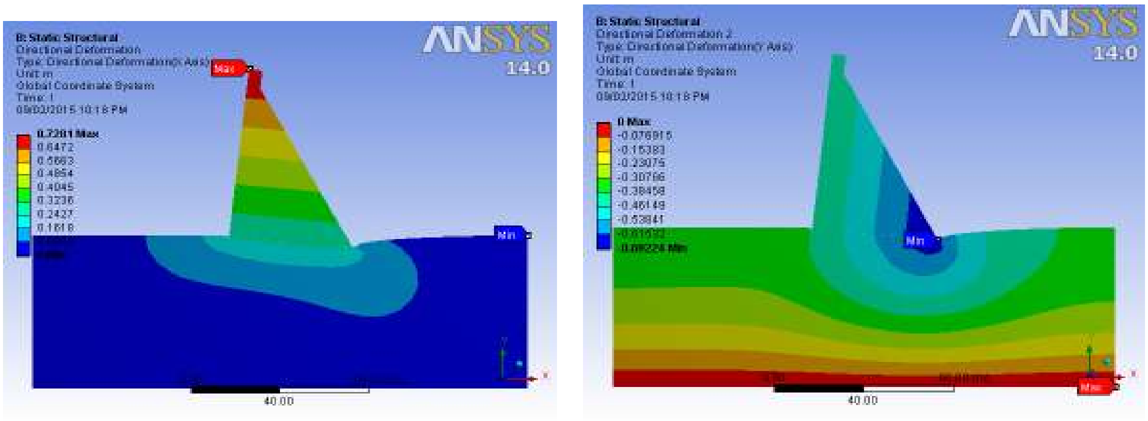


Figure 5. X &Y deformation in static analysis of dam with soil structural interaction

Table 2. Comparison of results for gravity dam without and with soil structure interaction.

Description	Without Soil Structure Interaction	With Soil Structure Interaction
Total displacement	4.7974 mm	840.41 mm
Maximum X displacement	4.7328 mm	728.1 mm
Maximum Y displacement	0.21328 mm	0
Equivalent Stress of dam	1.8428 N/mm²	4.3137 N/mm²

IV. RESULT OF PROBLEM BY SOFTWARE

4.1 Parametric Studies:

Results are also obtained by various cases changing modulus of elasticity of soil and different soil model dimensions. These results are obtained for considering soil structure interaction effect for of static analysis.

4.1.1 Changing the dimension of soil model

Results if the soil structure interaction effect is considered soil stiffness is attached to the structural stiffness. And so the stiffness of the structure is reduced. So the soil effects the displacement and stress in the structure. As the dimension of soil model surrounding the structure is increasing the effect of soil on structure get reduced. After some limitation, even increase in soil dimension does not affect the displacement and stress result in the structure.

Table 3. Results of displacement and stress of the gravity dam section for different size of soil model

Dimension of Soil Model width x depth	Maximum-X Displacement (mm)	Principle Stress at toe (-ve) (N/mm²)
224 x 100	623.21	1.2713
224 x125	647.85	1.2741
224 x 150	672.33	1.2749

224 x 175	694.10	1.2743
224 x 200	711.51	1.2755
224 x 225	724.56	1.2744
224 x 250	733.79	1.2734
224 x 270	738.84	1.2764
224 x 280	738.89	1.2760
224 x 290	738.91	1.2760

Results for Different Soil Model

1. **Soil width 224m and soil depth 100m.**

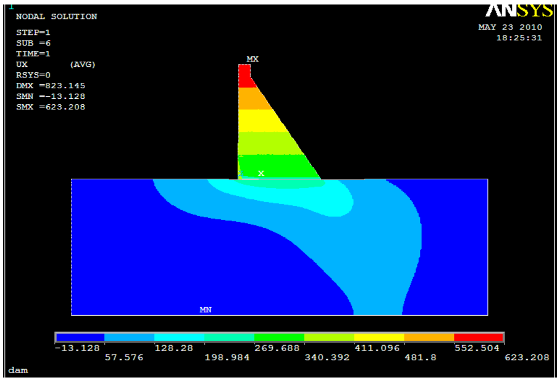


Figure 6. X - Displacement of gravity dam

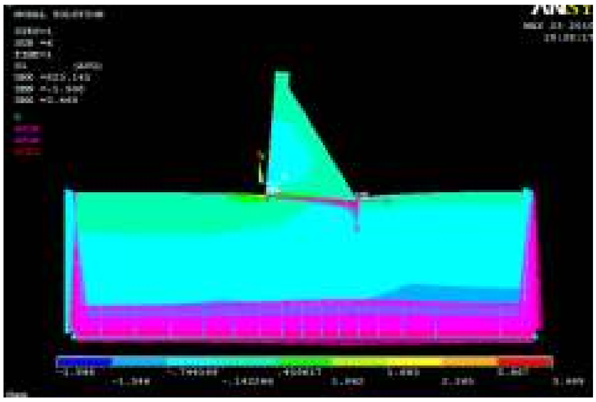


Figure 7. Stress result for gravity dam

Soil width 224m and soil depth 280

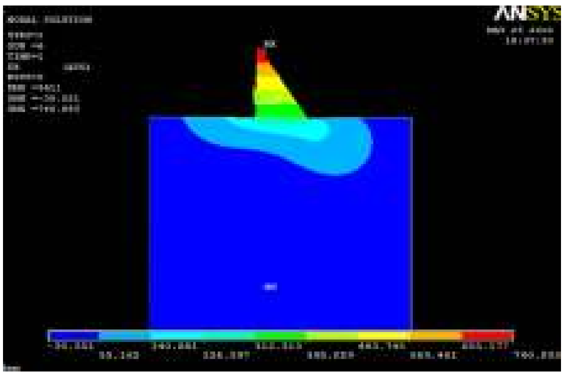


Figure 8. X - Displacement of gravity dam

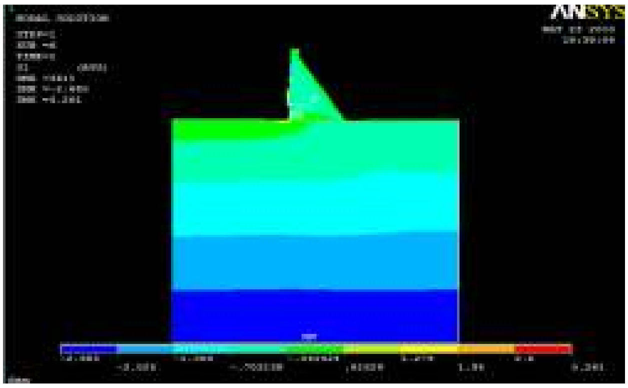


Figure 9. Stress result for gravity dam

4.1.2 Results after changing modulus of elasticity of soil (E)

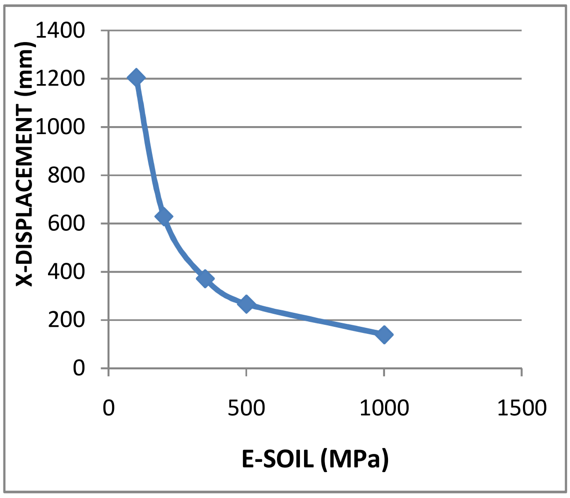
Table 4. Results of displacements on changing E of soil

E (MPa)	X-displacement (mm)	Y-displacement (mm)	Principle stress at toe of dam (N/mm^2)
100	1204.7	-5414.8	-0.81826
200	629.00	-2707.9	-0.6691
350	371.26	-1547.6	-0.5738

500	265.99	-1083.5	-0.68104
1000	138.92	-542.17	-0.32543

The graph of modulus of elasticity of soil and displacement is as follows:

❖ **For E-soil between 100 to 1000 MPa**



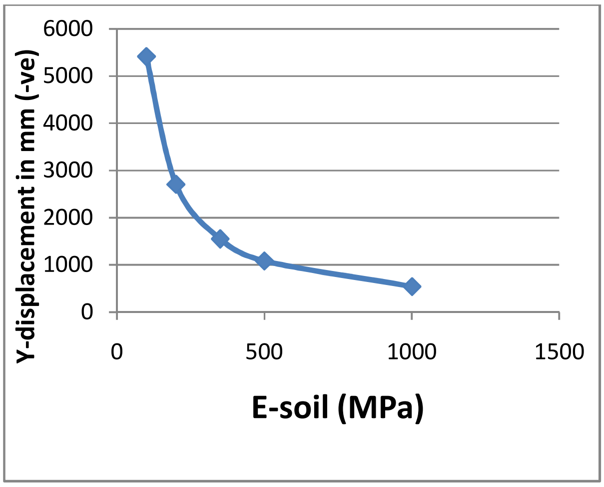


Figure 10. The graph of X-displacement & Y-direction displacement

IV CONCLUSION

[01] From the analysis, it can be concluded that, if soil stiffness and mass of the soil is considered the displacement is higher for the soil structure interaction compared to that of without soil structure interaction (fixed base).

[02] Also concluded that, if soil is considered the stress at the toe in the gravity dam section increase. [03] Also, after some soil depth the effect of soil on gravity dam section can be neglected. From the results, after soil depth equal to 280 m gravity dam stress and displacement in the gravity dam section become constant.

[04] For different type of soil, as the modulus of elasticity of the soil reduced displacement in the structure is increased.

[05] As we increase modulus of elasticity of soil the horizontal and vertical displacement reduces and for hard rock it comes closer to the value of solution of fixed base problem i.e., without considering soil structure interaction effect.

[06] Overall, It can conclude that soil structure interaction generally represents an important effect, which must be considered. Neglecting the actual interaction analysis will lead to overlay conservative design.

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