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A case study on failure of a tunnel intake

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ABSTRACT
This paper deals with the study of causes of failure of a tunnel during excavation and the design of pre-support system for proceeding the tunneling. The tunnel, 3396m long, driven by full face method, encountered a failure at the intake during the course of tunneling. Soil tests were carried out to identify the type of soil. The most probable reason for the failure was identified .A pre-support system known as pipe roofing or umbrella arch method was suggested to recover from failure and for proceeding the tunneling. It was modelled using Creo Parametric 1.0 and analysed using ANSYS 12.0 software. This paper concludes that pipe roofing is a practically feasible pre-supporting technique recommended at the site for carrying out further excavation by means of conventional method of tunneling.
Keywords– Tunnel failure, pre-support system, pipe roofing, Creo Parametric, ANSYS

I. Introduction

Many cases of tunnel failures have been reported recently. An engineer who designs or constructs underground works probably encounters more uncertainties than those dealing with structures above the earth surface. It behoves the creator of underground structures to observe past failures, to understand their causes and to device precautions against their recurrence.

A case of tunnel failure occurred in Pallivasal, near Munnar, Kerala. The history of hydro power development in Kerala begins with commissioning of Pallivasal hydroelectric project in 1940.The Construction of a tunnel as a part of Pallivasal extension scheme (PES) encountered a failure 550m ahead of exact intake pool location.

This study deals with engineering analysis of its cause and establishment of pre-supporting technique for the collapsed section.

II. Literature Review

Jerome.C.Neyer**[1]** reported many cases on soft ground tunnel failures in Michigan. Failures were due to ground settlement over tunnel, change in geological formation, improper preliminary investigation and ground water overflow.

Schubert W **[2]** inferred that freezing of the ground is a pre-support method.

According to R.R Osgoui, A.Poli**[3],** Hannes Gamsjager, Marcus Scholz**[4]**, the roof pipe umbrella is a tunnel pre-support technique recommended in case of difficult ground conditions..

M.Pescara**[5]**,Volkmann **[6],** pipe diameters 200mm or lower is recommended in most of the ground conditions.

Harazake**[7]** presented the result that pipe roofing or umbrella arch method is an effective method for the stability of tunnel face and for the improvement of ground in front of tunnel face by measuring the surface settlement and stress on steel pipe.

Design criteria for tunnel construction were selected as per Tunnel design guidelines.

III. Methodology

Method of tunneling employed at the site was Full face method which is suitable only for tunneling through self supporting rock strata. During the course of tunneling, failure was encountered at about 550m ahead of the exact intake pool location.

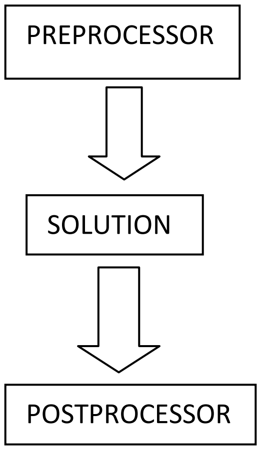
Any type of construction whether underground or not depends primarily on soil properties. Soil tests were conducted to identify the soil properties. The results obtained are given in TABLE 1.

TABLE 1. SOIL PROPERTIES

Particle size distribution Gravel, % Sand, % Coarse Sand, % Fine sand, % silt, %	 12.2 83.7 16 30 4.1
Type of soil	Well graded sand
Specific gravity	2.56
Permeability (cm/s)	$8.99x10^{-4}$
Angle of internal friction (□)	30^0

Due to the presence of unexpected sandy strata in the course of tunneling, heavy soil inflow resulted which lead to the failure of tunnel at that region. Further tunneling requires a suitable pre- supporting system to avoid the soil inflow during underneath excavation. Pipe roofing is one such pre supporting system which was found to be most effective with regard to the weak ground conditions of the site. In this system, steel pipes of specific diameters (ranging from 89mm to 200mm) and length 6m to 9m are installed at the crown of the tunnel. Grouting is done in the annular gaps of the pipes and between the ground and pipes.
Considering the structural action, it is a pre-support system with longitudinal beam action in the direction of tunnel excavation. Installed steel pipes are interconnected to form a roof-like structure, called a pipe roof, above the tunnel excavation. In soil ground condition, pre reinforcement of the core which has to be excavated, using longitudinal steel pipes grouted into the ground, allows the excavation of tunnels in very difficult ground conditions.

Inorder to suggest a suitable diameter and length for the pipes to be used in the system, pipes of different diameters (101.6, 152.4,165.1,193.7,219.1) mm and length 6m were analysed for the same loading condition using ANSYS 12.0. As an initial step, modeling was done using Creo Parametric 1.0. The modeled figure was imported to the ANSYS 12.0 software, then the analysis was carried out and the diameter showing minimum deflection on loading was finalized for using in the system. In ANSYS, the general process of finite element analysis is divided into three main phases, preprocessor, solution, and postprocessor.



1. Preprocessing: Defining the problem; the major input data given in preprocessing stage are given below:
- Type of analysis (structural)
- Element type
- Real constants
- Material properties
- Geometric model
- Meshed model
- Loadings and boundary conditions

The amount of detail required will depend on the dimensionality of the analysis. (i.e. 1D, 2D, 3D, axi-symmetric).

2. Solution: Assigning loads, constraints and solving. Here we specify the loads (points or pressure), constraints (translational and rotational) and finally solve the resulting set of equations. Solution phase is completely automatic. The output from the solution phase (result data files) is in the numerical form and consists of nodal values of the field variable and its derivatives.
3. Post processing: Further processing and viewing of the results; in this stage one may view:
- Deflection plots.
- Stress contour diagrams

IV. Results and Discussions

Results obtained in the form of deflection and stress intensities, on analysing pipes of different diameters using ANSYS for the same loading conditions are given in TABLE 2.From the results obtained, it was observed that pipes of diameter 165.1 mm and length 6 m gave minimum deflection and uniform stress distribution (stresses within the permissible limit)without any concentration of stress at a particular point of the pipe, which means that pipe section is most effective in resisting the earth load due to overburden. Figures showing the deformation and the stress distribution in the case of pipe diameter corresponding to the best section (165.1 mm dia) are given below (Fig.1to3).

TABLE 2. RESULTS FROM ANALYSIS

Sl.No	Pipe diameter (mm)	Length of pipe (mm)	Deflection (mm)	Stress intensity (N/mm^2)	Remarks
1	101.6	6000	0.001913	15.094	When pipe dia = 165.1mm Min. deformation and uniform stress distribution on the system. ECONOMICAL SECTION : PIPE DIA = 165.1 mm LENGTH = 6m
2	152.4		0.001711	5.059	
3	165.1		0.001662	6.425	
4	193.7		0.002556	7.349	
5	219.1		0.003694	13.647	

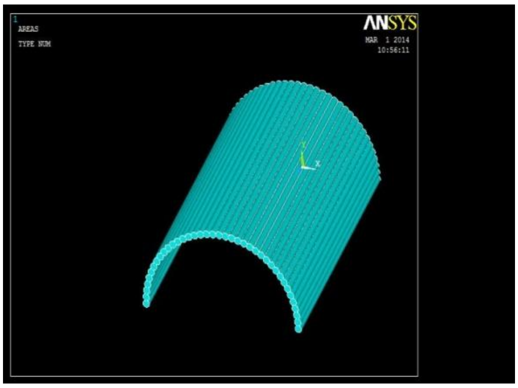


Fig. 1 Pipe roof model in ANSYS

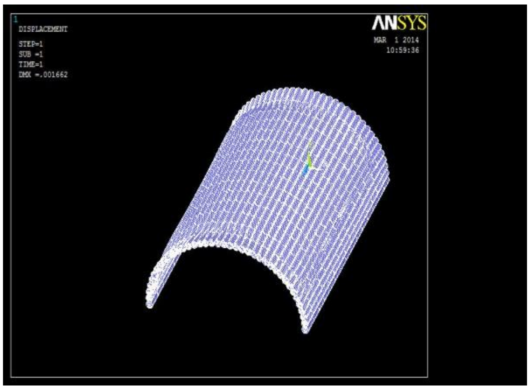


Fig.2 Deformed shape

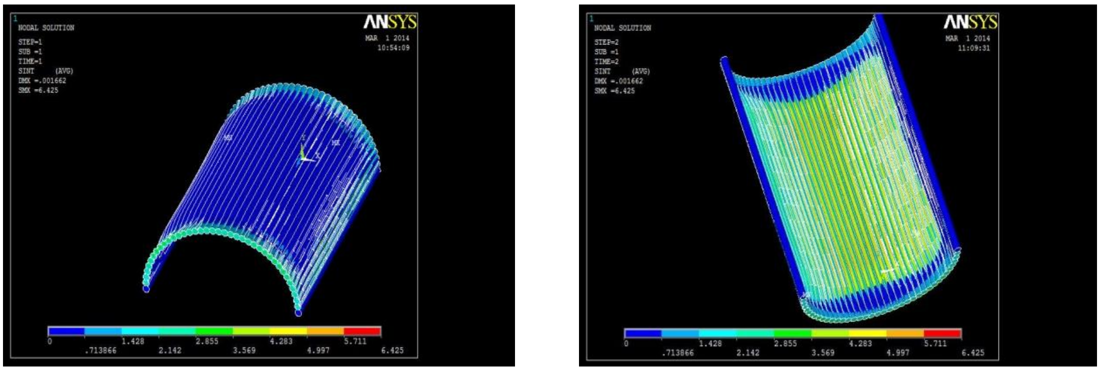


Fig.3 Stress distribution

V. Conclusions

From the soil tests conducted on the sample of soil collected from the location of failure, the soil at the site was found to be well graded sand. As the tunneling method employed at the site was full face method which is suitable only for self supporting hard rock, tunnel driving failed when they encountered sandy strata near the intake region. A suitable pre-supporting system has to be implemented at the site for carrying out further tunnling process. From the detailed study conducted on various types of pre supporting systems used in tunnels such as ground freezing, pipe roofing etc., the most feasible method that can be employed conveniently in the field was found to be pipe roofing method. The design of pipe roof support system consists of selecting the diameter and length of pipes to be used. From the results obtained from analysis, a section which showed minimum deformation was selected as the best section.

Pipe roofing is a practically possible method which is recommended at the site because of its simplicity in design and implementation.

VI. Acknowledgement

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