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STEMMING AND CONTAINMENT PHENOMENOLOGY FOR THE HYBLA FAIR EVENT

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April 9, 1980

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INTRODUCTION

The Hybla Fair underground nuclear event was conducted by the Defense Nuclear Agency (DNA) to assess the feasibility of using low yield devices to reduce the expense of nuclear weapons effects testing. The economy of low yield tests was facilitated by placing of the test bed chamber closer to the source, thereby allowing the use of a shorter horizontal line-of-sight (HLOS) tunnel than used for higher yield testing. The philosophy incorporated in the design of the Hybla Fair tunnel and stemming plan reflected the ideas of many interested parties. Complete details of the design and rational along with experimental results for the event are given in Reference 1.

One main design concern for the Hybla Fair event centered around the desire for the radiation environment in the test chamber to be equivalent to that of higher yield tests. This concern imposed a severe constraint on the stemming column design, which was to increase the angle subtended by the shorter tunnel out to the test chambers to a taper greater than that normally used. Experience with low yield underground nuclear events indicated that the possibility of cavity gas leakage would be significantly higher than for the usual range of yields used in weapon effects tests. After detonation cavity gases were in fact detected at late time in the unstemmed portion of the U12n.09 drift. Subsequent mineback into this drift showed highly fractured and blackened debris in the stemming plug region close to work point. Further down, the tunnel was lined with glass indicating exposure to the hot cavity gases. The intent of the present report is to focus on the phenomenology of the stemming closure process for the Hybla Fair event and on the mechanism or mechanisms leading to failure of the stemming plug.

CALCULATIONAL APPROACH

To prevent cavity rupture and the venting of cavity gases from occurring in future low yield tests, it is important to derive an understanding of the phenomenology of stemming plug formation and its subsequent integrity in a highly tapered HLOS configuration. This report discusses numerical simulations of the stemming plug formation and the subsequent behavior of the stemming region during the development of the containment zone around the cavity for the Hybla Fair event. Two calculations were performed with an explicit finite-difference two-dimensional Lagrangian code, TENSOR (References 2 and 3), using an Arbitrary Lagrangian Eulerian (ALE) treatment in the stemming closure region.

The Hybla Fair stemming configuration was highly asymmetric with the tunnel off center in the stemming column and three concrete baffles keyed into the column (Figure 1). The end baffles were located on the bottom of the tunnel, and the middle one was positioned on the top of the tunnel. They were keyed into the grout and tuff to impede motion along the grout-tuff interface and to reduce the potential of late time extrusion of stemming material outward. An exact numerical simulation of the stemming behavior is not possible without recourse to a three-dimensional code. To circumvent this limitation somewhat, two axially-symmetric 2-D TENSOR calculations were performed. The configurations are shown in Figure 2. The first calculation, denoted as Case A, models the three asymmetric concrete baffles in the stemming column as symmetric "donuts." In the other calculation, denoted as Case B, they are removed and replaced by stemming material. The constitutive properties used for all the stemming materials and the surrounding tuff were the same for both calculations (Figure 3). Some specific objectives of this calculational effort are: (1) to study the phenomenology of ground shock induced stemming plug formation for low yield events, (2) to assess the effect of baffles on the stemming process, and (3) to evaluate the integrity of the stemming closure region for containment of cavity gases.

CALCULATIONAL RESULTS

An examination of the calculations, with baffles (Case A) and without baffles (Case B), provides important insight into the closure process associated with a divergent stemming configuration and illustrates the influence of the baffles on this process. The phenomenology of the two calculations are compared in Figure 7. A comparison of the results of the two calculations show the following features (Figures 7-30):

- o A high velocity (jet-type) flow of grout develops very early in the stemming closure process along the axis of the tunnel (Figures 8-11). The tendency for jetting ceases around 3.2 ms when the velocity of the jet has decreased to the level of the closure rate of about 1300 m/s (Figure 9). The baffles do not influence the jetting process because the ground shock has not interacted with the first baffle by 3.2 ms.
- o Although the formation of the stemming plug is somewhat similar for both cases out to about 10 ms, the ultimate effect of the baffles is to retard the growth of stemming plug and shorten its length (Figure 12). The stemming plug thickness for Case A is 8.9 m or 1.27 R_c (cavity radius) while for Case B the stemming plug thickness is 15.6 m or 2.23 R_c. Stemming plug growth ceases in both cases around 30 ms.

- For Case A a portion of superlean grout collapses on the tunnel axis at about 20.6 ms well ahead of the slowly advancing stemming plug, thus forming a bubble under the second and third baffles in the rock matching-superlean grout region (Figures 12-14). The bubble remains formed throughout and after the rebound phase and residual stress cage development.
- Passage of the ground shock induces hoop stress tensile failure in portions of the baffles with radial cracks aligned parallel to the tunnel axis (Figure 20).
- The residual stress cage thickness formed in the stemming region, 0.7 R_c for Case A and 1.6 R_c for Case B is significantly thinner than that for the free field region of 4.2 R_c and is degraded by the presence of the baffles (Figures 23-30).
- No extrusion of grout through the keyway is observed in either case out to the end of calculations at 80 ms.

FAILURE SCENARIO

A phenomenological scenario of events which occurred after detonation of the Hybla Fair event has been reported previously (References 4 and 5). This scenario was based on active experimental measurements reported in Reference 1, on mineback reentry observations presented in Reference 6, and on some calculational results given in Reference 4. These calculations were for large yield stemming designs with dimensions scaled down to the Hybla Fair yield. The results from the present calculations support some of the phenomenology of that scenario and provide more definitive information on which to speculate reasons for failure of the stemming plug region.

A brief summary of a proposed scenario based on the data observations and arguments previously reported in References 1, 4, 5, and 6, and augmented by the present calculations is as follows. Upon detonation of the device, high energy plasma propagated down the HLOS tunnel ahead of the ground shock-induced closure and pressurized the tunnel. The plasma was followed by debris resulting from early collapse induced jetting of the grout column. Both the plasma and the grout jet debris would have caused considerable damage to structures in the test chamber and drift complex. The ground shock formed a stemming plug which came to rest, isolating the cavity from the unstemmed portion of the tunnel. Tensile fractures developed in the concrete baffles during motion subsequent to the passage of the ground shock. During the rebound phase of the ground shock and residual stress cage formation, portions of grout from the bypass drift and some tuff fractured and dropped into the cavity. The high temperature environment in the cavity resulted in the liberation of water in the form of steam from the sloughed material causing an increase in cavity pressure. The increased cavity pressure induced a hydrofracture-type failure in the thin stemming plug region which communicated with the first fractured baffle and allowed cavity gas to leak slowly into unstemmed portion of the tunnel. A continual buildup of cavity pressure, resulting from the generation of steam, finally resulted in removal of the stemming plug from the vicinity of the cavity. Later rubble from collapse of the chimney spilled into the HLOS tunnel near the cavity.

CONCLUSIONS AND RECOMMENDATIONS

The calculated results and the figures attached illustrate the phenomenology of the stemming closure, flow field rebound, and residual stress cage formation processes out to 80 ms where equilibrium is firmly established. The conclusions from these calculations which lend support to the above scenario are: (1) Jetting which formed early in the collapse would have been extremely hazardous to experiments in the test section. The jetting problem is particularly acute for low yield events because of the requirement for a more divergent HLOS. (2) Symmetric baffles clearly inhibit the stemming closure process. Asymmetric baffles may also inhibit or prevent the formation of a competent stemming plug. (3) A residual stress cage is developed but is thinner in the stemming region and degraded by the presence of baffles. (4) Calculated displacements along the grout-tuff interface are small and no noticeable grout extrusion is evident out to 80 ms.

The integrity of the Hybla Fair stemming plug region may have been strongly influenced by the massive asymmetrical baffles. It is recommended to avoid using such baffles in future low yield events. If a highly asymmetric stemming configuration is of future interest, we strongly urge the use of three-dimensional calculations to evaluate its design. It is also recommended to continue investigating ways to prevent or disrupt ground shock induced jetting and perform parametric calculations on laboratory and scaled high-explosive stemming experiments.

REFERENCES

1. William J. Summa, "Hussar Sword Series (U), Hybla Fair Event (U) Preliminary Report (U)," Defense Nuclear Agency, POR-6841, 11 August 1975 (S).

2. D. E. Burton and J. F. Schatz, "Rock Modeling in TENSOR74," Lawrence Livermore Laboratory Report UCID-16719 (1974).

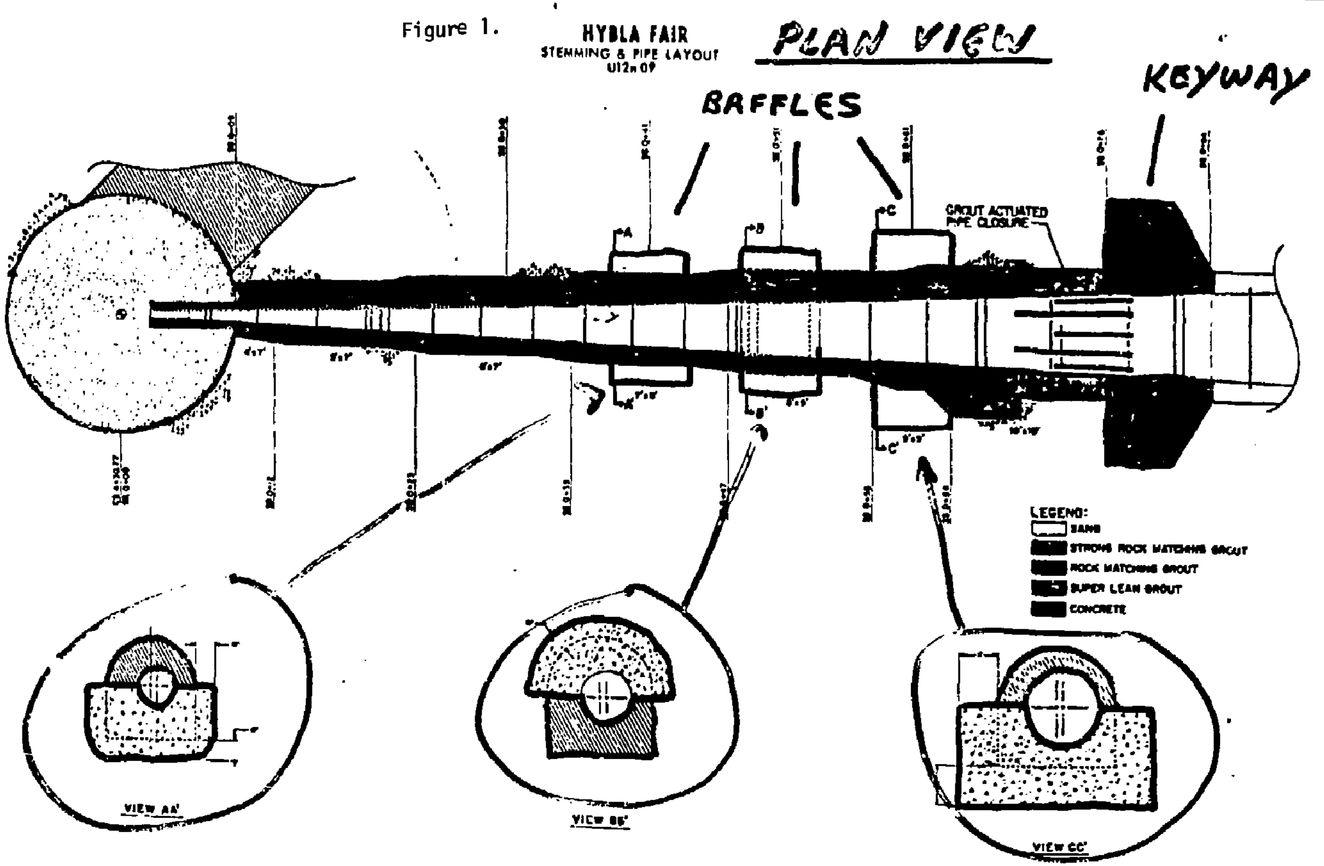
3. G. Maenchen and S. Sack, "The TENSOR Code," Lawrence Livermore Laboratory report UCRL-7316 (1963).

4. G. I. Kent and D. F. Patch, "Hybla Fair Containment Evaluation (U)," Defense Nuclear Agency, DNA-4437F, July 1977 (S).

5. D. F. Patch and G. I. Kent, "Hybla Fair Containment Phenomenology Pacifica Technology FEWOG Presentation," Proceedings of DNA Front End Working Group Meeting, Low Yield Testing (U), June 13-14, 1979.

6. Lawrence J. Gabriel, "U12n.09 Hybla Fair Interior Reentry Report," (Draft) Defense Nuclear Agency Field Command, 20 October 1974 to 2 March 1976.

Figure 1. HYBLA FAIR
STEMMING & PIPE LAYOUT
U12n.09



COMPUTATIONAL CONFIGURATIONS

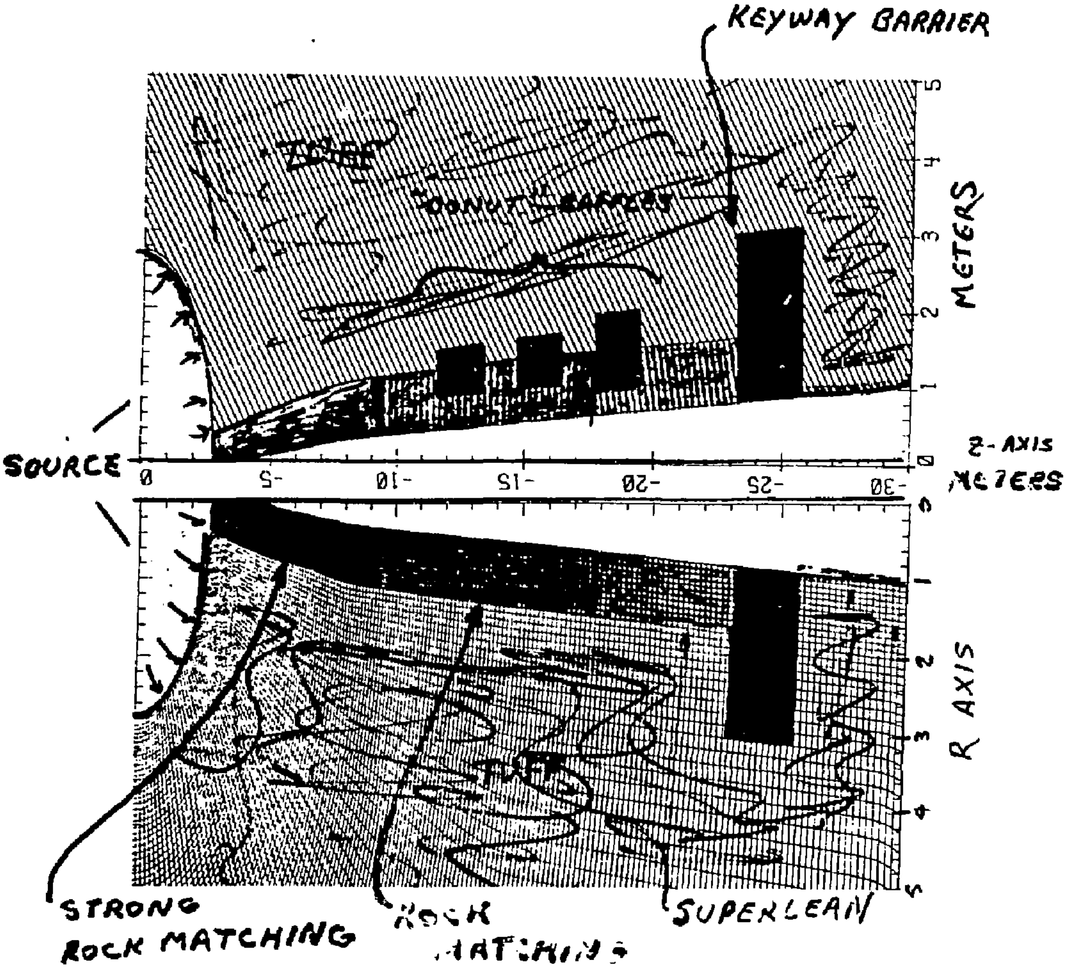


Figure 2. Hybla Fair Calculational Configurations.

Figure 3. **MATERIAL PROPERTIES FOR HYBLA FAIR TENSOR CALCULATIONS**

	TUFF	STRONG ROCK MATCHING GROUT HFRM (CC)	ROCK MATCHING GROUT (DSRM-2)	SUPERLEAN GROVE HSSL-1	CONCRETE MBC (cc)CSII 9.00
ρ_o - gm (cm^3)	2.00	2.09	2.04	1.74	2.290
POROSITY - %	32.0	7.0	4.0	4.2	2.0
WATER - %Wt	15.6				
P_c - BARS	50	100	50	70	400
$Y_{u.c.}$ - BARS	75	135	60	4.5	400
Y_{um} - BARS	100	250	90	6.4	600
P_m - BARS	1000	1000	1250	1000	1000
TENSILE STRENGTH - BARS	-5.0	-12.5	-6.0	0.0	-40.0
C_s - m/sec	2525	2652	2438	1122	3764
POISSON'S RATIO	.25	.300	.33	0.37	0.23

Figure 4. OBJECTIVES

- TO STUDY PHENOMENOLOGY OF GROUND SHOCK INDUCED STEMMING PLUG FORMATION FOR LOW YIELD EVENTS.
- TO ASSESS THE EFFECT OF BAFFLES ON THE STEMMING PROCESS.
- TO EVALUATE THE INTEGRITY OF THE STEMMING CLOSURE REGION FOR CONTAINMENT OF CAVITY GASES.

Figure 5. COMPUTATIONAL APPROACH

- HYBLA FAIR STEMMING CONFIGURATION WAS ASYMMETRIC
  TOTAL SIMULATION REQUIRES 3 D CODE.

- REPRESENT STEMMING IN AXISYMMETRICAL CONFIGURATION USING 2-D EXPLICIT FINITE DIFFERENCE CODE. TENSOR

- TWO CALCULATIONS PERFORMED

  GEOMETRY
  - WITH BAFFLES
  - WITHOUT BAFFLES

Figure 6. CALCULATIONAL CONCERNS

- RESPONSE IN STEMMING REGION IS OF PRIME CONCERN.

  HIGH DEGREE OF RESOLUTION FOR STEMMING REGION EMPLOYED IN CALCULATIONS. 1650 ZONES

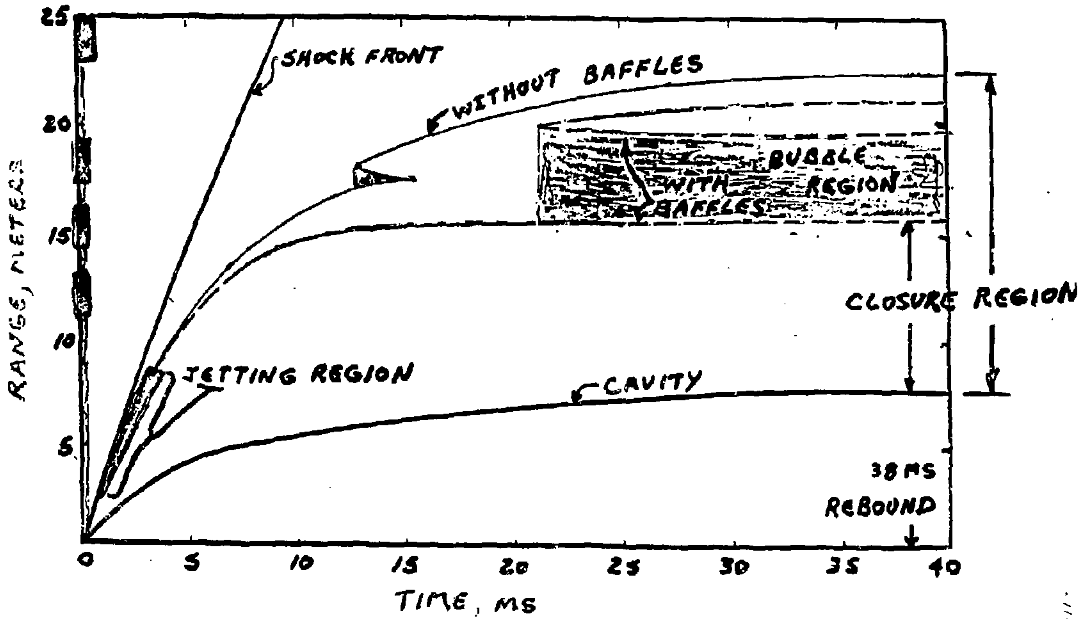
- ON-AXIS COLLAPSE OF GROUT CAUSES EXTREME MESH DISTORTION AND LEADS TO NUMERICAL INACCURACY.

  THE ARBITRARY LAGRANGIAN EULERIAN (ALE) TECHNIQUE IS USED IN STEMMING REGION. — — — LAGRANGIAN STEP FOLLOWED BY "EULERIAN" REMAP TO A RELAXED MESH.

- CARRY CALCULATION OUT IN TIME FAR ENOUGH TO INCLUDE RESIDUAL STRESS CAGE FORMATION AND TO ESTABLISH STRESS EQUILIBRIUM WITHOUT ADVERSE EFFECTS.

  CALCULATION PERFORMED OUT TO 80 MS WITH OUTER BOUNDARY AT 150 METERS.

Figure 7. PHENOMENOLOGY OF HYBLA FAIR CALCULATIONS



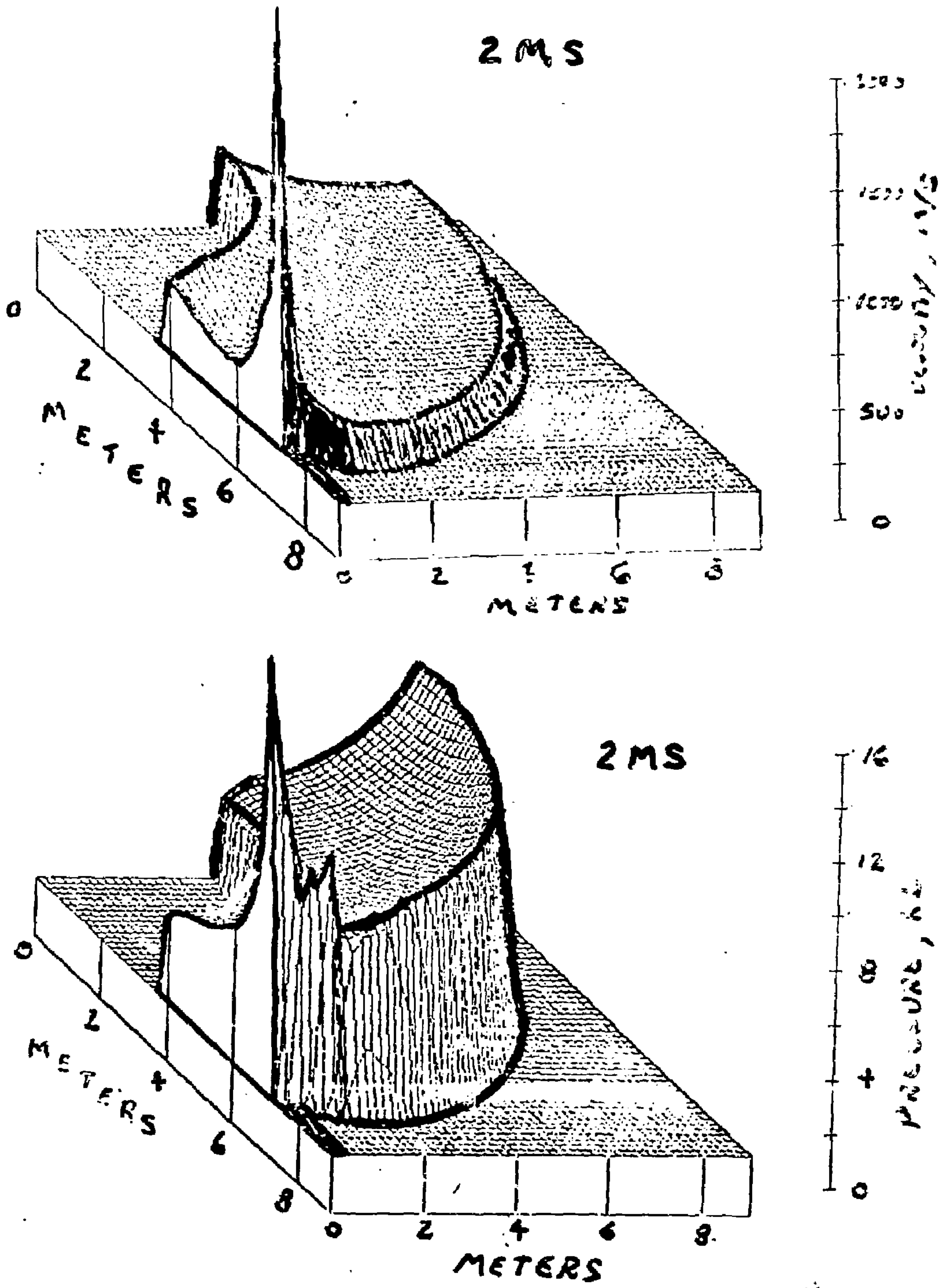


Figure 8. Isoviews at 2 ms.

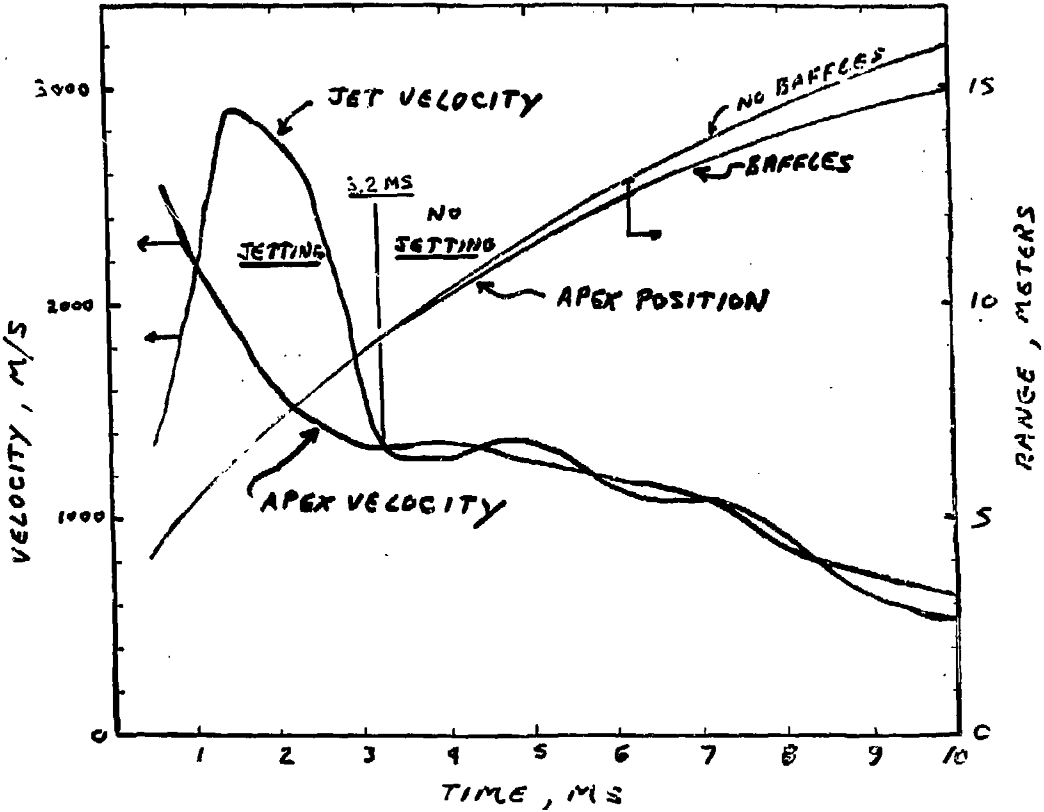


Figure 9. Comparison of Apex position and its velocity with velocity of induced jet.

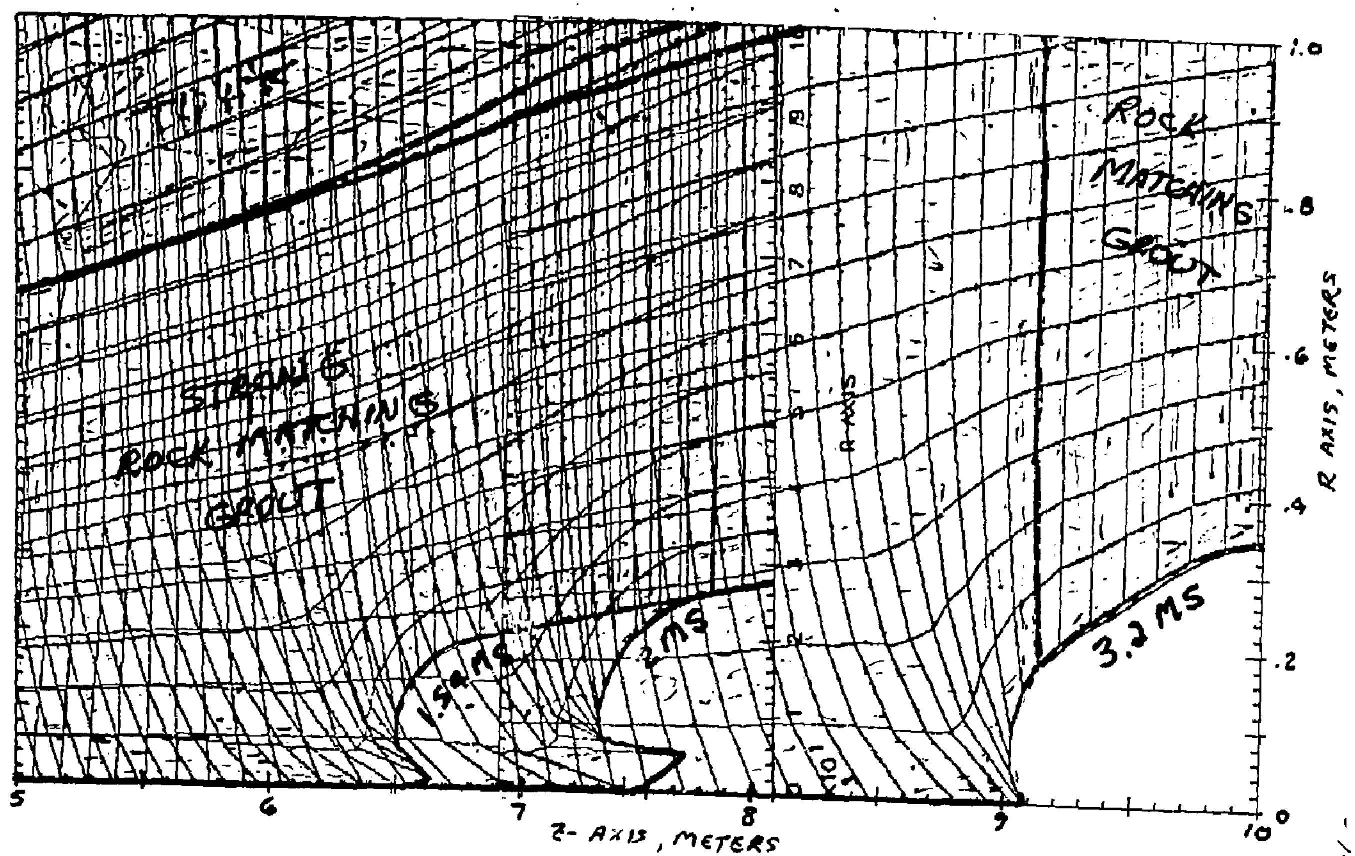


Figure 10. Position of Apex at early times.

Figure 11. **SUMMARY OF JETTING PROCESS**

- JETTING OCCURS ONLY IN STRONG ROCK MATCHING REGION.
- THE TENDENCY FOR JETTING CEASES AT ABOUT 3.2 MS WHEN THE JET VELOCITY HAS DECREASED TO THE LEVEL OF THE PLUG CLOSURE RATE ~ 1300 M/S. - STRESS LEVEL ORDER OF 3 KB.
- BAFFLES DO NOT INFLUENCE THE JETTING PROCESS BECAUSE THE GROUND SHOCK HAS NOT INTERACTED WITH FIRST BAFFLE BY 3.2 MS.

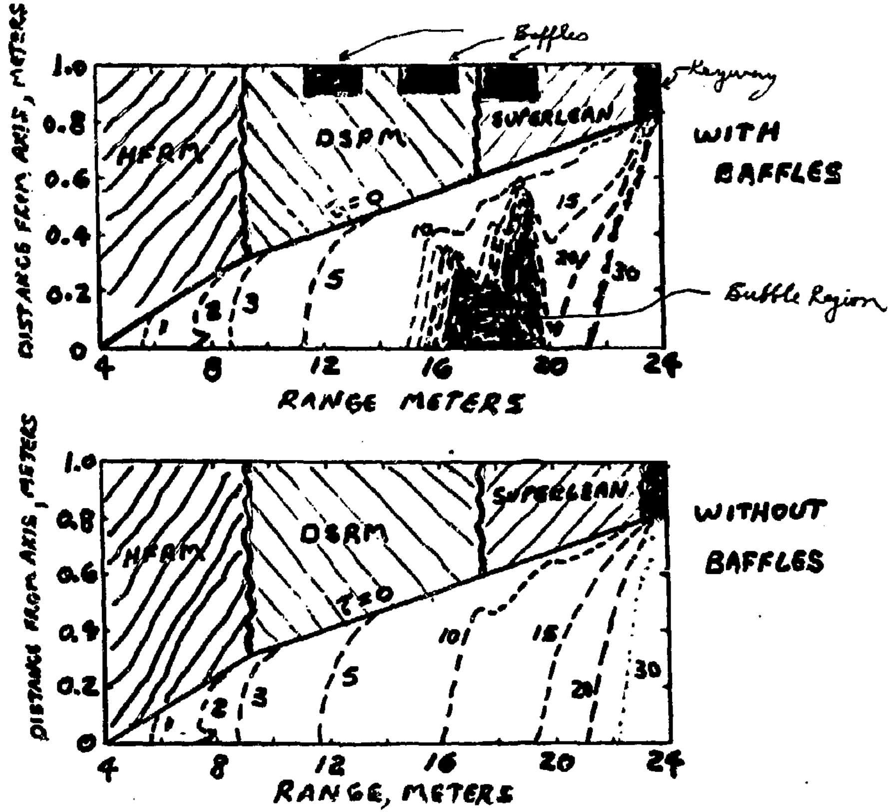


Figure 12 Contours of stemming plug formation at various times.

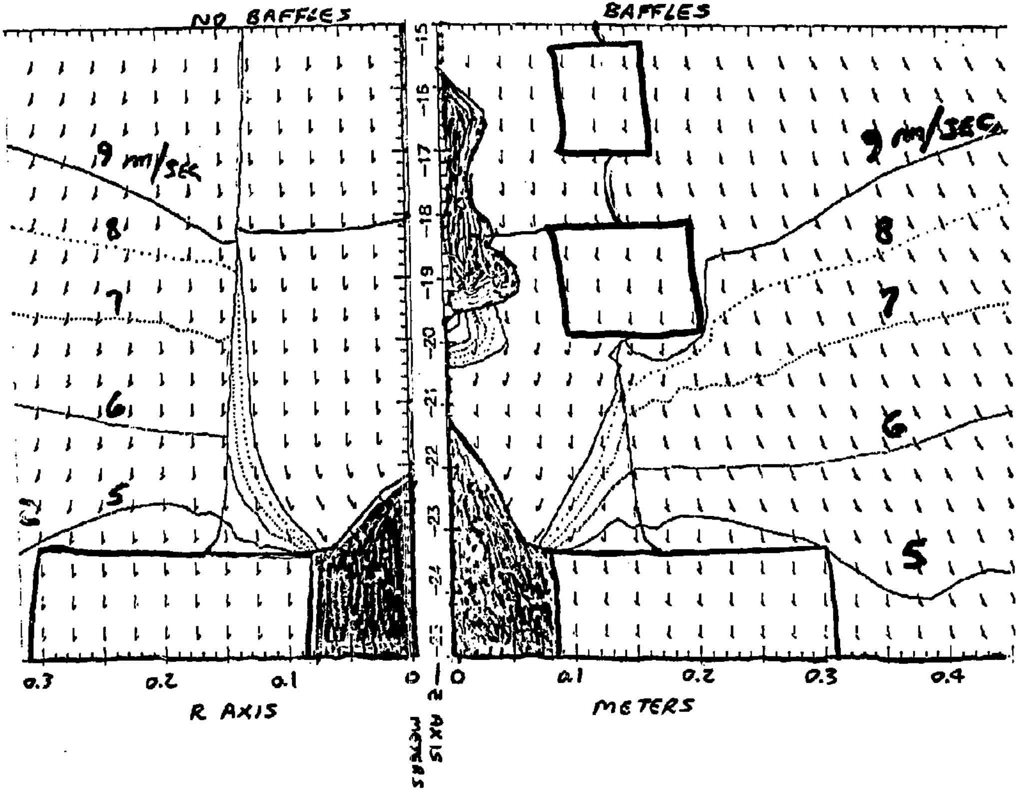
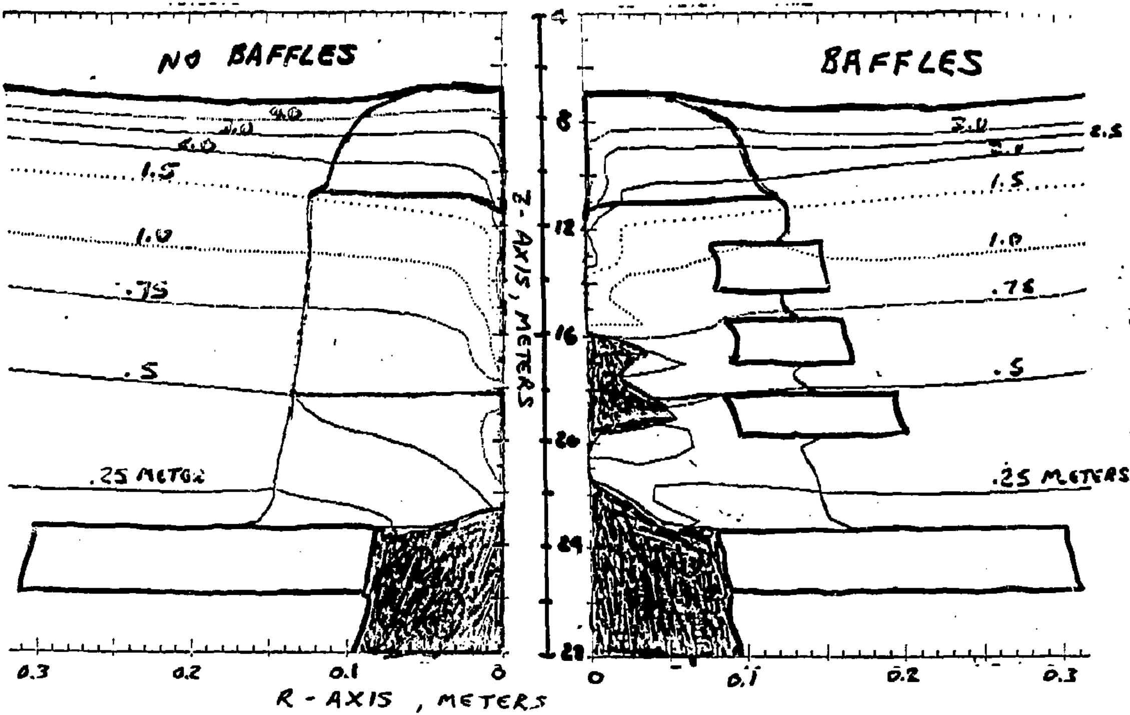


Figure 13. Velocity contours in collapse region at 30 ms.

Figure 14. DISPLACEMENT CONTOURS AT 80 MS.



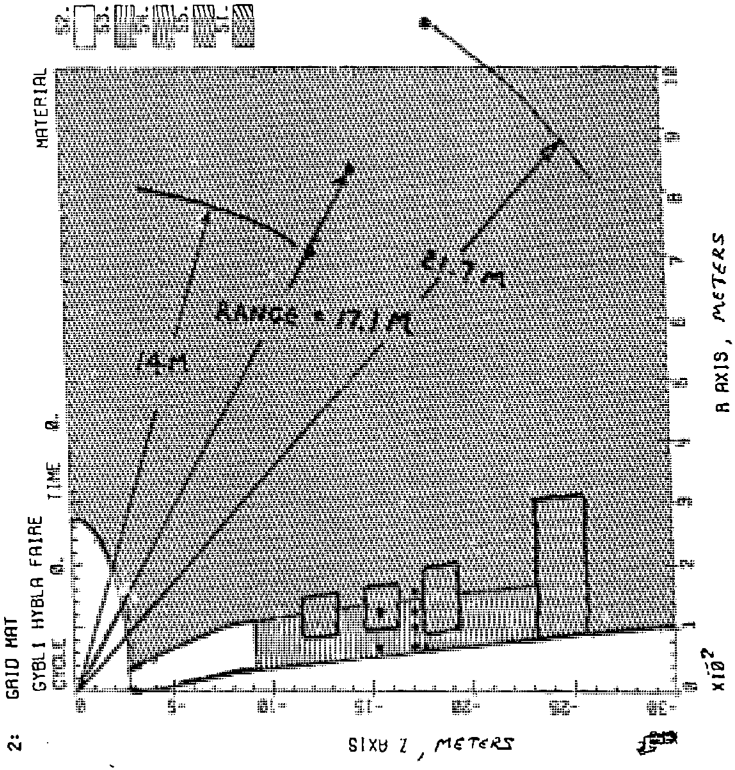


Figure 15. Time history points.

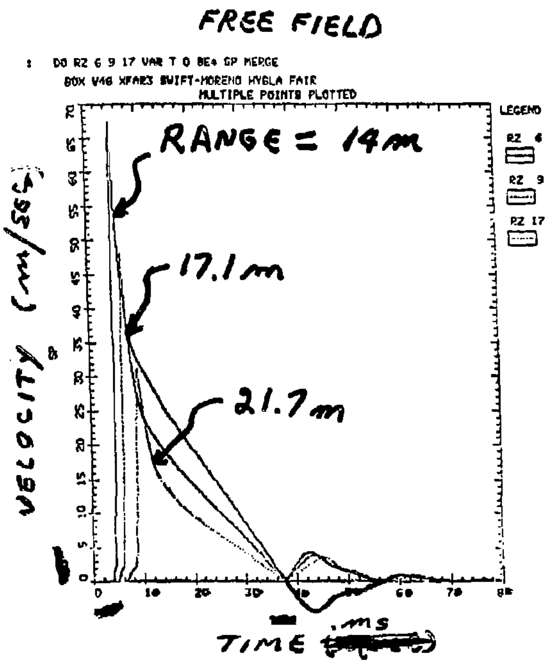


Figure 16. Free field particle velocity at different ranges.

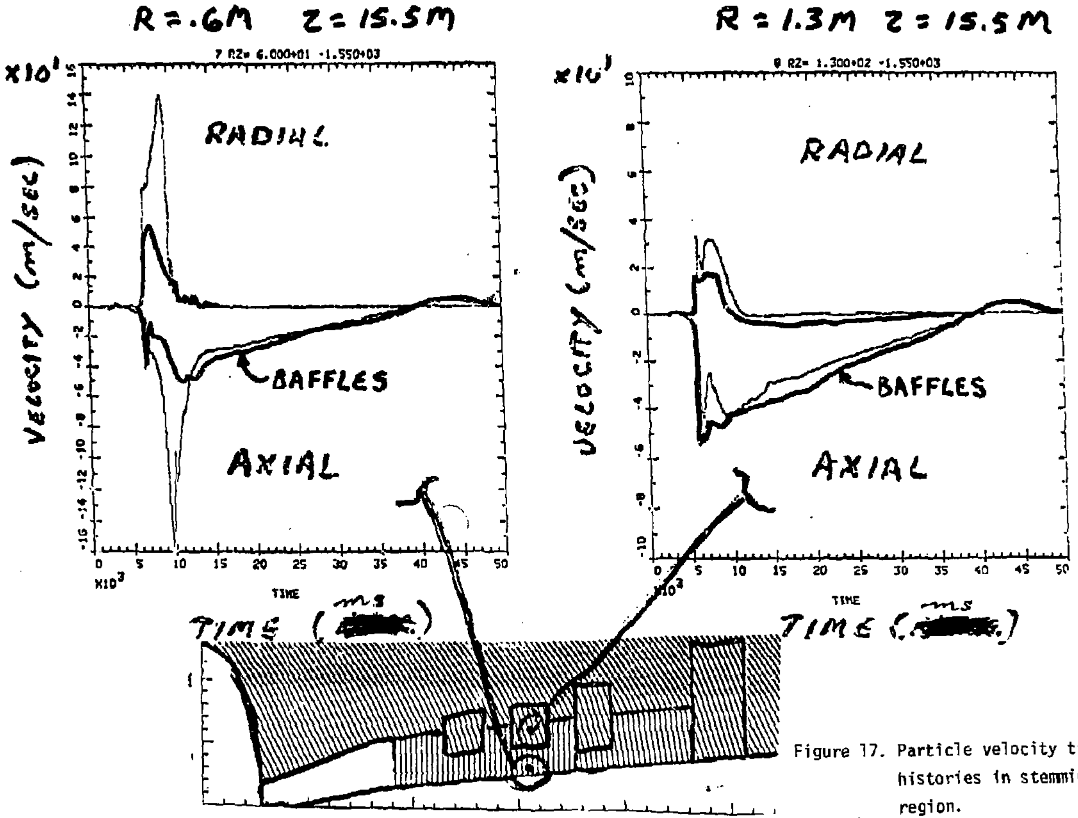


Figure 17. Particle velocity time histories in stemming region.

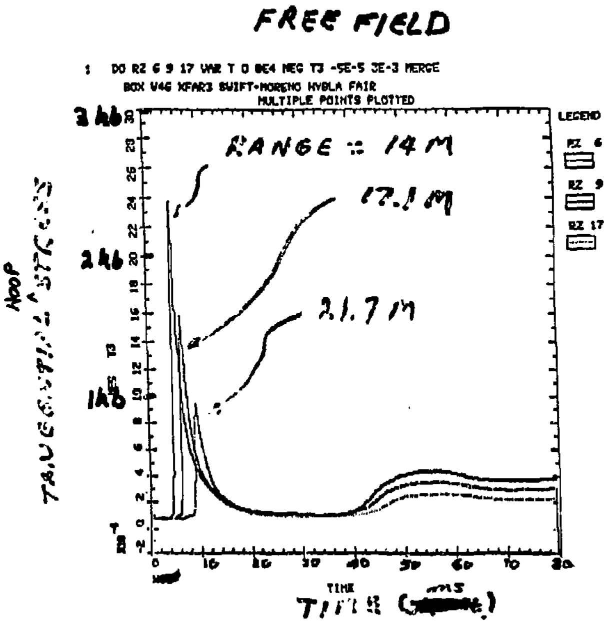


Figure 18. Free field hoop stress at different ranges.

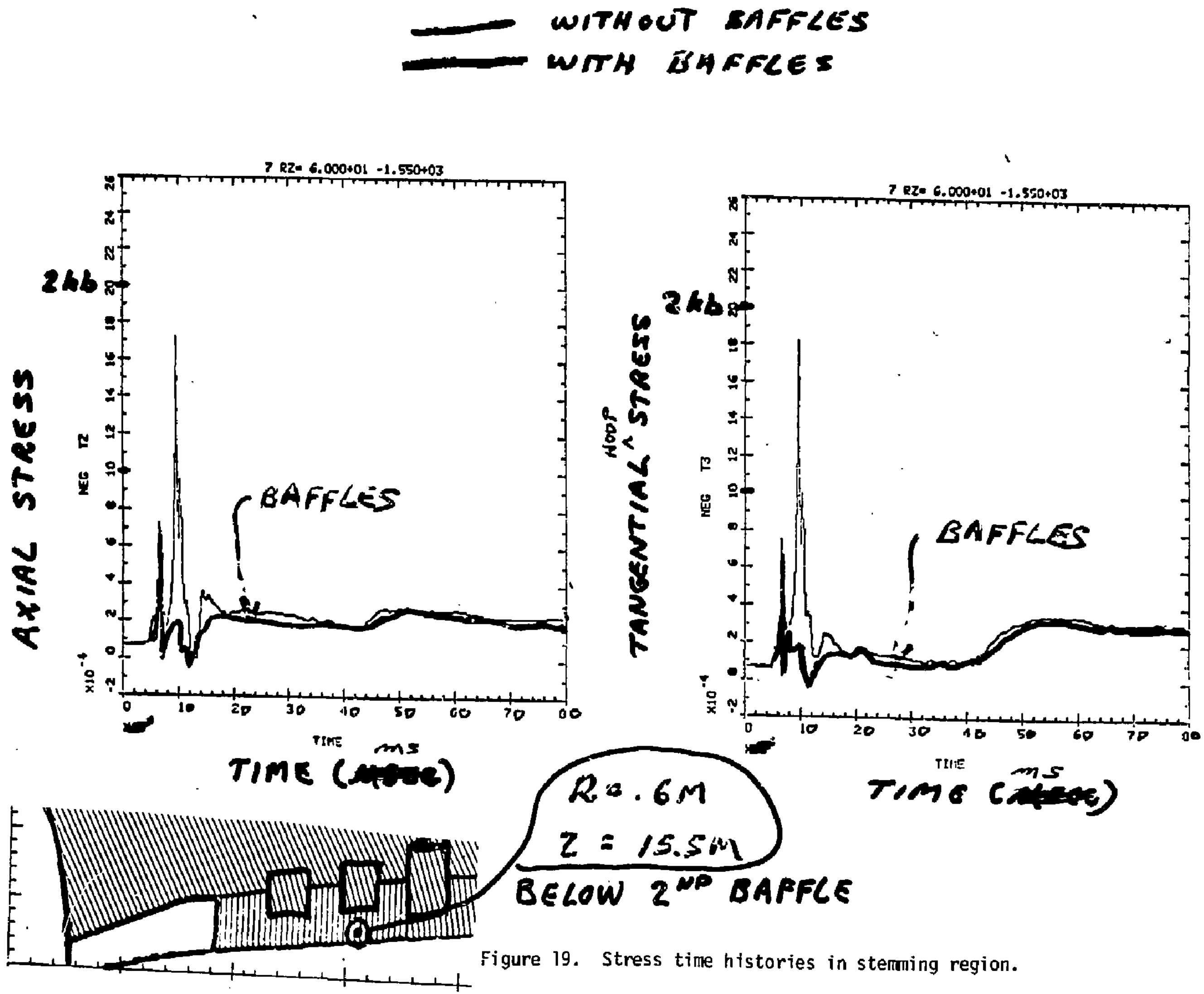


Figure 19. Stress time histories in stemming region.

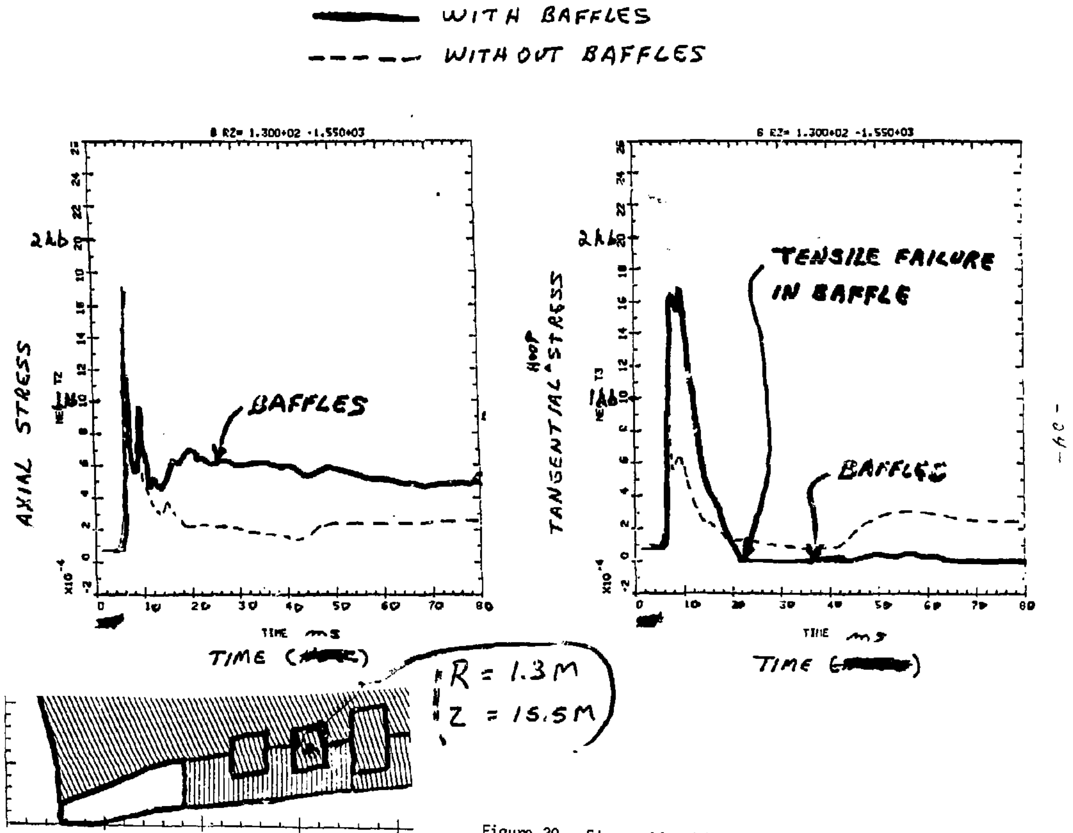


Figure 20. Stress time histories in stemming region.

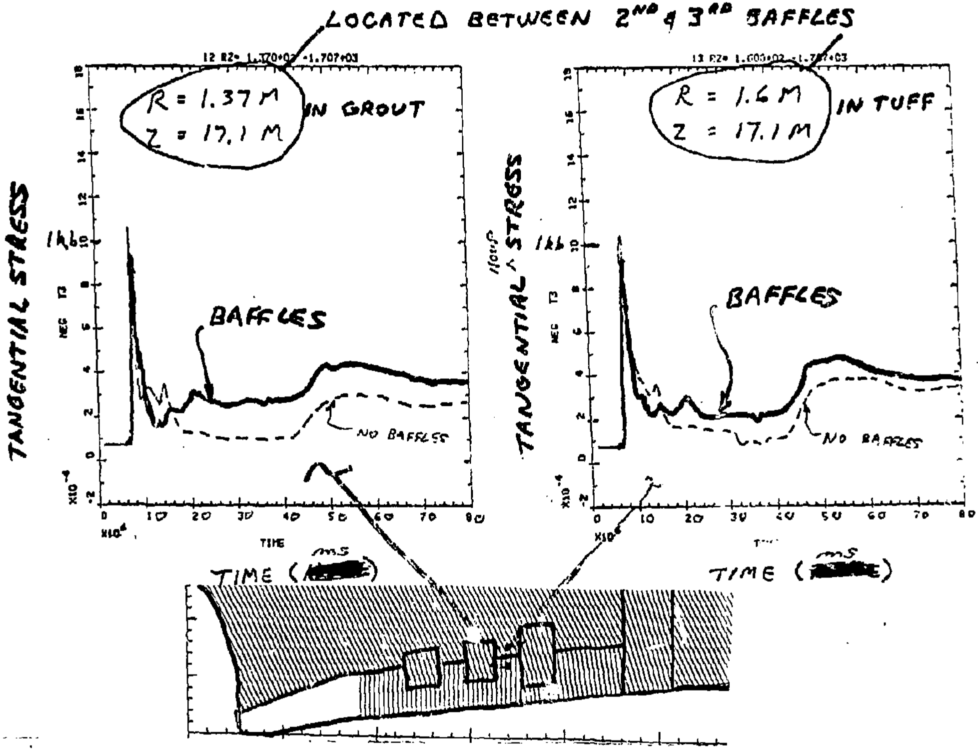


Figure 21. Stress time histories in stemming region.

Figure 22. **SUMMARY OF COLLAPSE PROCESS**

- COLLAPSE PROCESS IS SIMILAR OUT TO 10 MS FOR BOTH CASES.
- BAFFLES RETARD THE GROWTH OF THE STEMMING PLUG AND SHORTEN ITS LENGTH.

BAFFLES

- PLUG FORMED OUT TO 15.8 M IN ROCK MATCHING GROUT UNDER 2ND BAFFLE.
- BUBBLE FORMED AT 20.6 MS UNDER 2ND AND 3RD BAFFLES IN ROCK MATCHING - SUPERLEAN GROUT REGION. BUBBLE DOES NOT COLLAPSE.
- SUPERLEAN GROUT PART OF BUBBLE SPREAD ON AXIS FROM 19.7 TO 21.2 M.
- PLUG THICKNESS ~ 8.9 M (1.27 R_c).
- BAFFLES FAIL IN TENSION UNDER HOOP STRESS FORMING CRACKS PARALLEL TO TUNNEL AXIS.
- NO LATE TIME EXTRUSION OF GROUT OCCURS.

NO BAFFLES

- PLUG FORMED OUT TO 22.2 M IN SUPERLEAN GROUT.
- BUBBLE FORMED AT 13 MS AT ROCK MATCHING - SUPERLEAN GROUT INTERFACE. BUBBLE COLLAPSED AT 15.2 MS.
- PLUG THICKNESS ~ 15.6 M (2.23 R_c)
- NO LATE TIME EXTRUSION OF GROUT OCCURS.

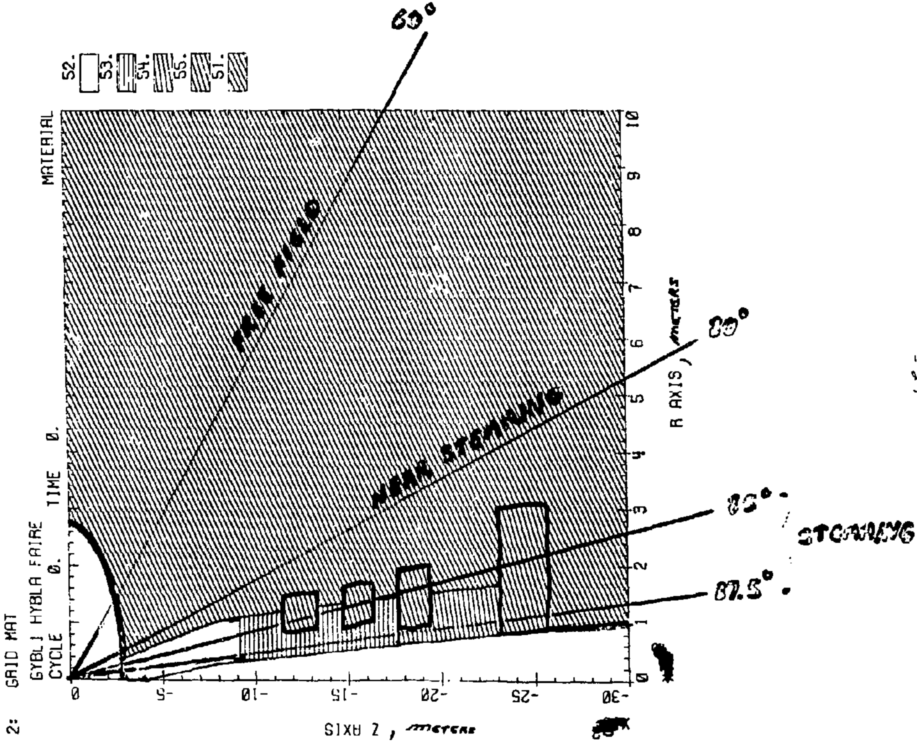


Figure 23. Profile lines.

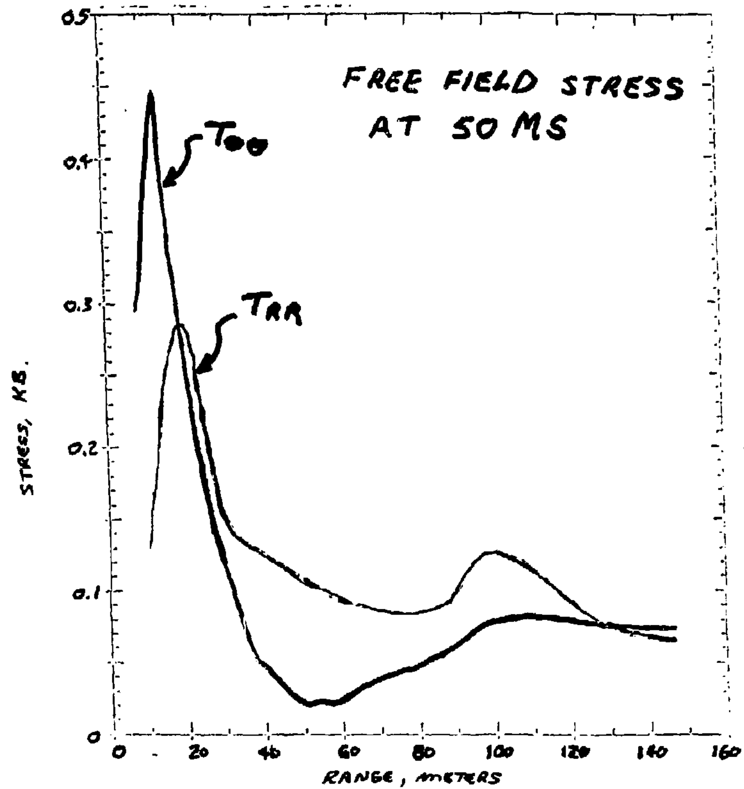


Figure 24. Free field stress at 50 ms.

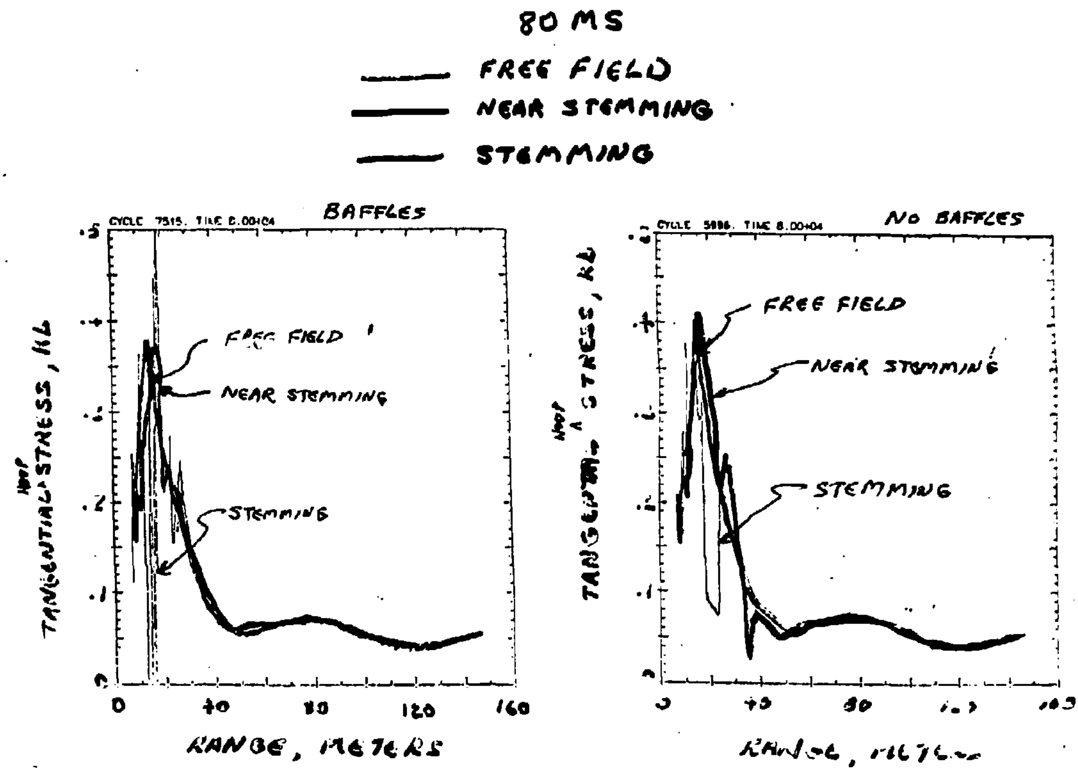


Figure 25. Hoop stress profiles at 80 ms.

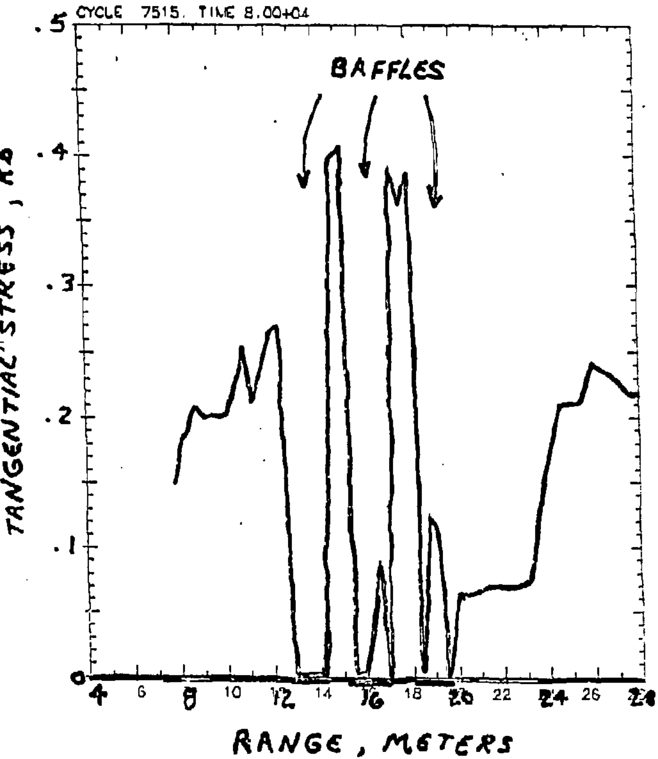


Figure 26. Hoop stress in stemming region at 80 ms for case with baffles.

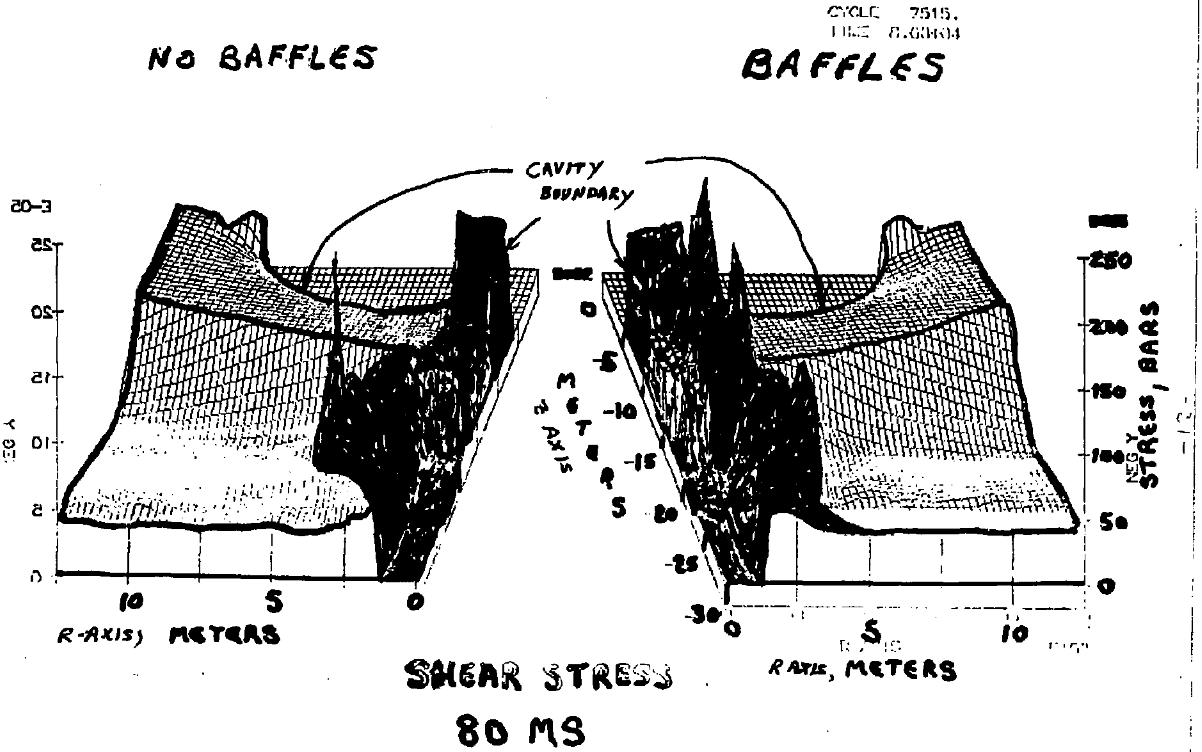


Figure 27. Isoview of shear stress at 80 ms.

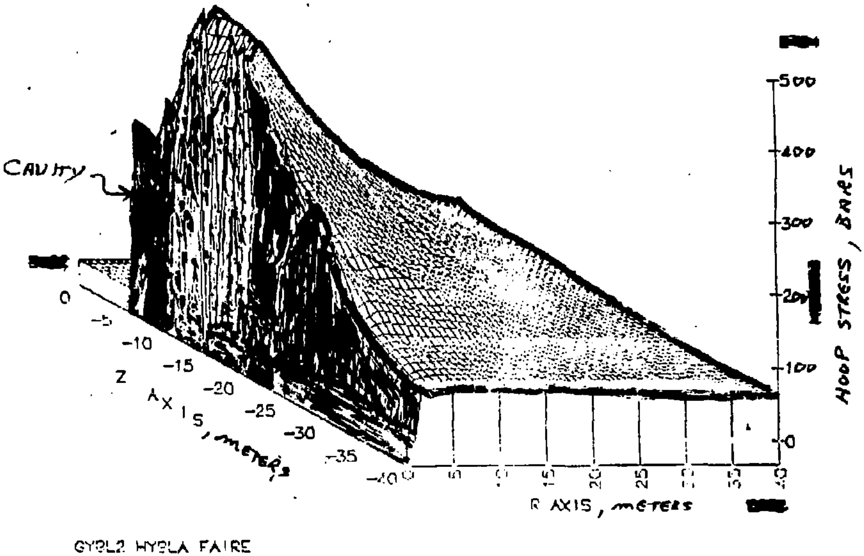
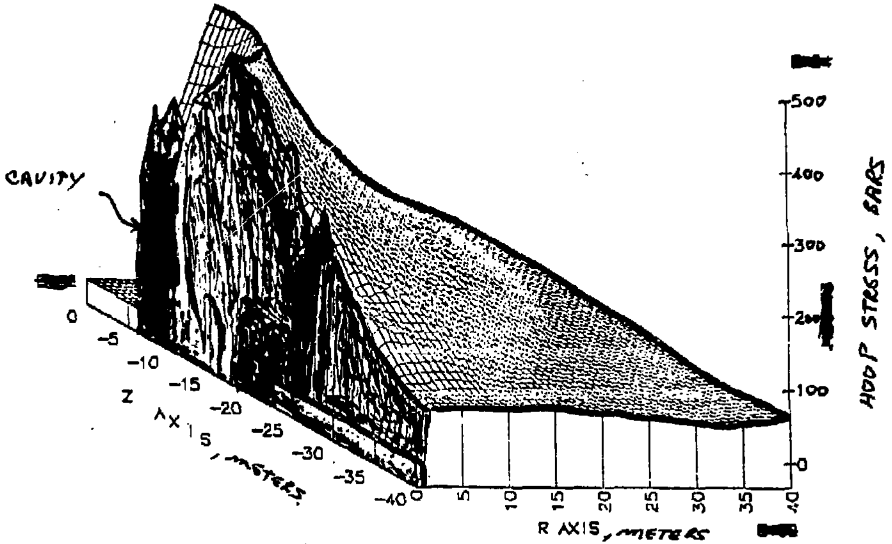


Figure 28. Isoview of hoop stress at 80 ms for case with baffles.



XFAR3

Figure 29. Isoview of hoop stress at 80 ms for case without baffles.

Figure 30. **SUMMARY OF CONTAINMENT**

- RESIDUAL HOOP STRESSES DO NOT BUILD UP IN BAFFLES.
- THE STRESS STATE IN STEMMING REGION IS DEGRADED BY PRESENCE OF BAFFLES.
- FREE FIELD 4.2 R_c ~ (32 M)

CAGE THICKNESS

STEMMING REGION

NO BAFFLES 1.6 R_c ~ (11 M)

BAFFLES 0.7 R_c ~ (5 M) AXIAL CRACKS IN FIRST BAFFLE.

Figure 31. CONCLUSIONS

- JETTING FORMS EARLY IN THE COLLAPSE PROCESS WHICH COULD BE HAZARDOUS TO EXPERIMENTS.
- BAFFLES INHIBIT THE STEMMING CLOSURE PROCESS.
- THE RESIDUAL STRESS CAGE FORMED IN THE STEMMING REGION IS SIGNIFICANTLY THINNER THAN THAT IN THE FREE FIELD REGION AND IS DEGRADED BY THE PRESENCE OF BAFFLES.
- RELATIVE DISPLACEMENT ALONG GROUT-TUFF INTERFACE IS SMALL AND NO LATE TIME EXTRUSION IS OBSERVED.

FIGURE 32. RECOMMENDATIONS

- EVALUATE HIGHLY ASYMMETRICAL STEMMING DESIGNS WITH 3D CALCULATIONS ALONG WITH 2D PARAMETER STUDIES.
- PERFORM STUDY ON WAYS TO INHIBIT GROUND SHOCK INDUCED JETTING. INVESTIGATE POSSIBLE CLOSE-IN ASYMMETRICAL FEATURES. TO PREVENT JETTING.
- PERFORM CALCULATIONS ON LABORATORY AND SCALED HIGH EXPLOSIVE FIELD STEMMING EXPERIMENTS.
- AVOID THE USE OF MASSIVE BAFFLES FOR FUTURE LOW YIELD EVENTS.