CALCULATION OF EXTERNAL PRESSURE FROM TUNNEL MAGAZINES USING AUTODYN-2D

James E. Tancreto and Kevin Hager
Naval Facilities Engineering Service Center
Port Hueneme, CA

26th Department of Defense Explosives Safety Seminar
Doral Resort and Country Club
Miami, Florida
16 - 18 August, 1994

ABSTRACT

This paper summarizes a tunnel parameter study with a commercially available hydrocode, AUTODYN-2D, run on PC's (486-33, 486-66, and Pentium). Results from straight "shotgun" tunnels, tunnels with a chamber, and tunnels with chambers and a closure block ("KLOTZ") are compared to test data and DOD safe distance criteria. The usefulness of conducting the analysis with AUTODYN on a PC is also evaluated for ease of use, accuracy, and speed. Analytical results compared well with test data, the hydrocode was easy to use, and with software enhancements, improved hardware, and user experience the analysis speed has become adequate.

INTRODUCTION

Background

A large data base from small scale and some full scale tests has been accumulated on the external pressures from detonations in tunnel magazines. This data has been used to develop very good empirical relationships for predicting external pressure as a function of the basic variables: explosive weight, chamber and tunnel volume, exit area (or hydraulic diameter) and range from the exit. However, not all tunnels conform to the basic tunnel configurations represented by most of the data. 'Hydrocodes' provide an analytical tool that should be very well suited to predicting the effects of tunnel configuration on external pressures. However, this type of code has required experienced users with access to high speed computers. Advances in software and personal computers (e.g. 486 and Pentium PC's) have made hydrocodes available to an increasing number of researchers and analysts. Although

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**
4. TITLE AND SUBTITLE **Calculation of External Pressure from Tunnel Magazines Using Autodyn-2D**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Facilities Engineering Service Center, ,1100 23rd Street,Port Hueneme,CA,93043**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.**		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**18**	

experience in use of the software will always be required, the software and computers are available for inexpensive, adequately fast, hydrocode analysis on PC's. This paper summarizes a tunnel parameter study with a commercially available hydrocode, AUTODYN-2D, run on PC's (486-33, 486-66, and Pentium-60).

Purpose

The purpose of this paper is to (1) conduct a parameter study on the effect of basic tunnel parameters (explosive weight, W; total tunnel volume, V; and exit diameter, D) on the peak side-on overpressure (P) vs. range (R), and (2) evaluate the utility of performing the study with a PC based hydrocode.

Scope

Two basic tunnel configurations are studied (straight "shotgun" tunnels, and tunnels with chamber) and the results are compared to test data and DOD safety criteria. The main variables are charge weight to volume ratio, W/V, and the tunnel exit diameter, D. The effects of charge location, number of exits, and passive closure "KLOTZ" blocks are also investigated.

ANALYSIS

Modeling

The basic tunnel models are shown in Figure 1 and the exterior space model is shown in Figure 2. Figures 1 and 2 also show the location of analytical target points (1 through 16) at which data was saved vs. time. Typical pressure history plots are shown in Figure 4 at Targets 9, 10, and 11 (R/D's of 13.4, 18.7, and 24.1). Two-dimensional axial symmetry models were used. The chamber and tunnel were modeled with 40 cm by 40 cm elements as shown in Figure 3. The external space was modeled with a variable sized elements (40 x 40 cm at tunnel exit to 360 x 360 cm at a range of 375 m. The initial models consisted of about 20,000 elements. These dimensions were chosen from a preliminary study of element size vs. accuracy and speed. The original AUTODYN-2D version was limited to 20,000 elements on a PC with 16 MB of RAM. User experience and software enhancements (remapping) allowed the use of a 1D wedge for the spherical shock wave expansion at lower pressures outside the tunnel. This greatly reduced the number of elements and the time to solve for low pressures at large ranges. The total time for a solution of the original 20,000 element model on a 486-33Mhz PC with 16MB of RAM was 1-2 weeks (and more). Improvements in modeling and speed (with 486-66Mhz and Pentium-60 PC's) allowed solutions in 6 - 12 hours. Accuracy was also improved. (Sample runs on SUN workstations showed a SPARC 2 to be about as fast as a 486-66 and a SPARC 10 to be about the same speed as a Pentium-60.)

Figure 5 compares an AUTODYN calculation with test data for spherical detonation in free air. The AUTODYN element size increased with range to maintain about 50 elements per positive phase. The full grid tunnel runs used about one-third that number of elements per positive phase. In later runs with enhanced software, the speed of the calculations using a 1D wedge (remapped from the full grid) allowed the use of smaller elements for improved accuracy.

A JWL Equation of State (EOS), from the AUTODYN material library, was used for TNT and air was modeled as an ideal gas. The Euler numerical solver was used. The closure block was originally modeled with Euler elements. Future runs will use Lagrange elements for the closure block and Euler elements for the TNT and air.

Straight "Shotgun" Tunnels

The straight tunnel models were 75.2 m long with diameters of 6.4 m and 9.6 m. W/V varied between 5 and 78 kg/m^3 (0.3055 and 4.89 pcf). Representative results are shown and compared to Naval Civil Engineering Laboratory (now NFESC) straight tunnel test data and DOD criteria in Figures 6 through 9. At the low pressures of interest for determining safe inhabited building distances, the calculations and test data are in good agreement and are slightly less than the DOD criteria.

The effects of two opposite exits (no interaction between the pressures from the two exits) are shown in Figures 10 and 11. A second exit significantly reduces the range for safe inhabited building distance. (DOD criteria for peak pressure at inhabited buildings = 0.9 to 1.2 psi).

Tunnels with Chamber

The tunnel with chamber model generally used a 28 m length chamber with a diameter of 20 m and a tunnel with a length of 23.6 m and a diameter of 6.4 m. Tunnel diameters of 5.6 and 9.2 m were also analyzed. W/V varied (by changing W) between 5 and 35 kg/m^3 (0.3055 and 2.2 pcf). Representative results are shown and compared to test data and DOD criteria in Figures 12 through 14.

Excellent agreement is found for W/V 1.2. The calculated scale pressures fort W/V = 0.3 (see Figure 13) were lower than the scaled pressures for higher W/V's and lower than the DOD criteria.

Tunnels with Chamber and Closure Block

Only one closure block geometry has currently been run. It was run to demonstrate the method rather than to model a specific prototype. A more complete parameter study will be completed this FY. The geometry of the modle is generally the same as the basic chamber model (28 m long by 20 m diameter chamber; 23.6 m long by 6.4 m diameter tunnel). The geometry was changed slightly, as shown in Figure 1, to reduce the pressures behind the block to allow the block to close faster (the diameter of the chamber was increased to obtain a W/V of 1.2 for comparison to the basic chamber model without block). A 1.2 m thick by 6.4 m diameter closure block weighing 155 pcf was modeled. It was given enough strength to keep deformation within functional limits.

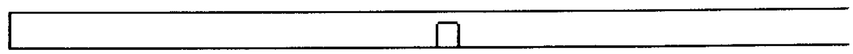
Results are shown in Figure 15. Comparisons of the configuration with no block, with a fixed block (280 cm from the tunnel) and a moveable block (with an original 280 cm setback) show a significant reduction in pressure vs. range, especially at the low pressures. The range for1 psi is reduced by a factor of more than 3 by the closure block.

CONCLUSIONS

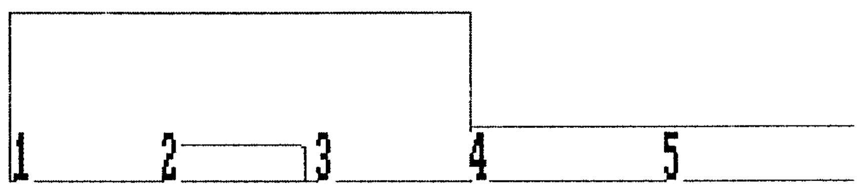
The parameter study showed that the DOD criteria with R/D = f(W/V, P) adequately accounts for most tunnel design variables. Multiple exits and passive closure blocks, not accounted for in the DOD criteria, can significantly reduce safe pressure ranges. The DOD criteria may also be overly conservative for small loading densities (W/V.'s) <about 5 kg/m^3.

In the beginning of the study AUTODYN-2D was too slow for efficiently calculating the low pressure (P < 5 psi) outside a tunnel. This was partly due to the inexperience of the users. Experience, software enhancements, and hardware upgrades have made AUTODYN-2D a valuable tool in our explosive safety work (for much more than pressure predictions). The solution speed has improved at least 10 times in the 3 years we have been using it. The combined Euler and Lagrange processors are very valuable in determining structural response to air shock and debris impact loads. Accuracy, where it could be verified, has been good. The ease of use, especially the interactive graphical input and output, is excellent.

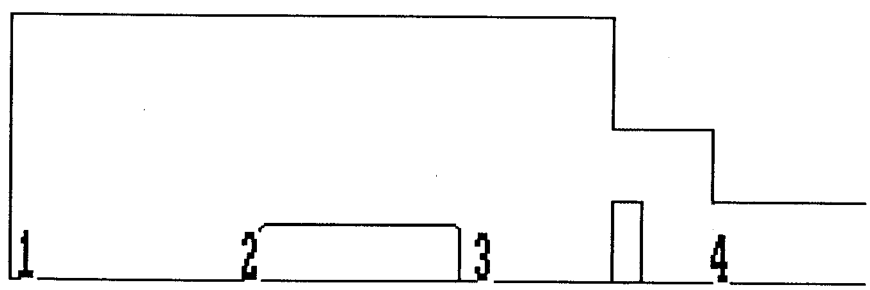
FIGURE 1.



STRAIGHT TUNNEL



TUNNEL WITH CHAMBER



TUNNEL WITH CHAMBER AND CLOSURE BLOCK

Figure 1. Tunnel Model Configurations

FIGURE 2.
AND
FIGURE 3.

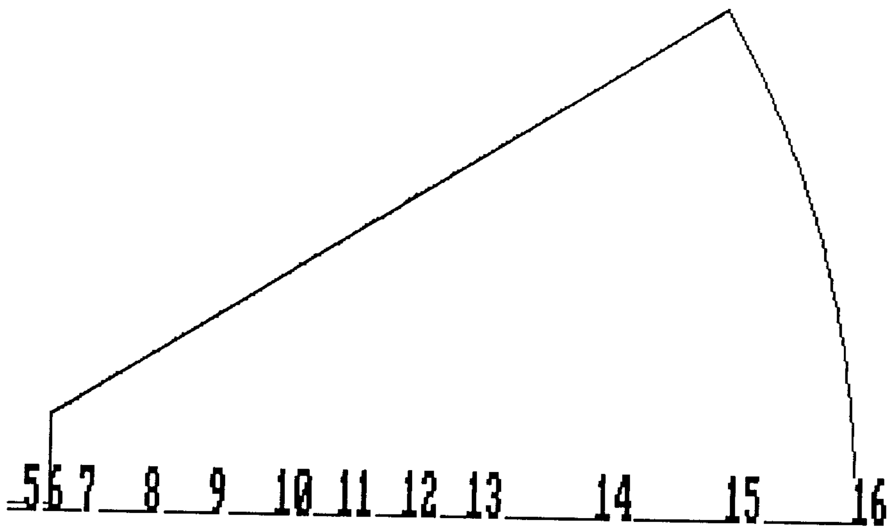


Figure 2. External Space Model and Target Points

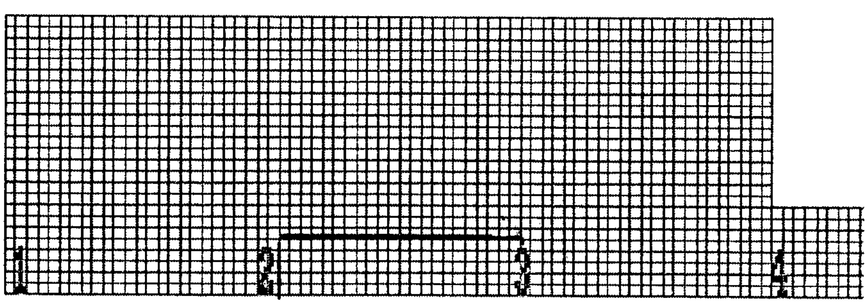


Figure 3. 40 cm x 40 cm Element Grid in Chamber

FIGURE 4.

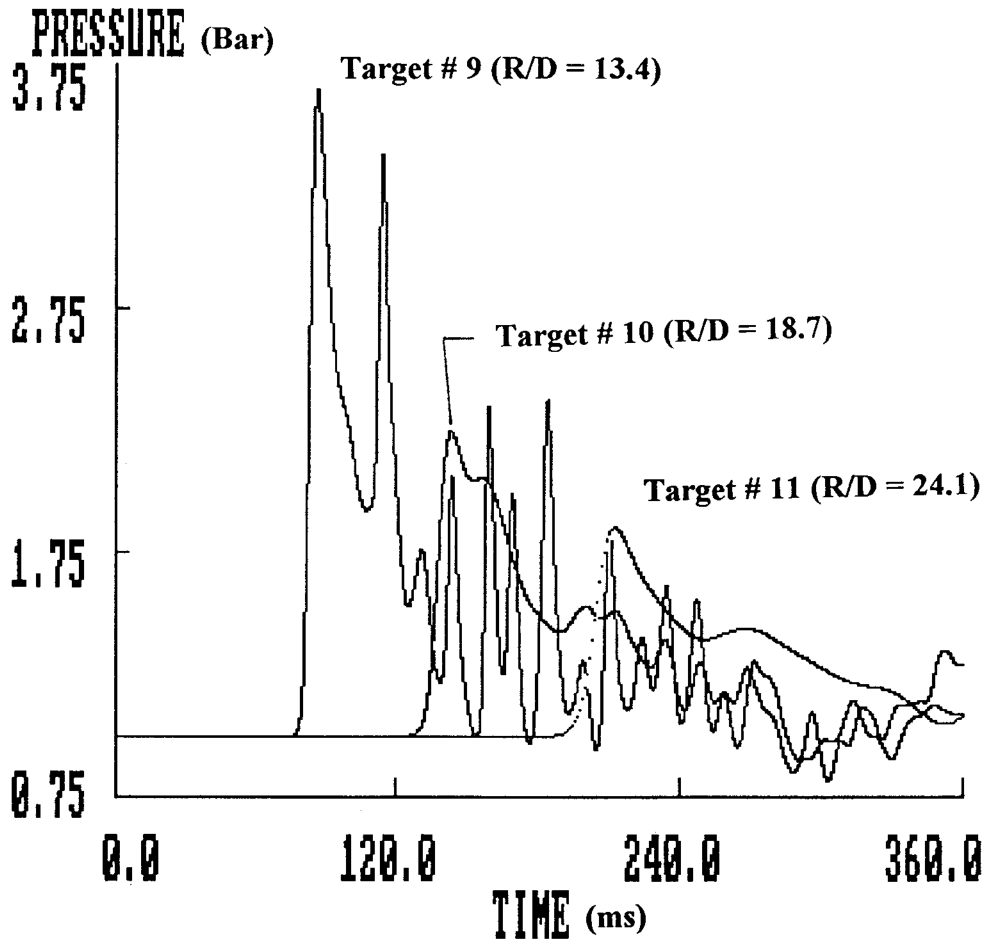


Figure 4. Typical Pressure History Plots

FIGURE 5

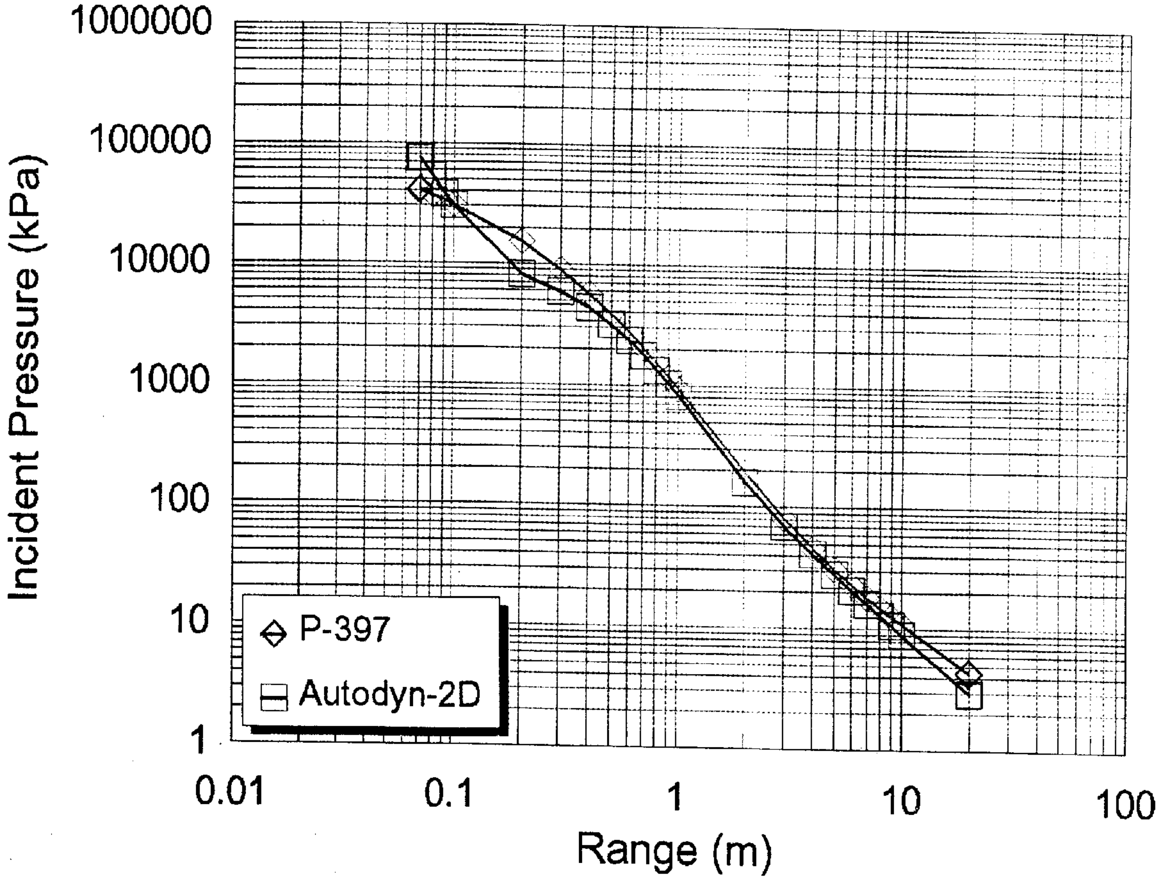


Figure 5. **Calculated (AUTODYN) vs. Empirical Peak Pressure vs. Range for a Spherical TNT Free Air Burst (50 elements in positive phase)**

FIGURE 6.

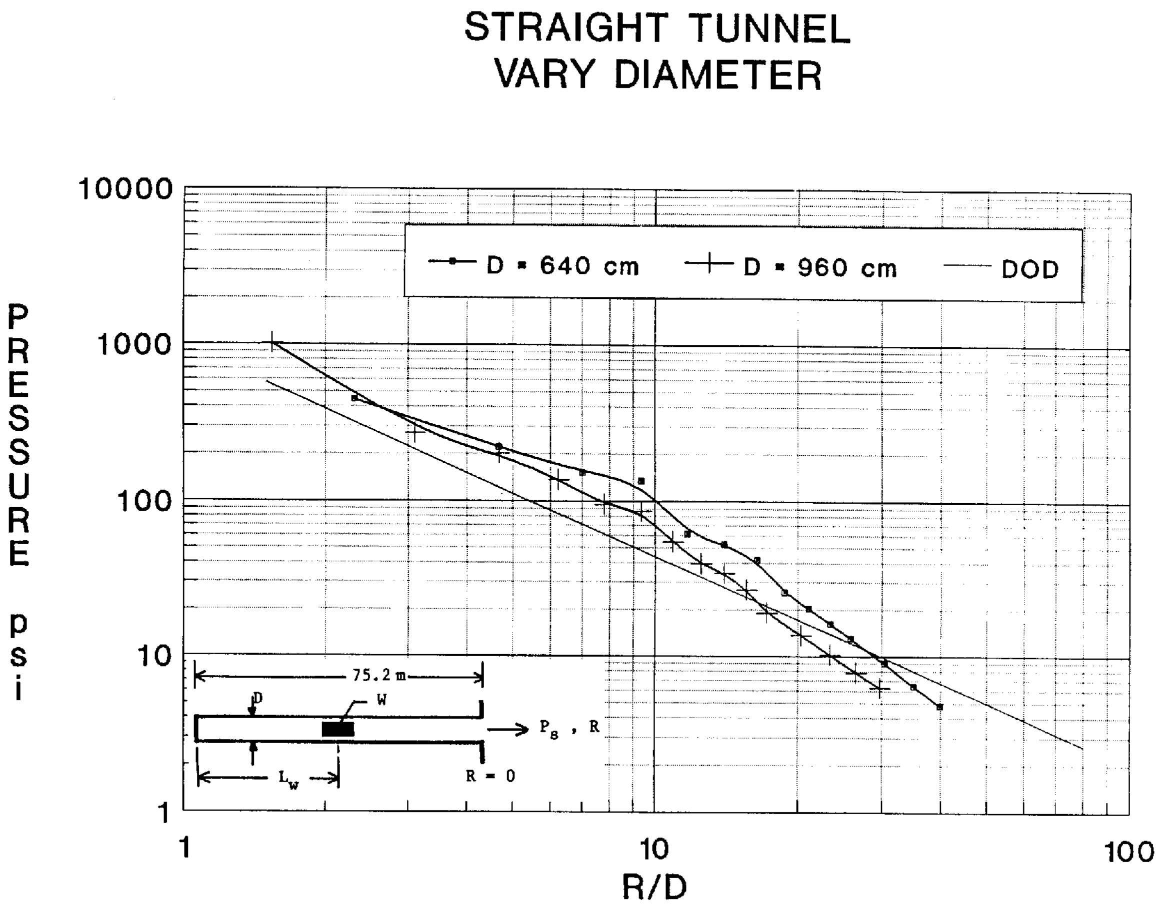


Figure 6. Calculated Peak Pressure vs. Scaled Range for Straight Tunnel W/V = 1.22; Variable Diameter

FIGURE 7.

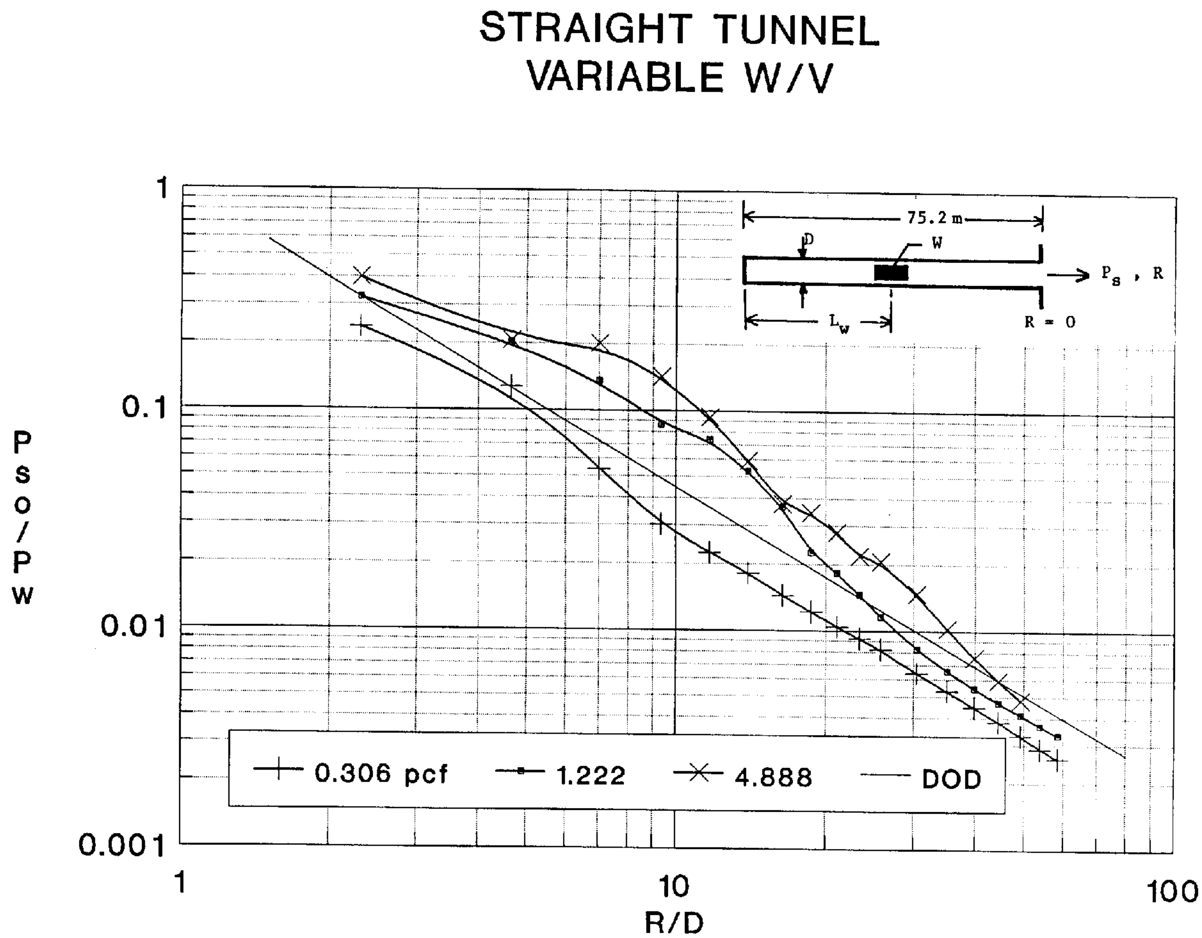


Figure 7. Calculated Scaled Peak Pressure vs. Scaled Range for Straight Tunnel
D = 6.4; Variable W/V

FIGURE 8.

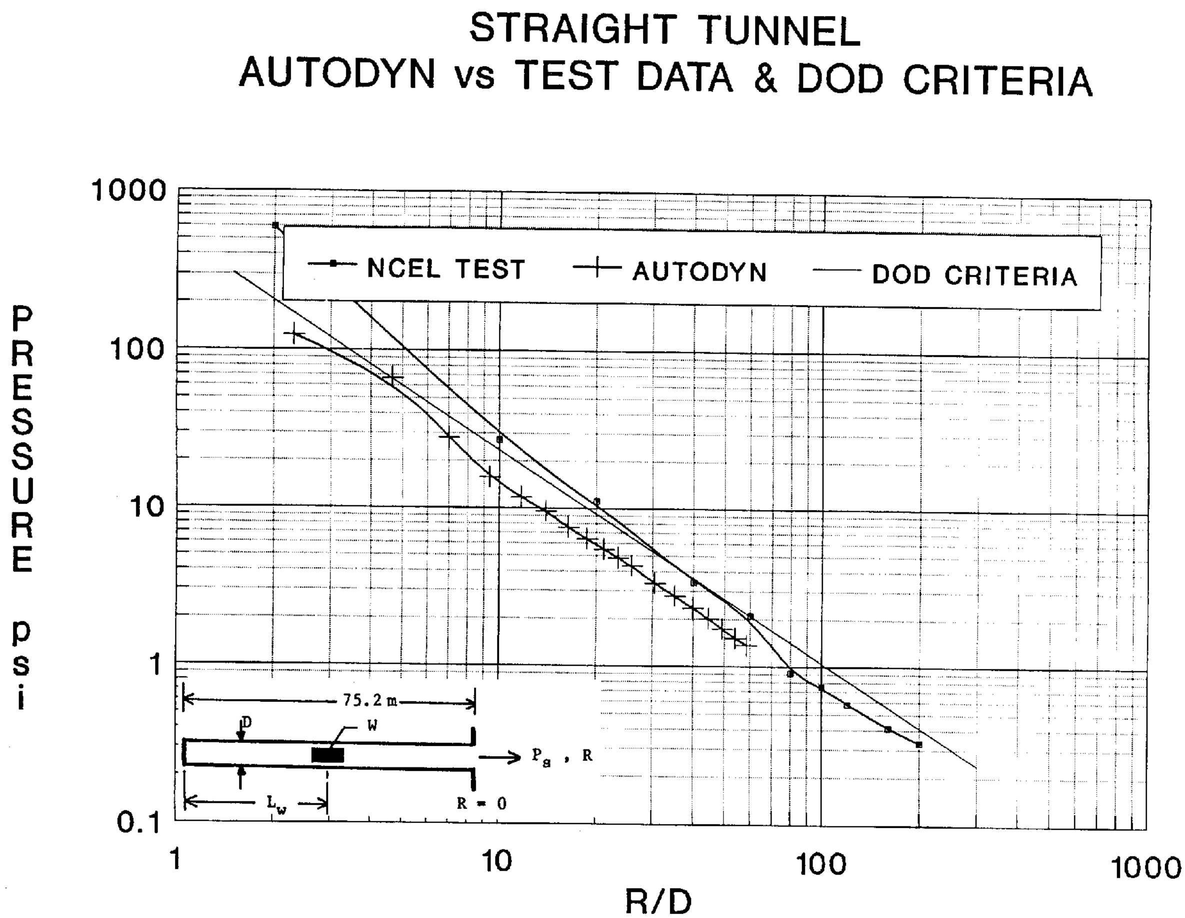


Figure 8. Calculated & Measured Peak Pressure vs. Scaled Range for Straight Tunnel with W/V = 0.3055 pcf

FIGURE 9.

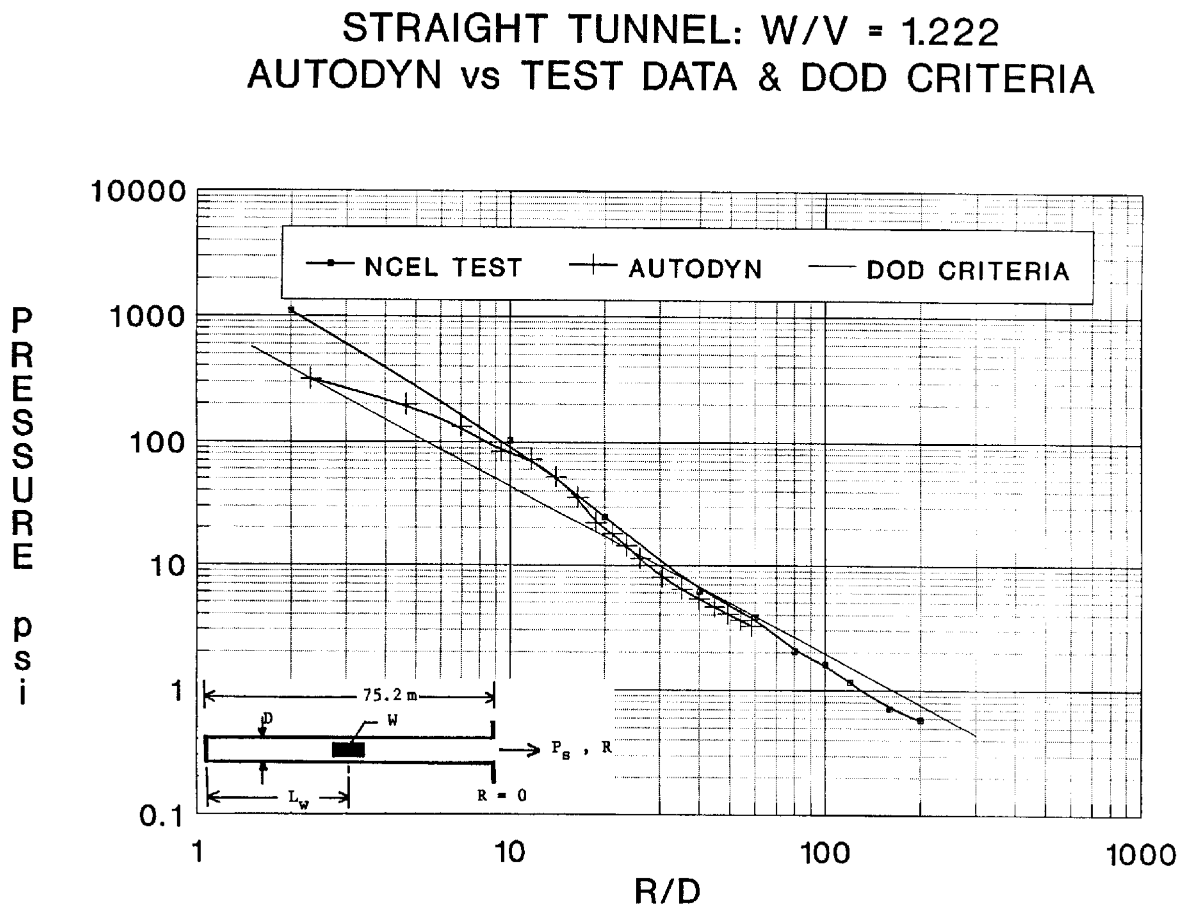


Figure 9. Calculated & Measured Peak Pressure vs. Scaled Range for Straight Tunnel with W/V = 1.22 pcf

FIGURE 10.

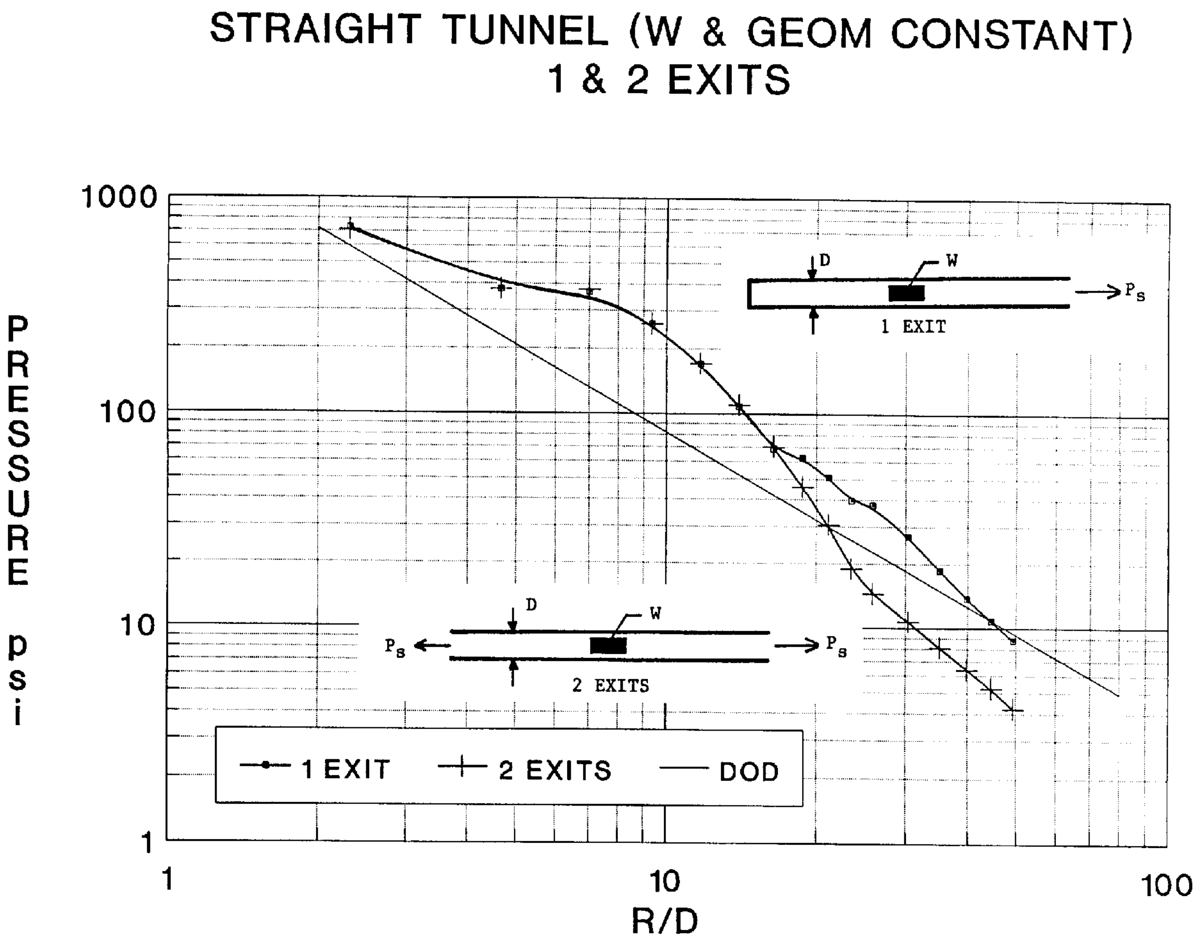


Figure 10. Calculated Peak Pressure vs. Scaled Range for Straight Tunnel One & Two Exits

FIGURE 11.

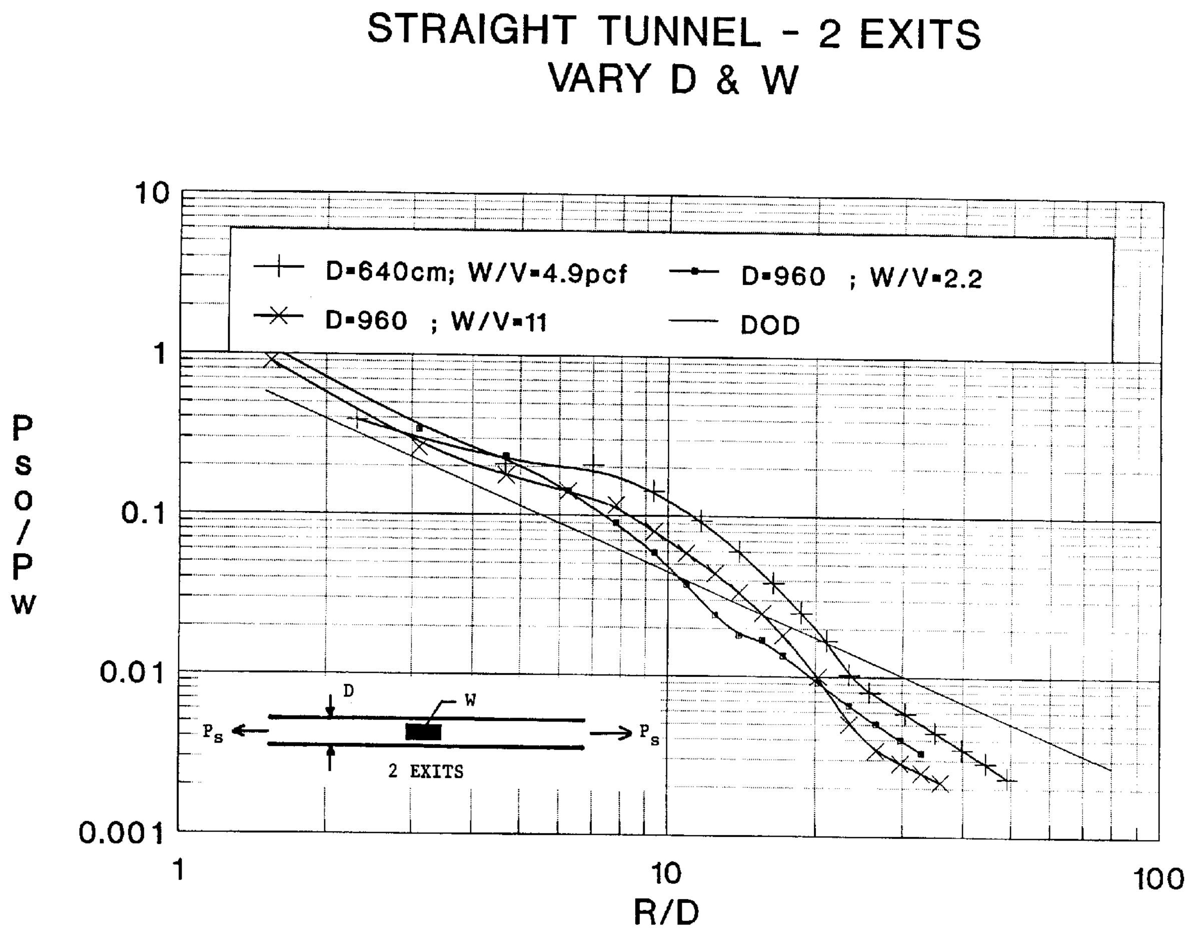


Figure 11. Calculated Peak Pressure vs. Scaled Range for Straight Tunnel Two Exits; Variable D & W

FIGURE 12.

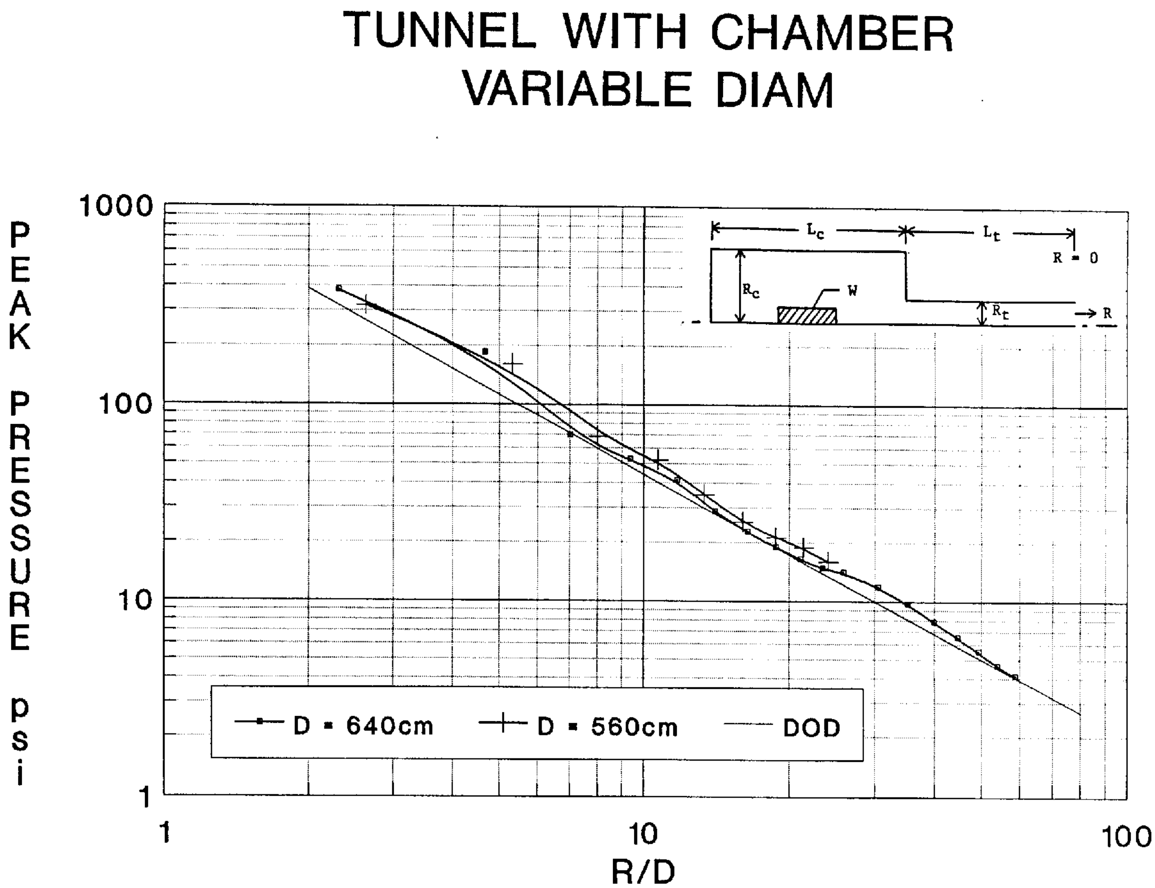


Figure 12. Calculated Peak Pressure vs. Scaled Range for Tunnel with Chamber W/V = 1.22; Variable D

FIGURE 13.

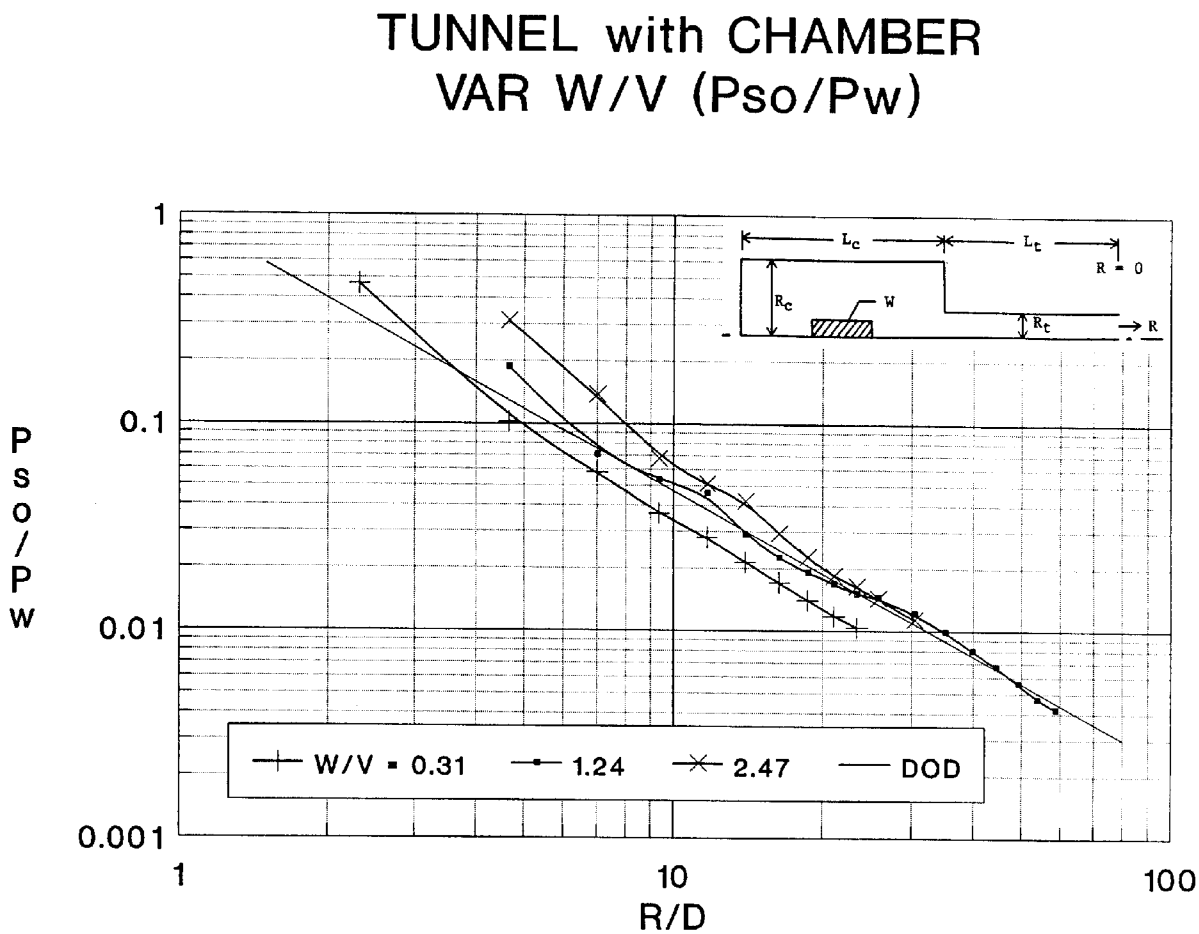


Figure 13. **Calculated Scaled Peak Pressure vs. Scaled Range for Tunnel with Chamber (V = Constant; Vary W)**

FIGURE 14.

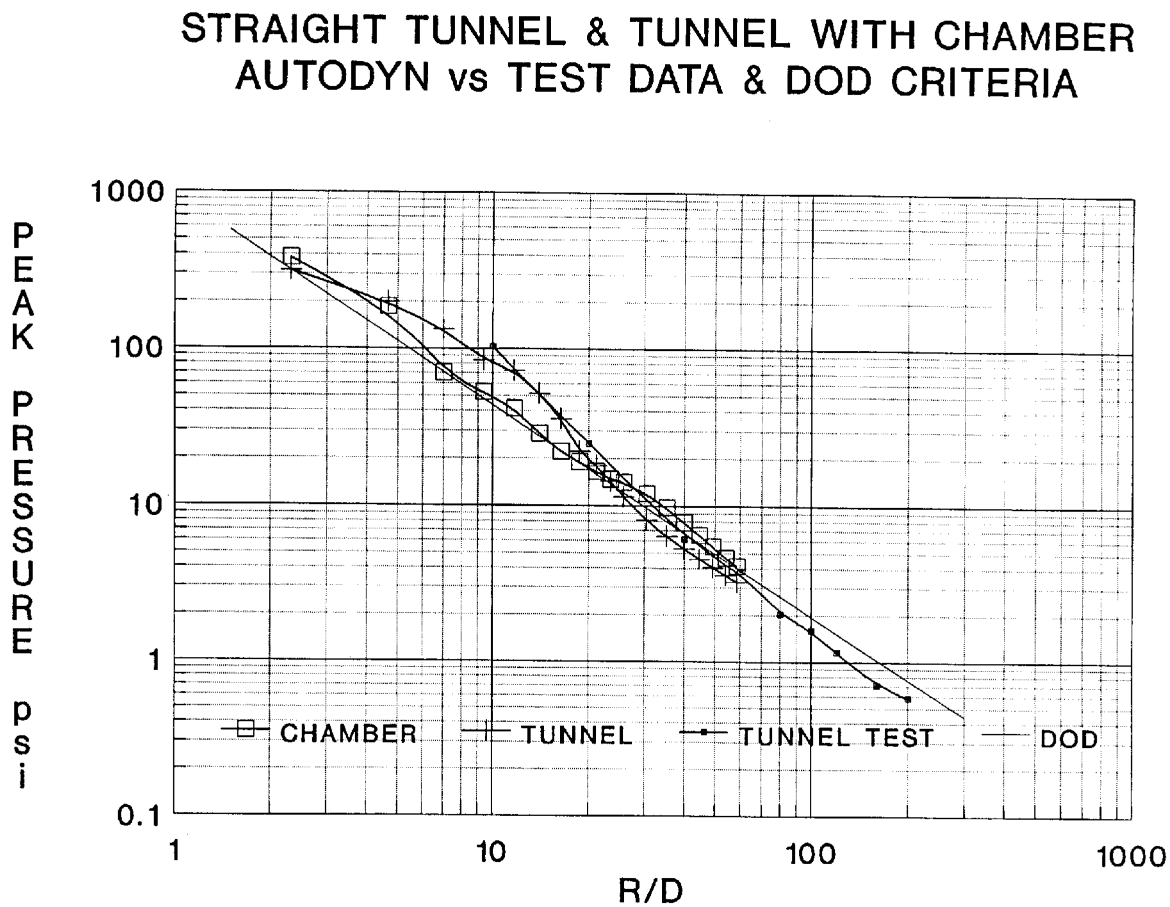


Figure 14. Calculated & Measured Peak Pressure vs. Scaled Range for Tunnels with and without Chamber

FIGURE 15

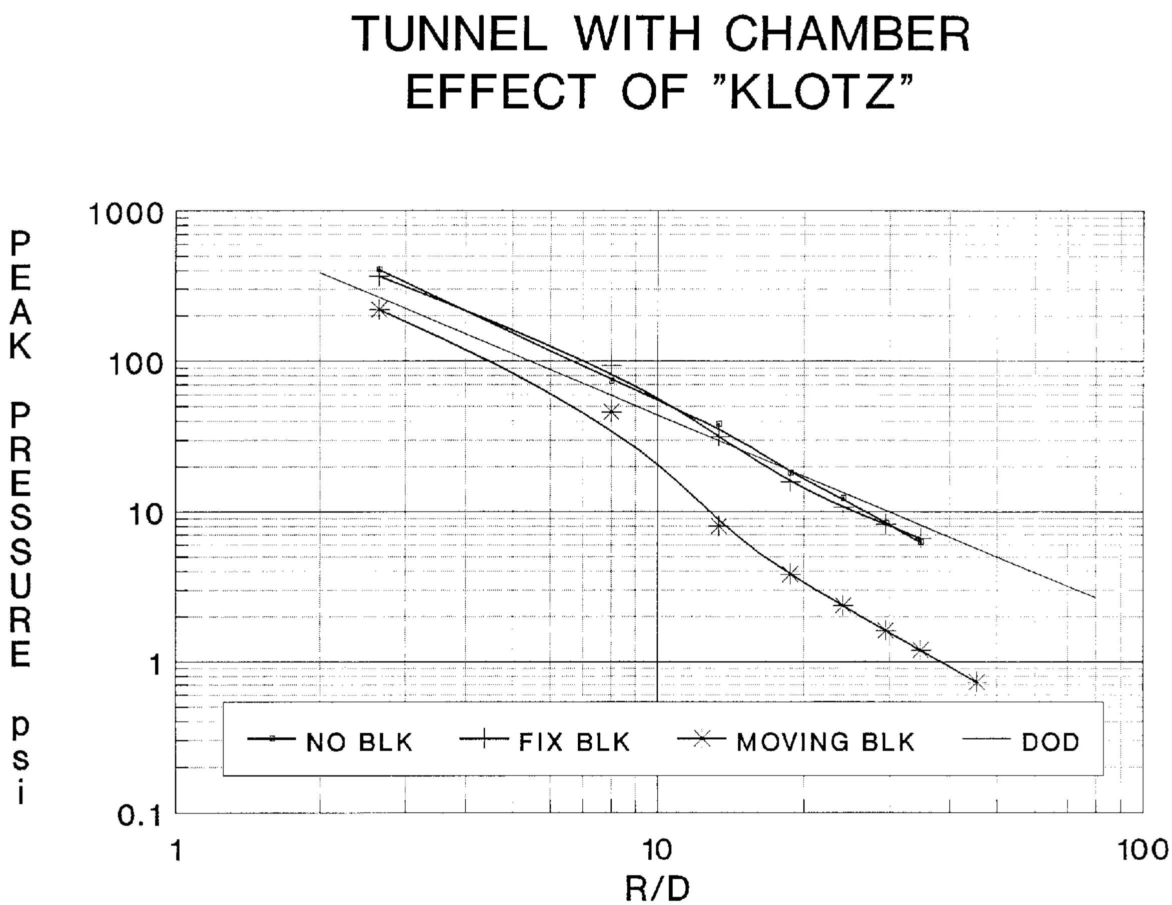


Figure 15. Calculated Peak Pressure vs. Scaled Range with and without a "Klotz" Closure Block (625 psf).