DYNAMIC STRUCTURE - MEDIUM INTERACTION OF UNDERGROUND NUCLEAR REACTOR CONTAINMENTS

by

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SYNOPSIS

The inherent structural, biological and ecological benefits of underground siting are of considerable interest to the nuclear industry. Parametric studies of the structural characteristics of the four principal underground concepts a) Cut-and-Cover, b) Unlined Cavity, c) Lined Cavity, and d) Lined Cavity with Annular Filling of Soft Material, indicate 1) the horseshoe shape to be the best profile, ii) active rock bolting superior to all other types of cavity reinforcement, iii) considerable decrease in liner membrane forces (by 80%) and stresses in the medium (by 10-15%) due to isolation, iv) significant reduction of stresses in the structure and the medium by proper combination of the density and elasticity of the backfill in the cut-and-cover concept. The work has a number of spin-off applications outside the nuclear industry.

INTRODUCTION

The paper deals with dynamic finite element analysis of underground nuclear reactor containments subjected to blast excitation. The work is based on the recent participation of the first author (Ref.1) in the Seismic Task Group of the ASCE Committee for Nuclear Structures and Materials. As the character, intensity, duration and frequency of earthquake and blast-induced ground motions are roughly similar, the results have practical value in studying earthquake effects. From analysis of ground data obtained in two nuclear explosions - CANNIKIN and MILROW and the San Fernando earthquake, Hays (2) has indicated that nuclear explosion time histories may be more useful in near-field geotechnical analyses than has previously been thought. The extensive work on aseismic design of above-ground reactors and recent studies on missile impact effects, aircraft impact, blast effects due to chemical explosions, reactor core melt-down and tornadoes indicate the advantages of underground siting with inherent general reduction in complexity of seismic amplification and benefits of structural and biological integrity. Other advantages are possibilities of urban siting, ecological considerations, reduced effects on the landscape, ability to design three-dimensionally, separation of component facilities, support capability to equipment, reduced power transmission costs, increased number of acceptable units and power capability from a single location and reduction of decommissioning problems.

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Parametric studies are presented (Refs. 2 and 3) for structural characteristics of the four principal underground concepts (Fig. 1): a) Cut-and-Cover in Rock or Soil, b) Unlined Cavity in Rock, c) Lined Cavity in Rock or Soil, and d) Lined Cavity in Rock or Soil with Annular Filling of Soft Material - with respect to Shape, Backfill Material, Cavity Wall Reinforcement, Passive and Active Rock Bolting and Lining and Annular Filling. The response to a step pulse, representing a blast excitation applied horizontally, is studied using a plane-strain finite-element analysis with triangular and rectangular elements over a sufficiently extensive finite region restricted to the time-history free from stress-wave reflection effects.

The longer time durations in earthquake analysis can be handled without an absorbing boundary by imposing additional material damping to the soil elements as indicated in Refs. 4 , 5 and 6.

ANALYSIS

1. Cavity Shape: For the same area of opening a comparison of four different shapes, i) circular, ii) semi-circular roof with vertical walls, iii) flat circular roof with vertical walls and iv) horseshoe, indicates the horseshoe shape to be the best with a stress decrease of 10-15% compared to other shapes. An analysis of the different horseshoe configurations is also presented. Figs. 2a to 2f and 3a to 3d give typical studies which indicate the high horseshoe shape to be the best from the viewpoint of stresses in the lining. However, the stresses in the adjacent medium are higher than those for flatter shapes.

2. Cavity Wall Reinforcement (Rock Bolting and Lining): Studies of passive and active rock bolting, reinforced and prestressed concrete liners, and steel liners indicate active rock bolting to be the best kind of reinforcement. Rock bolting, with about 80% of the amount of the steel required for a cavity liner, decreases the stress in the medium by 25% or more compared to 10% for the liner. Typical studies are presented in Figs. 4a to 4d.

3. Isolation: A surrounding medium of soft, energy absorbing material, e.g., closed cell polyurethane foam, reduces by about 80% the liner membrane forces and bending moments and the stresses in the medium by about 10-15% (Figs. 5a to 5d).

4. Backfill Material: Typical analyses of a cut-and-cover structure for six different filling materials are presented in Figs. 6a and 6b. The study indicates that the stress in the structure and the surrounding medium are not significantly affected by individual values of the density, P, and the elasticity, E, of the backfill material but only by certain combinations of the two values. Proper selections of the combined properties can lead to a considerable reduction in the stresses.

DISCUSSION

Conflicting comparisons of the Lumped Parameter (Half Space) and Finite Element Methods for above-ground reactors have focussed attention on the limitations and advantages of both approaches. However, for the case of underground containments, it seems difficult to match the finite element method by other methods for the following reasons: 1) the ability to cope with sequential stress analysis for the in-situ, excavation and construction, and operation phases inclusive of elastic and inelastic discontinuities, and 2) the facility to eliminate the need for an artifically absorbing boundary by the imposition of high material damping values varying with depth and distance from the structure in conjunction with a sufficiently extensive mesh to simulate radiation damping (Refs. 4,5 and 6). With the increasing number of reactors in seismic areas and other regions with risks of man-induced seismicity, there is an urgent need for intensive studies of the underground concept. A cut-and-cover nuclear reactor is being designed for Israel and there is considerable interest in the same concept in other countries like West Germany.

The research programme has a number of 'spin-off' applications outside the nuclear industry to tunnels, conduits, and cavities for oil and gas storage.

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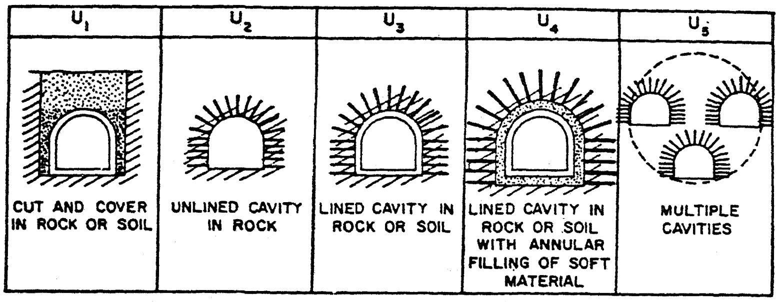
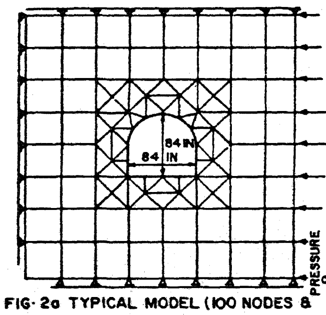
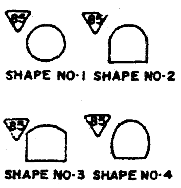


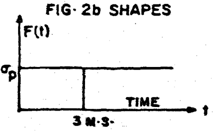
FIG· I· UNDERGROUND CAVITIES (SHOWING ROCK BOLTING)



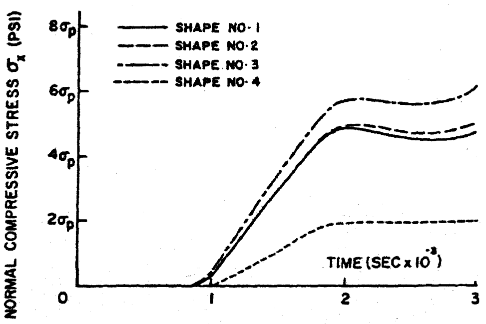
FIG· 2a TYPICAL MODEL (100 NODES & 120 ELEMENTS, LINING TKS.— 1 IN·)



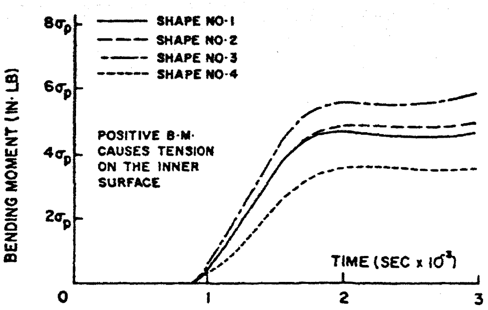
FIG· 2b SHAPES



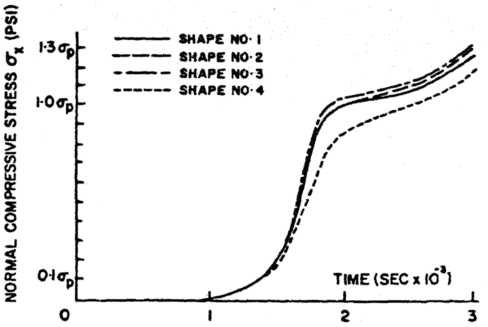
FIG· 2c LOADING



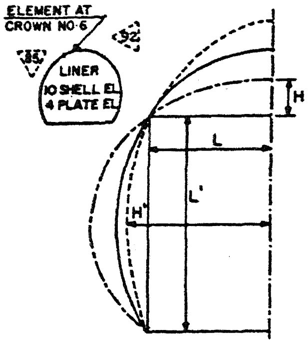
FIG· 2d MEMBRANE STRESS IN ELEMENT AT CROWN



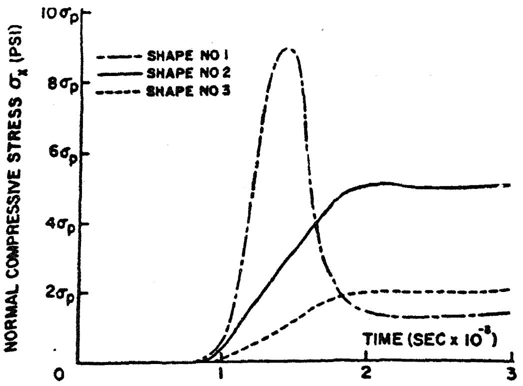
FIG· 2e BENDING MOMENT IN ELEMENT AT CROWN



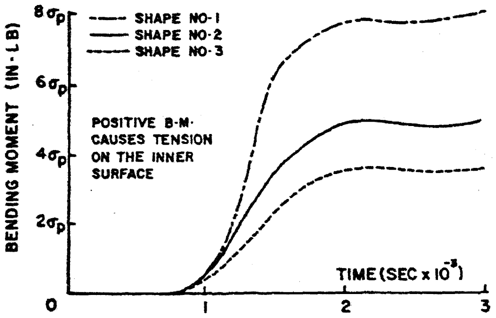
FIG· 2f· STRESS IN ELEMENT 85



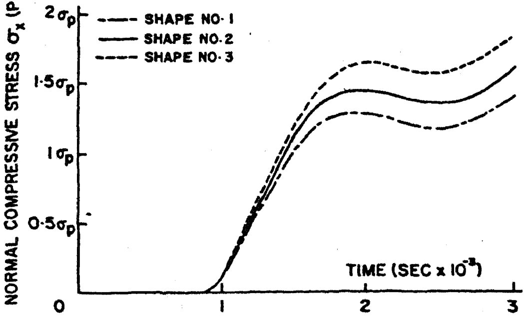
FIG· 3a DIFFERENT HORSESHOE SHAPES



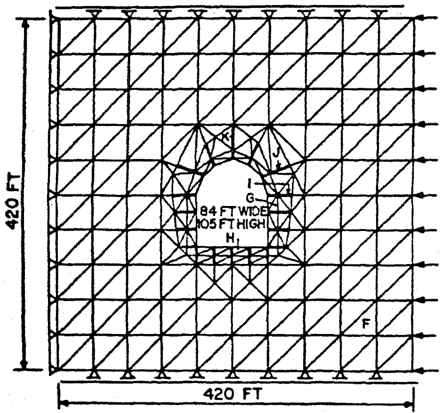
FIG· 3b MEMBRANE STRESS IN ELEMENT 6·



FIG· 3c BENDING MOMENT IN ELEMENT 6·

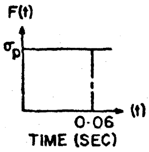


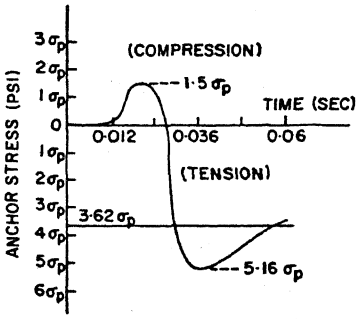
FIG· 3d STRESS IN ELEMENT 92·



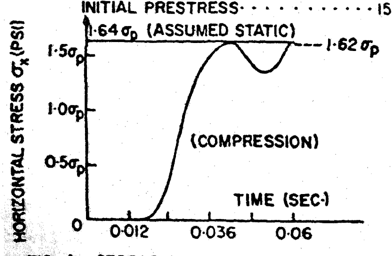
FIG· 4a MESH USED IN CASE OF ROCK BOLTING·

NO· OF NODES	168
TOTAL NO· OF ELEMENTS	316
NO· OF STEEL ANCHORS	36
AREA OF EACH ANCHOR	0·63 IN²
ANCHOR LENGTH	21 FT· (SIDEWALLS) 42 FT (ARCH ROOF)
INITIAL PRESTRESS	150 KSI

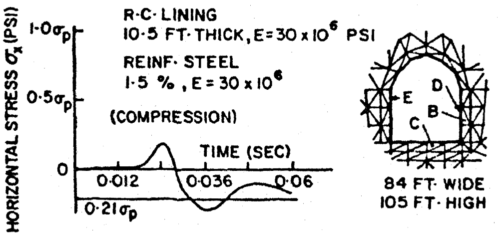




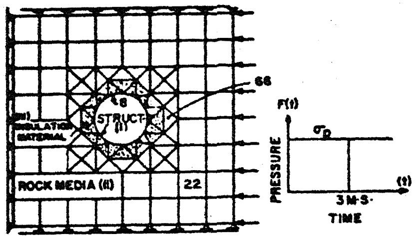
FIG· 4b STRESS IN ELEMENT I (ACTIVE ROCK BOLTING)



FIG· 4c STRESS IN ELEMENT H (ACTIVE ROCK BOLTING)



FIG· 4d STRESS IN ELEMENT B (R·C·LINER)

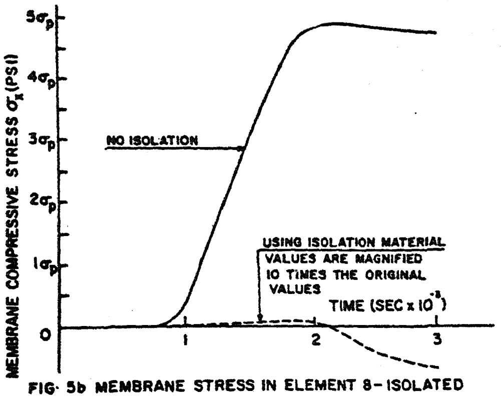


MODEL: STEEL SHELL 84 IN· DIAMETER, 1 IN THICK
PLANE STRAIN ANALYSIS
100 N·P·, 120 EL· INCLUDING
12 SHELL EL·

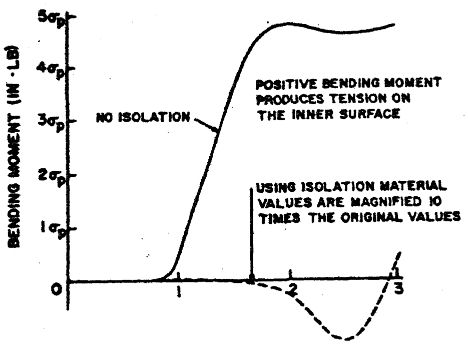
MATERIALS: i) STEEL: ρ = 0·000735, ν = 0·3, E = 29 x 10^6
ii) ROCK: ρ = 0·00025, ν = 0·3, E = 5 x 10^6
iii) CLOSED CELL POLYURETHANE FOAM:
ρ = 6 x 10^{-6}, ν = 0·3, E = 1400
THICKNESS = APPROX· 1/4 SHELL DIAM·

UNITS: INCH, LB·, SEC·

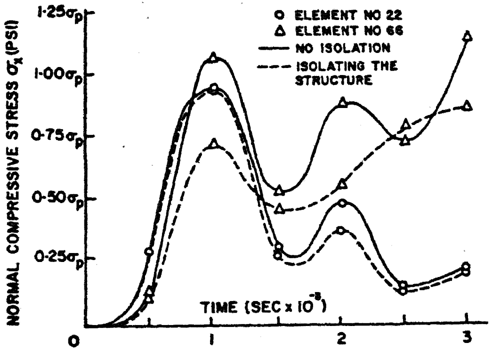
FIG· 5a ISOLATED STRUCTURE



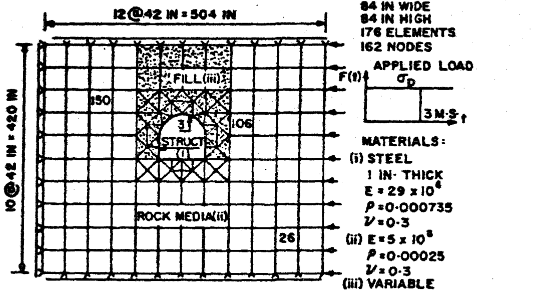
FIG· 5b MEMBRANE STRESS IN ELEMENT 8-ISOLATED STRUCTURE·



FIG· 5c BENDING MOMENT IN ELEMENT 8-ISOLATED STRUCTURE·



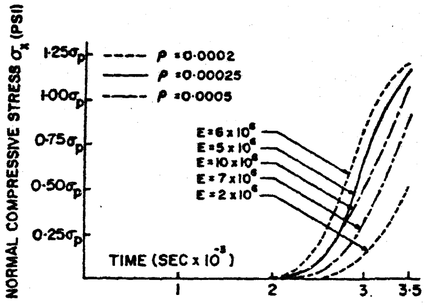
FIG· 5d STRESS IN ELEMENTS 22 AND 66-ISOLATED STRUCTURE·



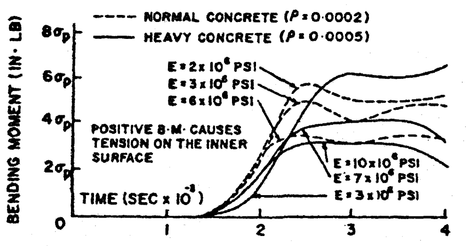
MODEL:
PLANE STRAIN ANALYSIS
84 IN WIDE
84 IN HIGH
176 ELEMENTS
162 NODES
APPLIED LOAD

MATERIALS:
(i) STEEL
1 IN· THICK
E = 29 x 10^6
ρ = 0·000735
ν = 0·3
(ii) E = 5 x 10^6
ρ = 0·00025
ν = 0·3
(iii) VARIABLE

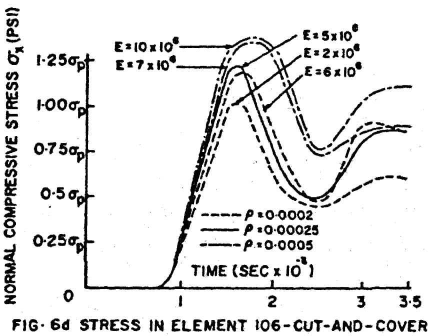
FIG· 6a MODEL USED FOR CUT-AND-COVER STRUCTURE



FIG· 6b STRESS IN ELEMENT 150-CUT-AND-COVER STRUCTURE



FIG· 6c BENDING MOMENT IN ELEMENT 3-CUT-AND-COVER STRUCTURE·



FIG· 6d STRESS IN ELEMENT 106-CUT-AND-COVER STRUCTURE