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TERRAIN EFFECTS ON SHOCK WAVES AS MEASURED USING A 1:1300 SCALE MODEL OF REITERA(PL)E PROVING GROUND

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18. SUBJECT TERMS (Continued)

Terrain Modeling
Overpressure
Air Blast Prediction
Impulse

19. ABSTRACT (Continued)

there was blast enhancement because of reflection which occurred when the shock wave struck the valley floor at an angle and traveled up a slope. At the two far field stations, there was blast attenuation because the shock wave expanded when it entered the lower valley.

Acknowledgements

There were many people who graciously assisted with this project. Each one would have willingly helped more if required, and the authors are sincerely appreciative. They are John Sullivan, Peter Muller, George Teel, Jim Bernhardt, Ken Holbrook, Brian Bertrand, John Simansky, and Rick Thane all from the Blast Dynamics Branch at BRL. We particularly wish to thank the US Army Ordnance School Photography Laboratory for creating a 2.6 x 3.4 m (8.5 x 11 ft) photograph of the Reiteralpe contour map.

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FIGURES

1. INTRODUCTION

The large blast simulator is a shock tube that was hollowed out of the Reiteralpe Mountain. It has a closed end inside the mountain and an open end which exits into the surrounding terrain. Figure 1 shows the nearby mountains and valley as seen from a location close to the shock tube exit. The facility was constructed to produce blast waves of up to one bar (14.5 psi). Because of the proximity of the shock tube to previously existing inhabited areas, shock wave related damage has occurred which in the past has inhibited the use of the facility. When a shot with a peak overpressure of 0.8 bars was fired, structural damages were incurred[1]. These damages included broken windows and even some minor damage to ceilings and walls in a neighboring village. In order to more fully examine these problems and document the terrain effects, a 1:1300 scale model was constructed of the Reiteralpe shock tube and nearby topography.

2. TEST PROCEDURES

2.1 Terrain Construction. The Federal Republic of Germany (FRG) provided the Ballistic Research Laboratory (BRL) with a contour map of the terrain in the region near the Reiteralpe Facility. The terrain model was confined to the region displayed on this map; see Figure 2 which is a reduced replica. The map provided by FRG describes the contours of the land at a 1:5000 scale. It was concluded that the map should be enlarged to a scale that would allow for a workable shock tube model. The first method of enlargement attempted was by the use of a pantograph which is a device consisting of four jointed bars in parallelogram form that may be used to copy on a predetermined scale. However, a pantograph large enough was not readily available, and it was determined that a great deal of time would be expended to get results by this method. The map was instead photographically reproduced and enlarged in sections roughly following the grid lines already present. By means of this sectioned augmenting process, the map was enlarged 3.8 times to a new scale of 1:1316 (In this paper, the scale is sometimes referred to as 1:1300 and at other times more exactly as 1:1316.) and covered a 2.6 x 3.4 meter (8.5 x 11 ft) area. An increase factor of 3.8 was as much as the available enlarging equipment would allow. To assure that all map sections had the same scale, the photographically enlarged sections were dried at room temperature instead of being heat dried which might have caused distortions.

A large space was cleared in a nearby warehouse to be the work area for this project. An indoor environment was chosen over an outdoor site primarily because of the weather factor. The cover of the warehouse would assure against any weather related side-effects during the actual testing. Additionally, working indoors also assured protection from inclement weather to the workers, maps, and construction tools. The building material chosen for construction of the terrain was plywood because it was readily available in a standard size and thickness of 1.2 m x 2.4 m x 2.54 cm (4 ft x 8 ft x 1 in) and because of its structural stability. A 3.7 x 3.7 meter (12 x 12 ft) platform elevated 15.2 cm (6 in) above the ground was assembled to provide a level base on which to work and plenty of room for cables to run underneath. Fortunately, the 1:1316 scale allowed for a very convenient transference of actual height to scale height. The major map contours ascend in 100 meter increments which converts to 7.62 cm (3 in) at 1:1316 scale with an error of 0.26%. In other words, three thicknesses of plywood equals a scale height of 100.26 meters. So, every 100 meter increase in height on the German mountains would constitute a 7.62 cm height increase on the model. A base altitude of approximately 500 m above sea level was found along the Saalach River near Reiterpoint and deemed the low point on the map. All height delineations were made referencing 500 m as the base, thus placing any altitude from 500-599 m (mostly all of the river basin) flat on the platform. Seven levels or 21 layers of plywood were needed to model the highest mountains on the test site which corresponds to

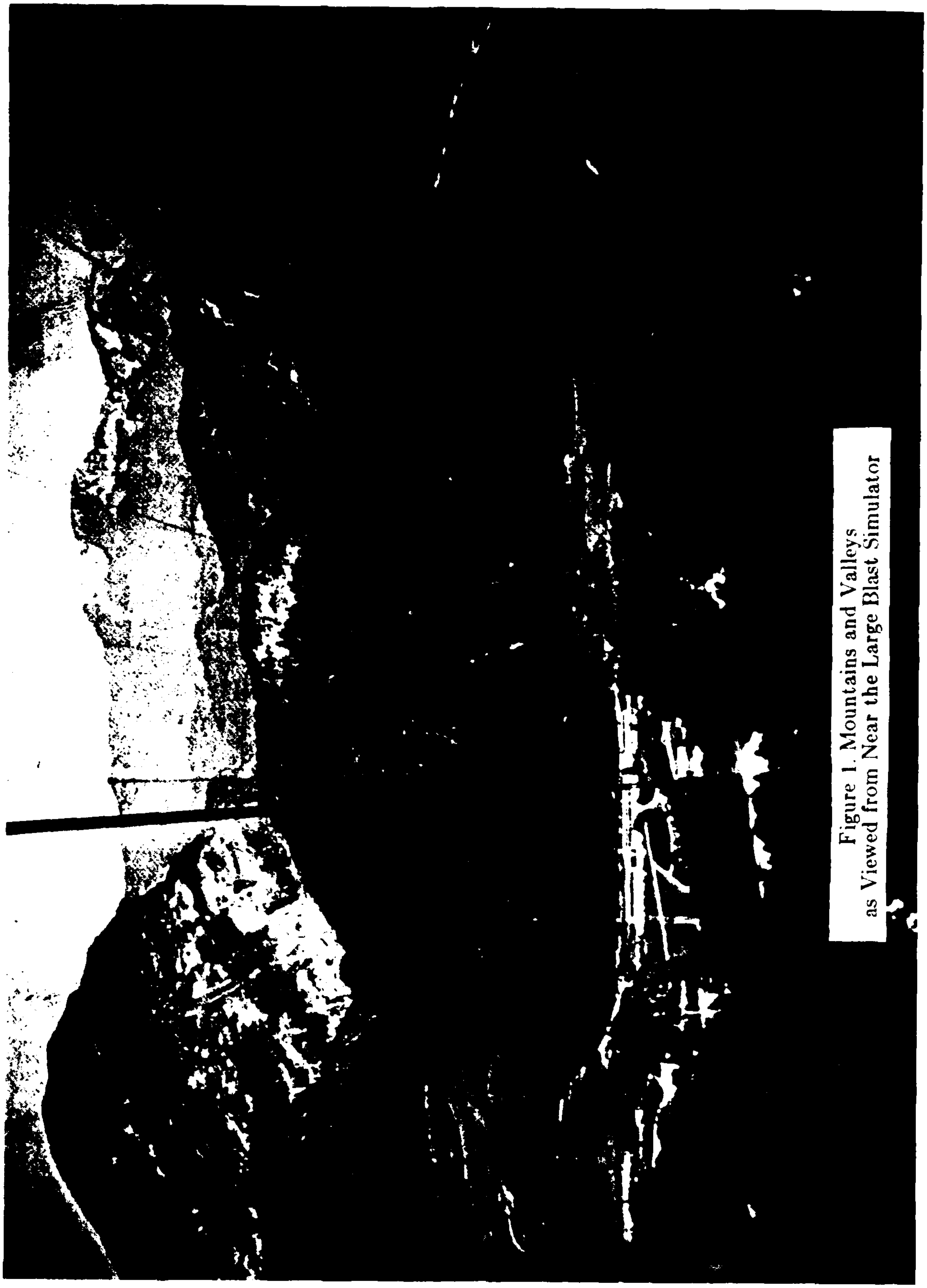

Figure 1. Mountains and Valleys
as Viewed from Near the Large Blast Simulator

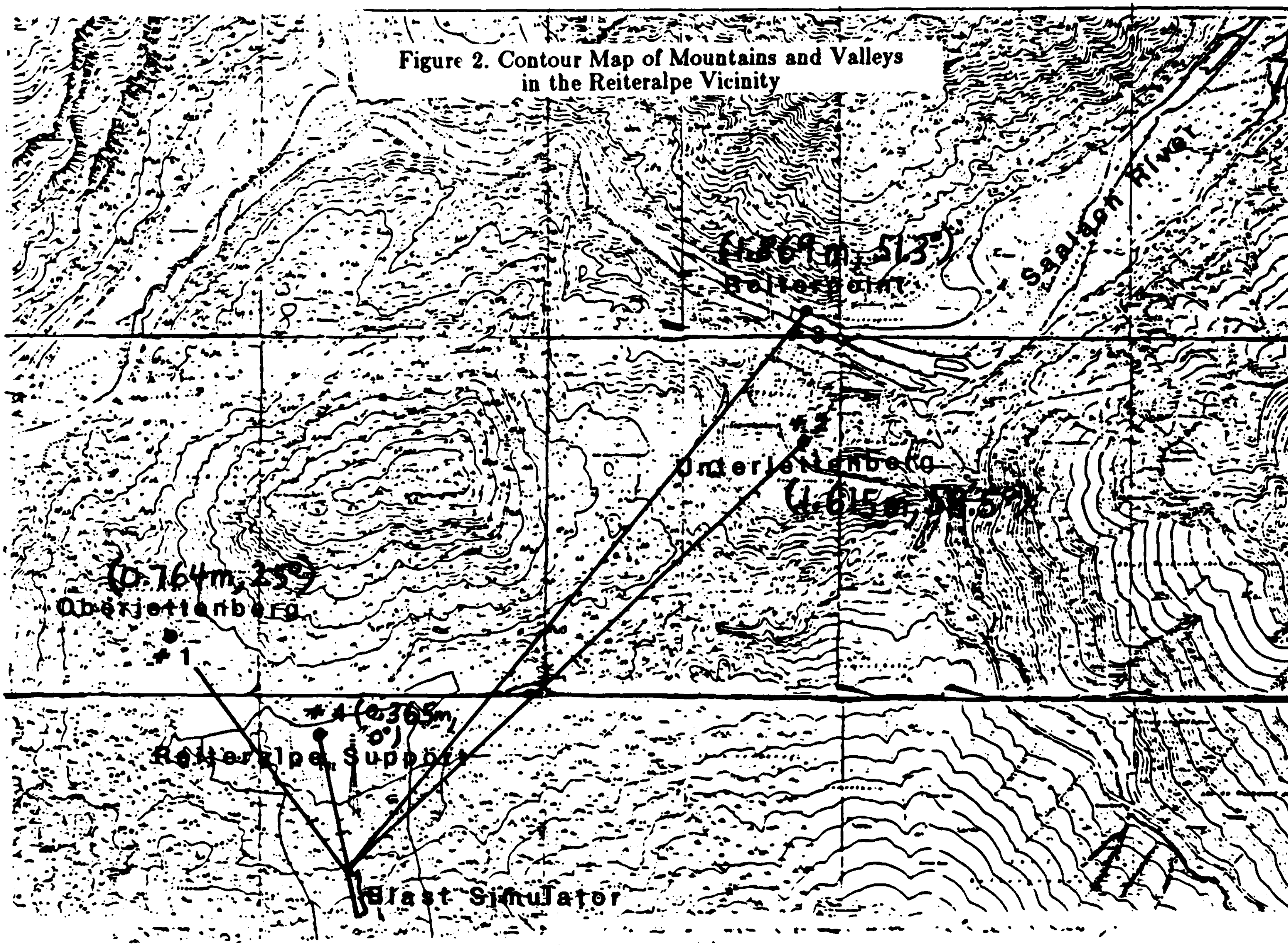

Figure 2. Contour Map of Mountains and Valleys in the Reiteralpe Vicinity

1200 m above sea level. Figure 3 shows some construction details of the plywood terrain. The wooden contours were covered with plaster in the critical areas to get the finer details of the altitude modeling; a photograph of the test site is shown on Figure 4. In the less critical regions, the plywood was covered with firmly packed soil.

2.2 Shock Tube Model. According to Reference 1, the Reiteralpe large blast simulator has a total length of 106 m, and a cross-section of 76 meter square. The floor is 13 m wide, and the height is 7 m with a 2.5 m vertical part and a semicircle on top. The blast wave generator or driver consists of 144 pressure bottles 6.34 m long clamped horizontally into a frame resting against the shock tube back wall.

From the dimensions reported in Reference 1, the cross-sectional area was calculated to be 75.3 meter square which is 0.7 meter square less than the number reported therein. Using 75.3 m as the cross-sectional area resulted in a hydraulic diameter of 9.79 m. Scaling by 1:1316 gave a hydraulic diameter of 0.744 cm (0.293 in). The scaled shock tube was constructed out of steel pipe having a nominal inside diameter of 0.767 cm (0.302 in). This means that the scaled tube is 3.1% larger than it should be. This small systematic error was considered acceptable for several reasons. It was not possible to locate a drill bit that would allow for machining a pipe to exactly 0.293 in. Also the error was on the conservative side and thus would give higher field pressures than a 0.293 in tube. Lastly, the cross-sectional area reported in Reference 1 was slightly larger than the area used herein.

It was infeasible to scale the 6.34 m high pressure gas bottles by 1:1316 so a simple compressed air driver which was filled from a pair of 6.9 bar (100 psi) bottles was used. The length of the driver, including air in the control valve, was 7.1 cm (2.8 in). The diaphragm material was 0.00635 mm (0.25 mil) mylar for the low pressure range and 0.0127 mm (0.5 mil) mylar for the high pressure range. Mylar was easy to cut, easy to handle, and gave consistent, repeatable results. The mylar diaphragm was ruptured by piercing it with a pin placed in a 1 mm hole in the downstream tube wall. (Other materials that were tried as diaphragms at this scale gave interesting but negative results. Ordinary writing paper was far too strong, aluminum foil was hard to handle without causing wrinkles and therefore did not give repeatable results, and wax paper became porous under pressure.) The downstream or test section of the shock tube was 30.5 cm (12.0 in) long. The driver to test section length ratio was chosen to give a flattop wave at the exit. An Endevco pressure transducer was placed 5.1 cm (2.0 in) from the open end to record the shock pressure within the tube near the exit. The operational shock tube may be seen on both Figures 3 and 4.

The shock tube was very easy to operate and had a turnaround time of only ten minutes. The circular mylar diaphragm was punched out of a sheet of mylar using a custom made hole punch and was placed on an O-ring that was seated at the end of the driver. The downstream section was screwed into the driver forming a pressure tight seal at the O-ring.

2.3 Instrumentation. Pressure-time data were recorded at five locations, one within the model shock tube using an Endevco gage Model 8510 and at 4 field positions using Susquehanna yellow dot gages Model ST-2. Neff Model 122 amplifiers, rated at 100 kz, were used to amplify the gage signals. Pacific Instruments Model 9820 transient data recorders, having 12 bit resolution and a 2 microsecond sampling rate, were used to digitize and store the data which was then transferred to a Hewlett Packard (HP) Model 9807A Integral Personal Computer. The HP electroluminescent monitor produced a graphic display that facilitated analysis of the shots. This very efficient data acquisition scheme made it possible to fire many shots with little turnaround time. In the event of a misfire, erratic diaphragm break, or instrumentation error, a quick look at the shock tube gage record was all that was needed in order to decide to throw out the shot and repeat it. Good shot

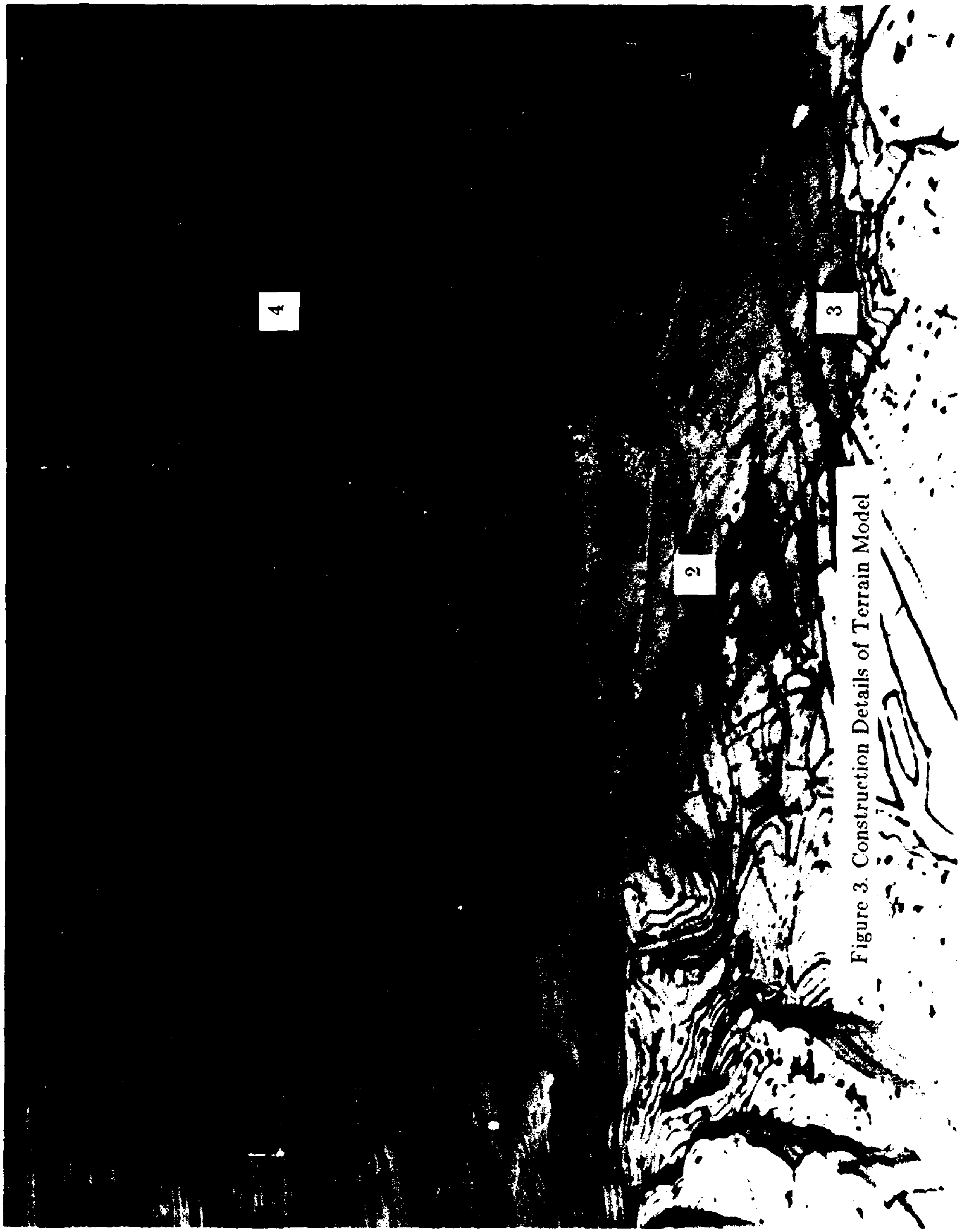

Figure 3. Construction Details of Terrain Model

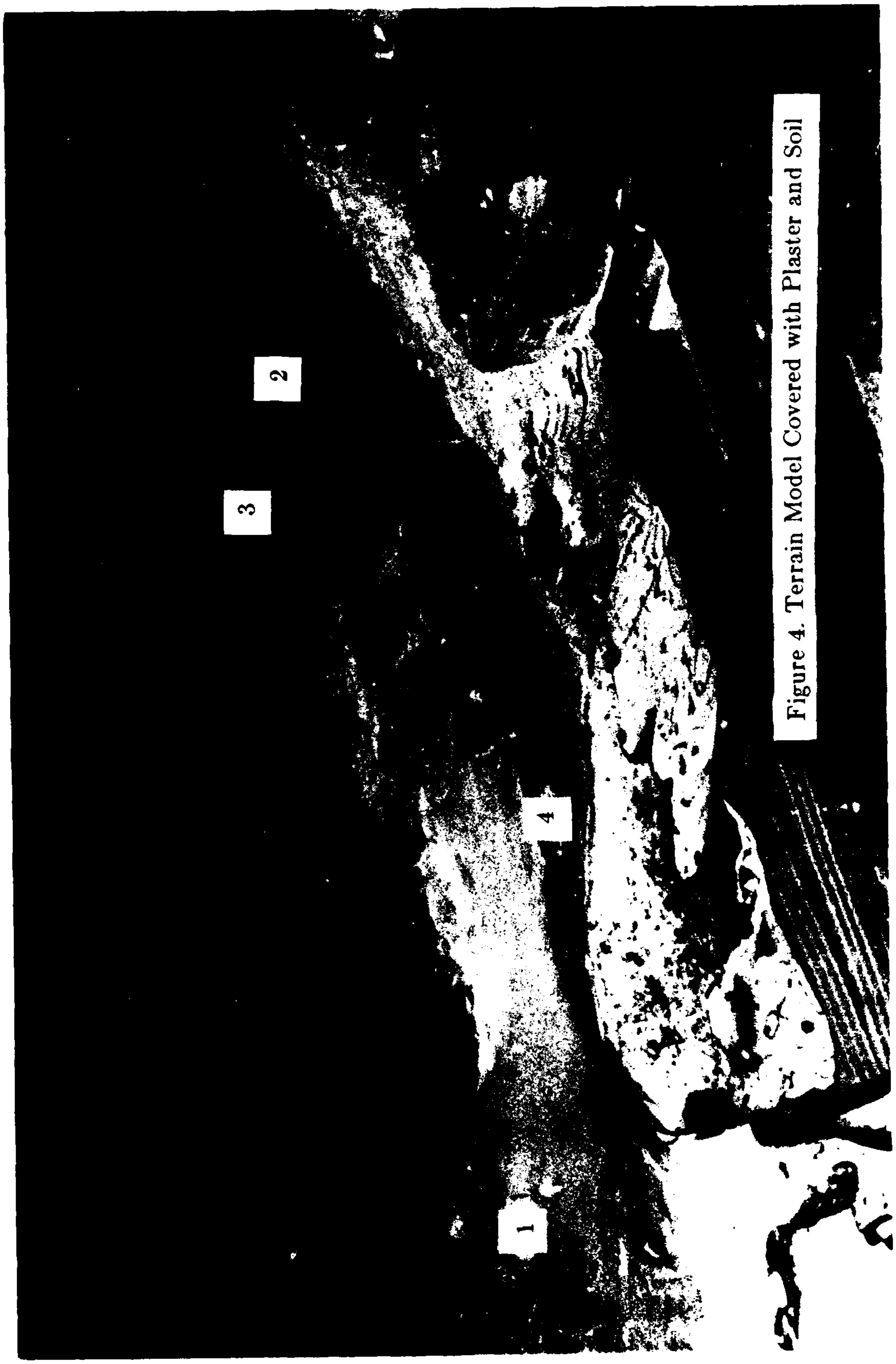

Figure 4. Terrain Model Covered with Plaster and Soil

pressure-time records were then plotted out using an HP Thinkjet printer. The records were stored on a 3.25 in, double density, double sided, 1.2 megabyte floppy disks and transferred to cassette tapes for further reduction on a Tektronix 4052A micro-computer, 4631 hardcopier, and 4662 plotter.

The Endevco gage was chosen for the shock tube station because the gage has a 2.34 mm (0.092 in) case diameter with a 1.25 mm (0.05 in) diameter sensing element. A small diameter gage was needed since the shock tube diameter is 7.67 mm (0.302 in), and a larger gage would have obstructed the flow that was being measured. This type gage had one noticeable disadvantage. It has a natural frequency of 100 kz and this periodic ringing was evident on each shock tube station record. The ringing was filtered out by smoothing the records on the Tektronix 4052A computer.

The Susquehanna gage was chosen for the field stations because no other available gages would adequately record these short duration, extremely low pressure records. PCB Inc. piezoelectric gages, having a quartz sensing element, were not sensitive enough to record low pressures. The electronic signal to noise ratio made the records useless when these gages were tried. The Susquehanna gages have 200 kz natural frequency and 100 mv/psi sensitivity, but are unstable to temperature changes. The temperature instability is inherent to gages having a sensing element composed of manmade ceramic crystal material. The temperature problem was solved by calibrating each gage from 60° F to 100° F in 10 degree increments, recording the temperature at the time of each shot, and then making a scalar correction to the gage calibration level. Since only short duration waveforms were being measured, AC coupling was used to cancel most of the baseline drift which was a result of the temperature sensitivity. The Susquehanna gage element diameter is 1.27 cm (0.5 in)

The 1:1300 scale imposed difficulties on the ability of the instrumentation to adequately capture and record the shock. The most significant losses in the field records were a result of the amplifier response time and the yellow dot gage crossing time. As much as 20% of the field record peak pressures may have been lost because of the instrumentation limitations. The largest losses for the shock tube gage were caused by the gage response time and the amplifier response time. The shock tube station losses were insignificant.

2.4 <u>Experiments.</u> Experiments were conducted on the free field plaster board to establish a baseline to compare with results from the topographical model. After this baseline was established, experiments were performed on the topographical model. Shots were fired at two pressure levels, nominally 55 and 96 kPa shock tube exit pressure. Before experiments were conducted on the plaster covered model, preliminary tests were performed on the model which was covered with firmly packed soil. The soil was too rough, granular, and porous to be used on a 1:1300 scale model. Therefore, the pressures recorded on the soil model were low and at the far field stations difficult to interpret. Using a plaster model increased the pressures and made it much easier to interpret the records. Also, the field gages were shock mounted on the plywood board by emplacing the 5.08 cm (2 in) brass gage mounts in oversized mounting holes within the plywood and cushioning the mounts with foam rubber and duct seal (a malleable filler); this was done to reduce the signals transmitted to the gages by mechanical vibration of the solids and was very effective. Even with this measure, however, because the system was recording Pa level pressures, there was still some noise superposed on the records which made it difficult to determine the baseline. To be consistent, the baseline for each record was determined in the same manner; it was set to 0 Pa at the shock discontinuity.

3. RESULTS

The results are summarized in Table 1 and presented graphically in Figures 5 - 9 where the test label 'Plaster FF' refers to the plaster covered flat surface, and the label 'Plaster Model' refers to the plaster covered terrain model.

Table 1. Peak Pressure at the Four Field Gage Positions

Shock Tube Station Pressure (kPa)	Test Configuration	Field Pressure (Pa) Station			
		1	2	3	4
55	Flat Surface	141	54	47	390
	Terrain Model	195	25	18	487
96	Flat Surface	270	86	69	716
	Terrain Model	354	43	32	772

The four gage positions were provided by the FRG and are indicated on Figures 2 - 4. Station 1 is at Oberjettenberg, 0.764 m from the shock tube open end and at an angle of 25° with respect to the shock tube axis; Station 2 at Unterjettenberg, 1.615 m and 58.5°; Station 3 at Reiterpoint, 1.869 m and 51.3°; and Station 4 at the Reiteralpe support facilities, 0.365 m and 0°.

4. DISCUSSION

Figure 5 shows the shock tube exit pressure records at low and high pressure for each plaster shot configuration. These shots were chosen for comparison because the exit pressures are quite similar. Figures 6 - 9 compare the records at Stations 1 - 4 at both low and high pressure. The most important phenomenon observed was the pressure enhancement on the topographical model[2] at Station 1 which was caused by a reflection as the shock wave moved up the slope. Station 4, which is located in the valley directly in front of the shock tube also shows an enhancement because of the reflection that occurs when the shock wave reaches the flat area at the bottom of the valley. Stations 2 & 3 show a clear blast attenuation when compared with the flat surface.

The free field plywood surface results for Stations 1-4 are compared with Equation 1.

$$P_{ex_{\nu}} = \frac{B_1 P_{ex} \left(\frac{d}{R}\right)^{B_2}}{1 + \left(\frac{\nu}{B_3}\right)^2} \tag{1}$$

where,
$P_{ex_{\nu}}$ is the expected overpressure in the environment
$B_1 = 1.2 \pm 0.2$
$B_2 = 1.35 \pm 0.08$
$B_3 = 56° \pm 3°$
P_{ex} is the overpressure in the tunnel outlet
d is the tunnel diameter

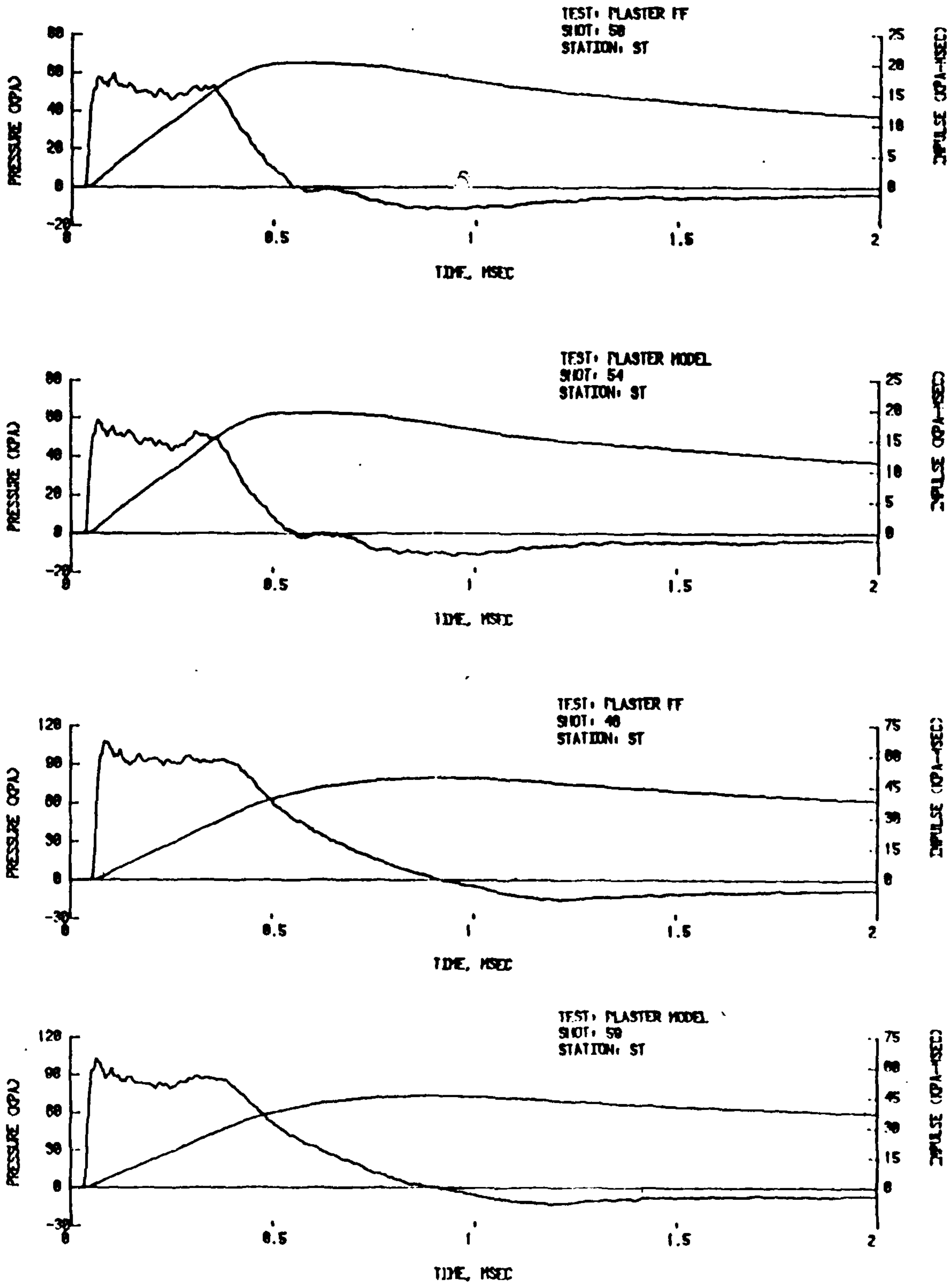

Figure 5. Shock Tube Station Records for Each Test Configuration

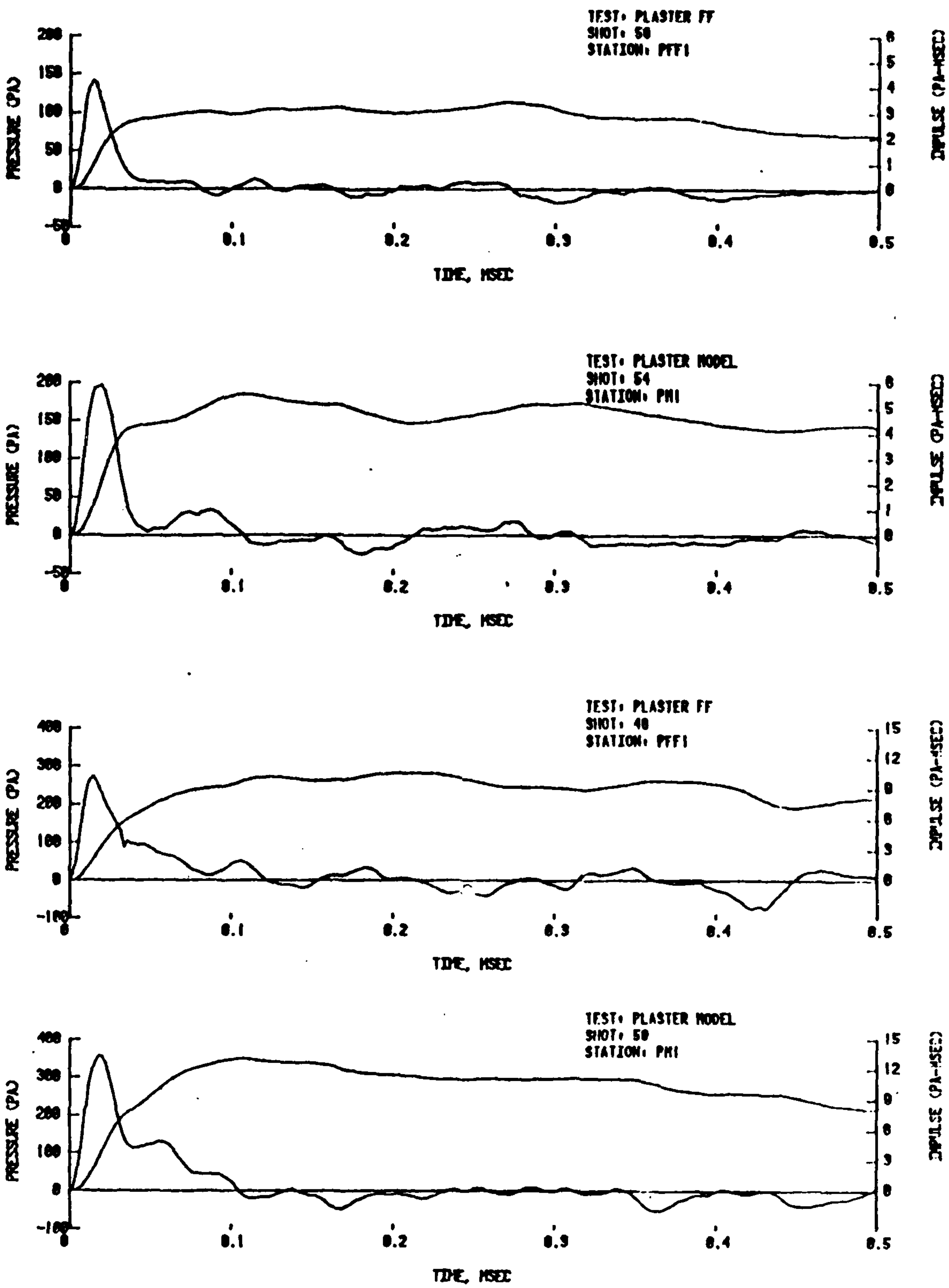

Figure 6. Pressure-time Records at Station 1

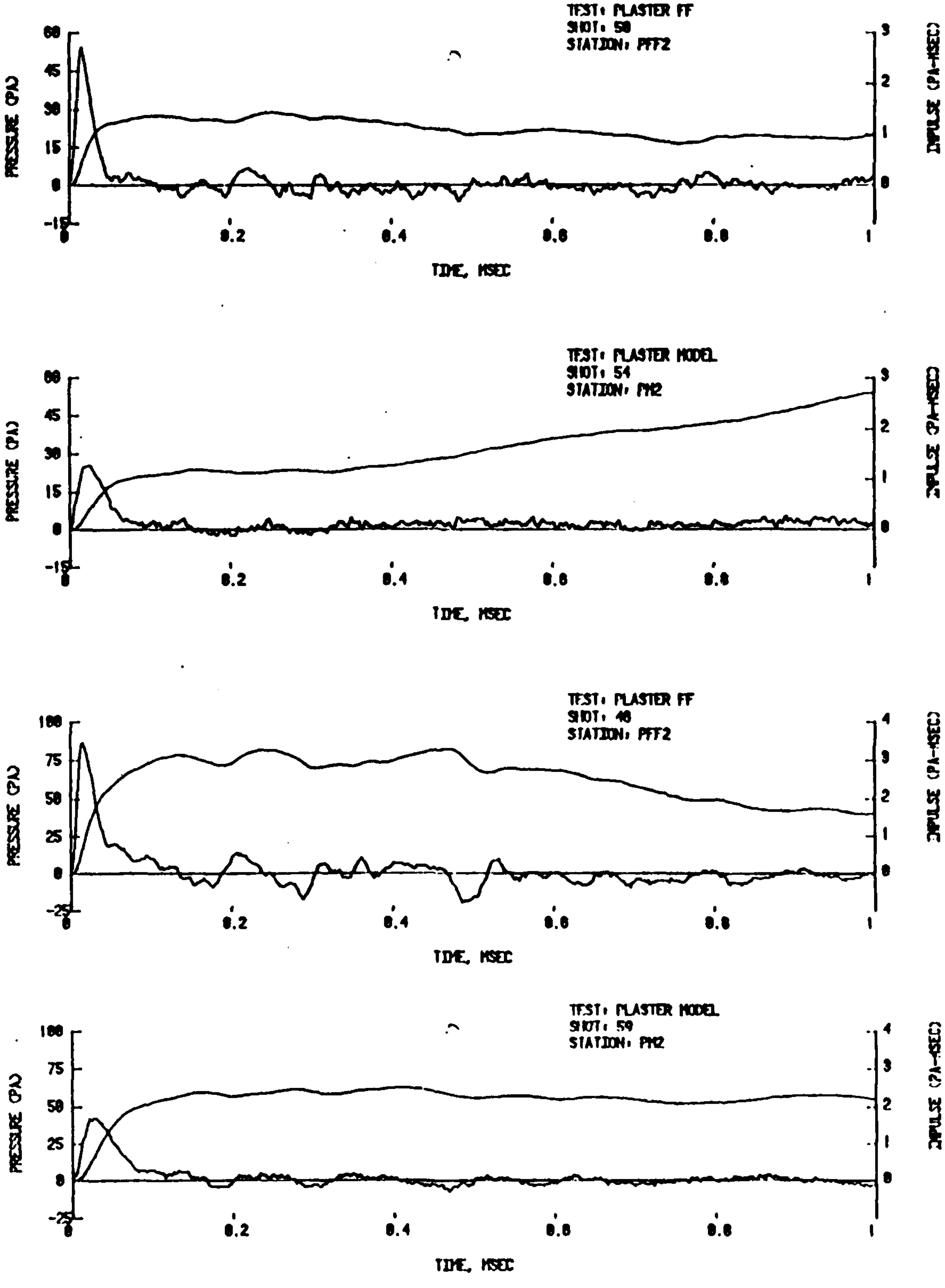

Figure 7. Pressure-time Records at Station 2

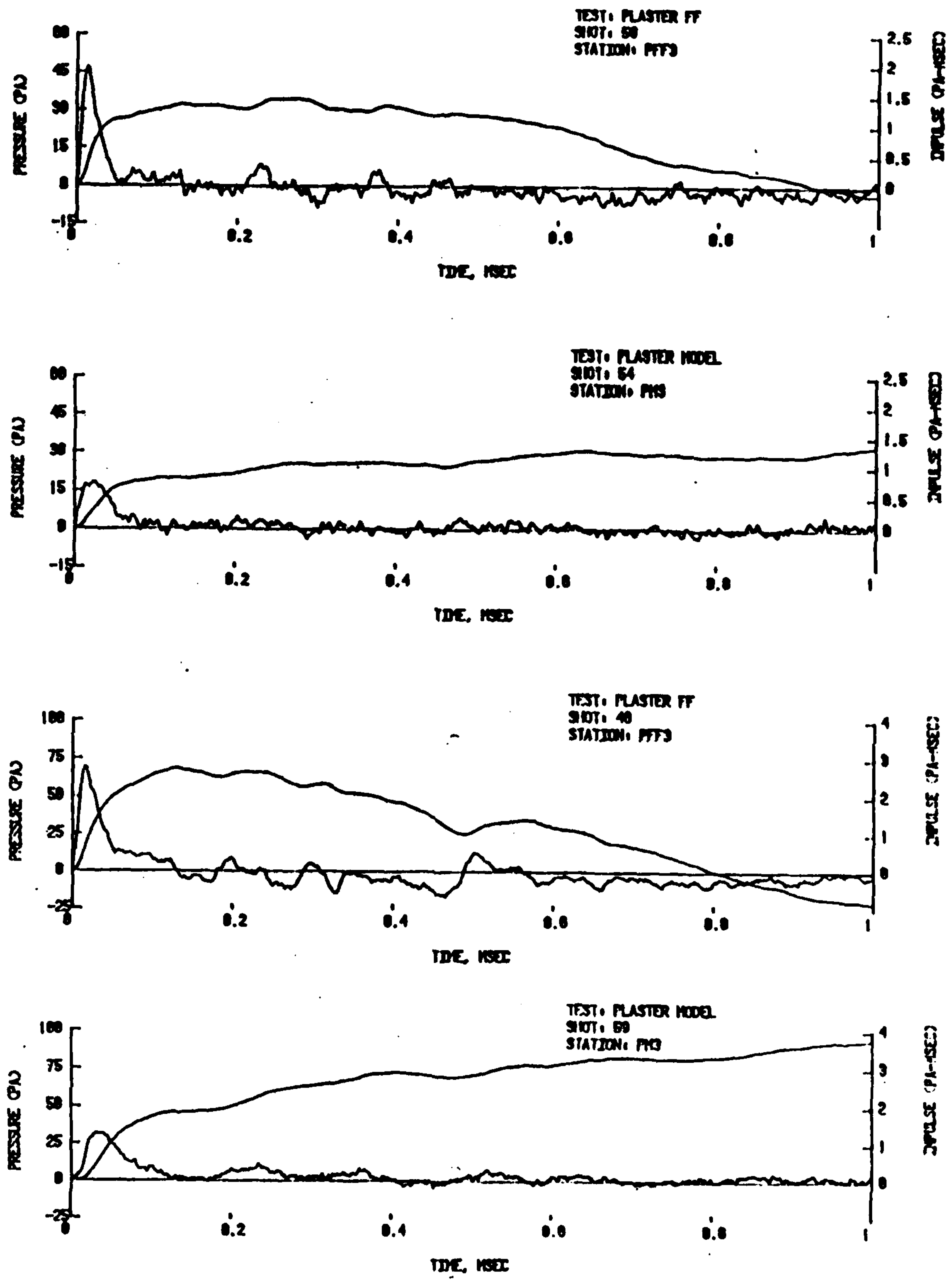

Figure 8. Pressure-time Records at Station 3

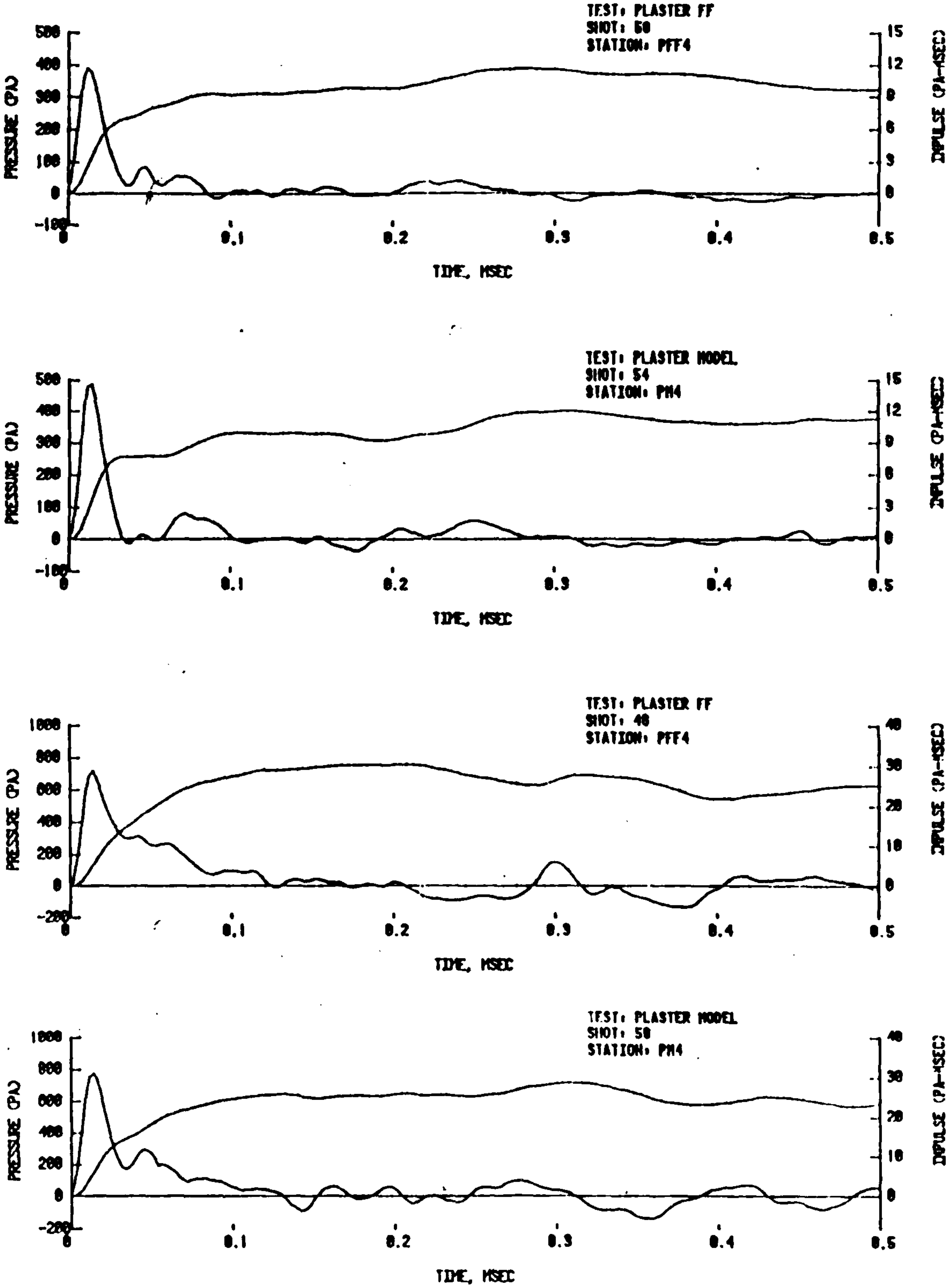

Figure 9. Pressure-time Records at Station 4

R is the distance between the tunnel outlet and the object in the environment, and
ν is the angle between the tunnel axis and the radial R.

This formula was reported by Dr. Amann of the Ernst Mach Institute as indicated in Reference 1. (In Reference 1, $B_2 = 1.35 \pm 0.8$) The equation is an empirical fit to data; it was reduced from experiments where TNT charges ranging from 9.5 gm to 151.5 gm were detonated in a non-responding chamber connected by a passageway (tunnel outlet) to the outside environment and was reported at *MABS* 5.[3] According to Reference 3, the data was compared with data from compressed air shock tubes, and the fitted parameters showed qualitative agreement. Kingery[4] has compared this empirically derived equation with other similar equations and found that for a large variety of explosive and shock tube data Equation 1 adequately predicts the environmental overpressure. The predictions generated by Equation 1 are shown as a straight line on Figure 10 and may be compared with the experimental results and other data. A comparison indicates that the results measured on this 1:1300 scale flat surface are similar to what would be measured at full scale.

5. CONCLUSIONS

The enhancement at Station 1 and the attenuation at Stations 2 & 3 are real effects that are present at Reiteralpe. The enhancement at Station 4 may or may not be occurring at Reiteralpe, depending upon just how well the 1:1300 scale model simulates the topography at this near field position.

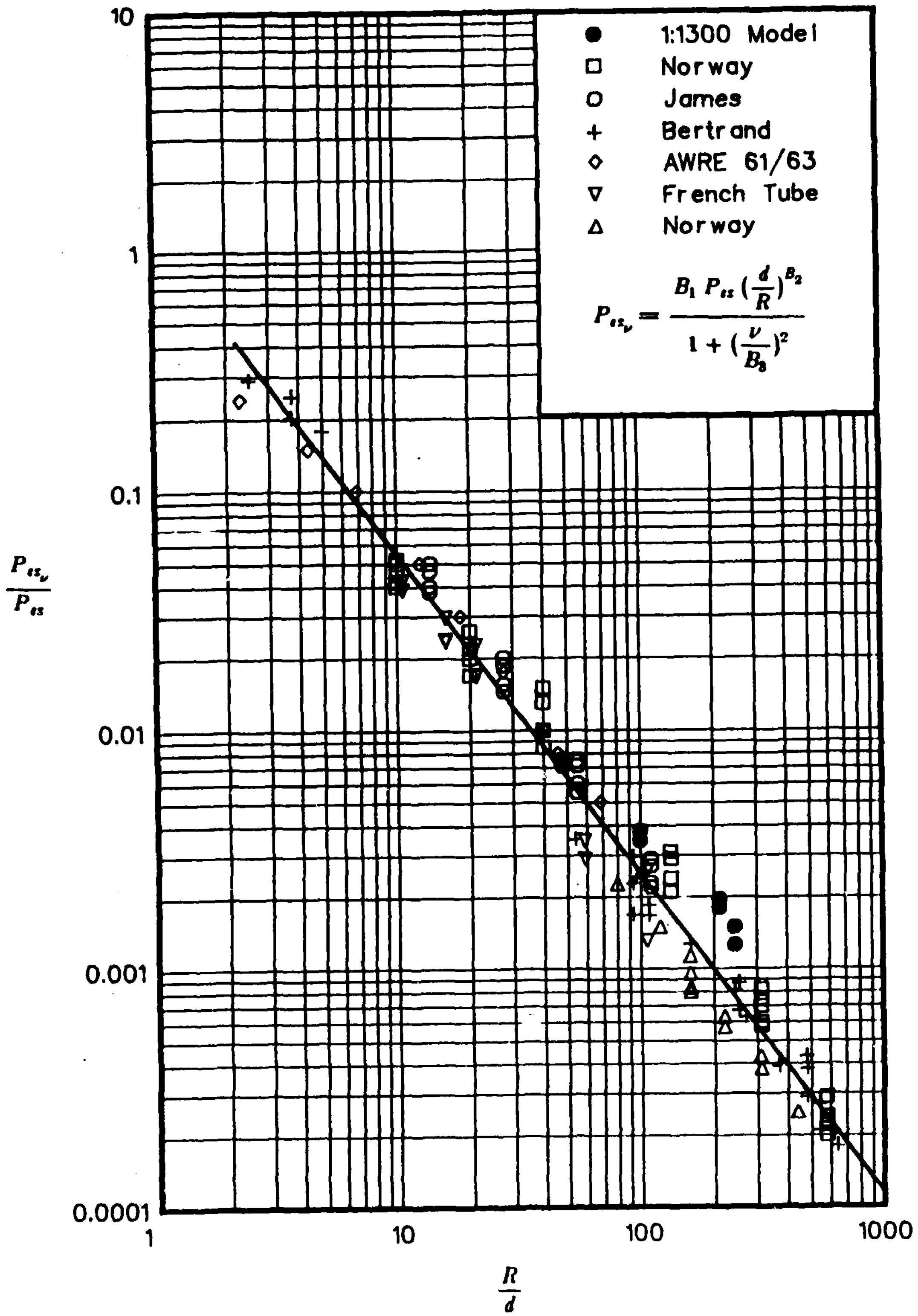

Figure 10. Comparison of Equation 1 with Scale Model Results and Other Data

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