UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 148, "IN SITU STRESS MEASUREMENTS IN THE EARTH'S CRUST IN THE EASTERN UNITED STATES"

The purpose of this memorandum is to transmit the results of in situ stress measurements (Rundle et al., 1986) conducted at three intraplate seismic areas in the Eastern United States: (1) Moodus, Connecticut, (2) Ramapo Fault, New York-New Jersey, and (3) Central Virginia. The studies were sponsored by RES in order to define the stress field in these seismic areas of the Eastern United States.

Determination of the stress field is of relevance to the concept of tectonic provinces in Appendix A to 10 CFR Part 100. Changes in the direction and/or magnitude of the stress field could indicate that a tectonic boundary has been crossed and may indicate the need for reevaluation of the design basis earthquake at specific sites. The stress field also indicates which faults are favorably oriented for potential reactivation by the current stress field.

INTRODUCTION

1. Background

The neotectonics of the Eastern United States are poorly understood. There are no identified active fault zones which are part of a system of coherent tectonic strain such as is found on the San Andreas and associated faults in the Western United States or the New Madrid fault system of the Mid-Continent. For the design of nuclear facilities and the evaluation of their safety, it is important that the seismic hazard be understood with some measure of confidence. However, the sparsity of available data is a significant source of uncertainty in identifying the seismic hazard for the Eastern United States. There have been large historical seismic events in Eastern North America, e.g., the 1886 Charleston earthquake, the 1755 Cape Anne earthquake, the 1925 Charlevoix earthquake, etc. Also, throughout the Eastern United States there are other locations that have experienced moderate seismic events of up to Richter magnitude 5 or slightly higher. The potential for these locations to generate larger earthquakes is not well known or understood.

In situ stress measurements using the hydraulic fracturing method were used in this study as a means of understanding the causes of seismicity in the Eastern United States. The reliability of such in situ stress measurements for engineering purposes and in the petroleum industry is well understood. Their use

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for neotectonic applications is relatively new, but they have been used (e.g., Zoback and Zoback, 1980) to define stress provinces of the United States, particularly in conjunction with fault plane solutions of the seismicity in these zones. The direction of stress is important in that it determines the structures in the region that are potentially seismogenic. The magnitude of stress is important in that it indicates the likely mechanism of failure and provides insight into the nature of tectonic processes in the area. However, it must be emphasized that results from hydraulic fracturing stress measurements require a considerable amount of judgement in their interpretation and application to geologic and seismic problems.

2. Testing Program

Engineers International Inc., Napierville, Illinois, was selected as a contractor to conduct a series of in situ stress measurements using the hydraulic fracturing method in three areas of known seismic activity, namely the Moodus, Ramapo, and Central Virginia seismic zones. Two boreholes were drilled in each of the three areas investigated, one within and one outside the seismic zone. The borings were drilled to a maximum depth of 1,432 feet. In situ stress magnitudes and directions were then measured at two to four elevations in the borehole by hydraulic fracturing. Only in the Moodus seismic zone were any stress measurements made at the hypocentral depth (>1,000'). This is significant in that stress measurements at shallow depths may not be true representations of stress at hypocentral depths. The general borehole locations are shown in Figure 1. The specific hole locations, the geology and seismic history of the three areas, details of the measurements, and results of these tests are described in Rundle, et al., 1986.

TEST RESULTS

Table 1 shows measured stress magnitudes and orientations of the principal horizontal stress in the three zones. Figure 2 graphically illustrates the measured stress magnitudes. Also shown on Figure 2 is a dashed line, calculated from the Mohr stress plot and representing, for a given depth, the value of horizontal stress at which Mohr's circle is tangent to the Mohr failure envelope. Below the dashed line, hypothetically, no failure could occur, while above the line the potential for faulting exists. It can be seen that the magnitude of the measured stresses is high. In all three areas the rock is at incipient failure by reverse faulting and, therefore, is potentially seismically active.

The stress directions in the Ramapo and Central Virginia seismic zones are mostly northeast to east. This is consistent with the general direction of stress in the Eastern United States which ranges from eastnortheast to east. Focal plane solutions of seismicity in the Ramapo and Central Virginia zones indicate a northeasterly direction of stress (Quittmeyer et al., 1985; Nelson and Talwani, 1985), which is in agreement with the measured stress directions reported for this study.

At the Moodus seismic zone, the measured direction of stress is northwest. The most recent seismicity at Moodus has been shallow (some depths less than 1 km), and it is generally assumed that earlier seismicity was also shallow. Thus the

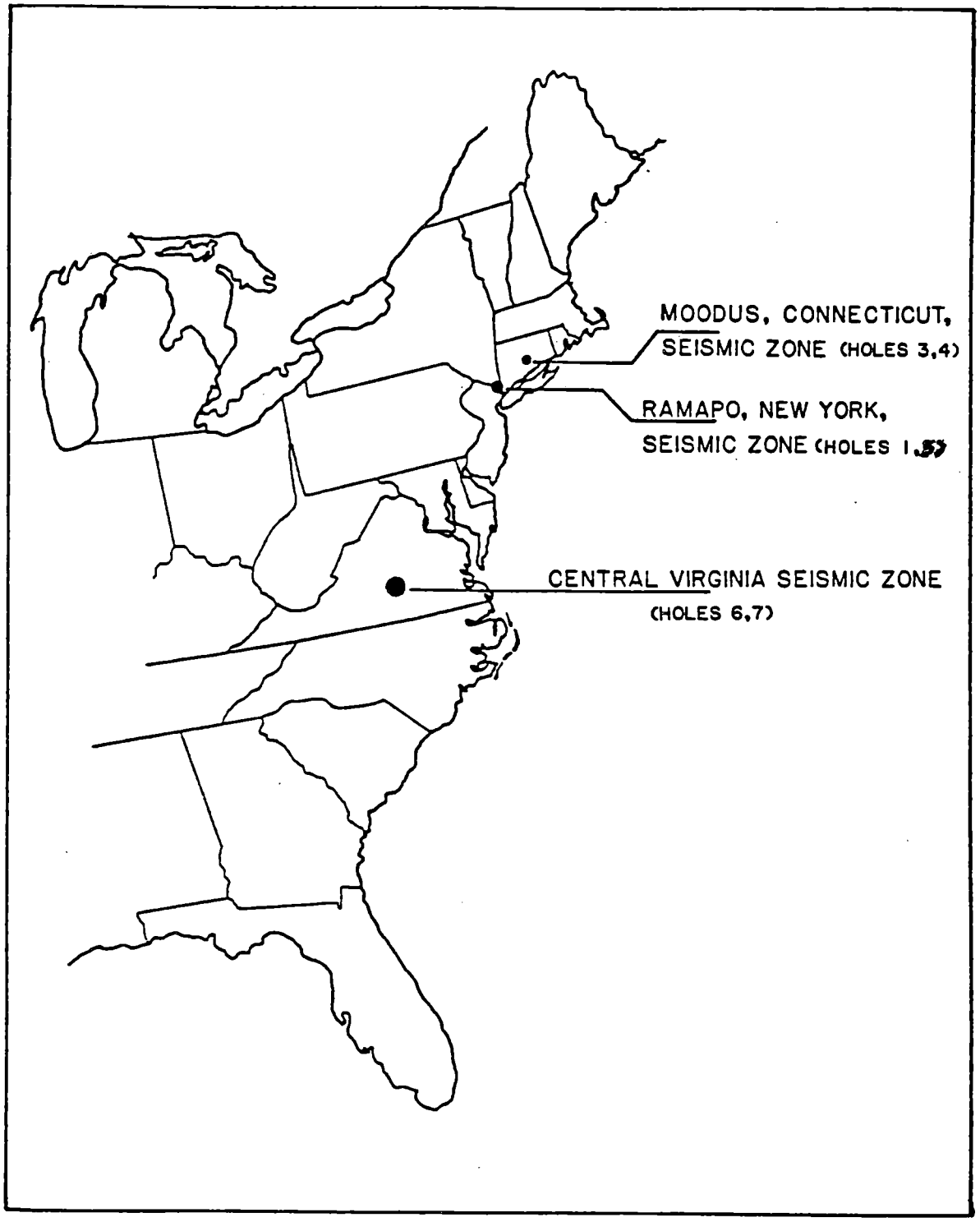

Figure 1. Seismic Zone Locations

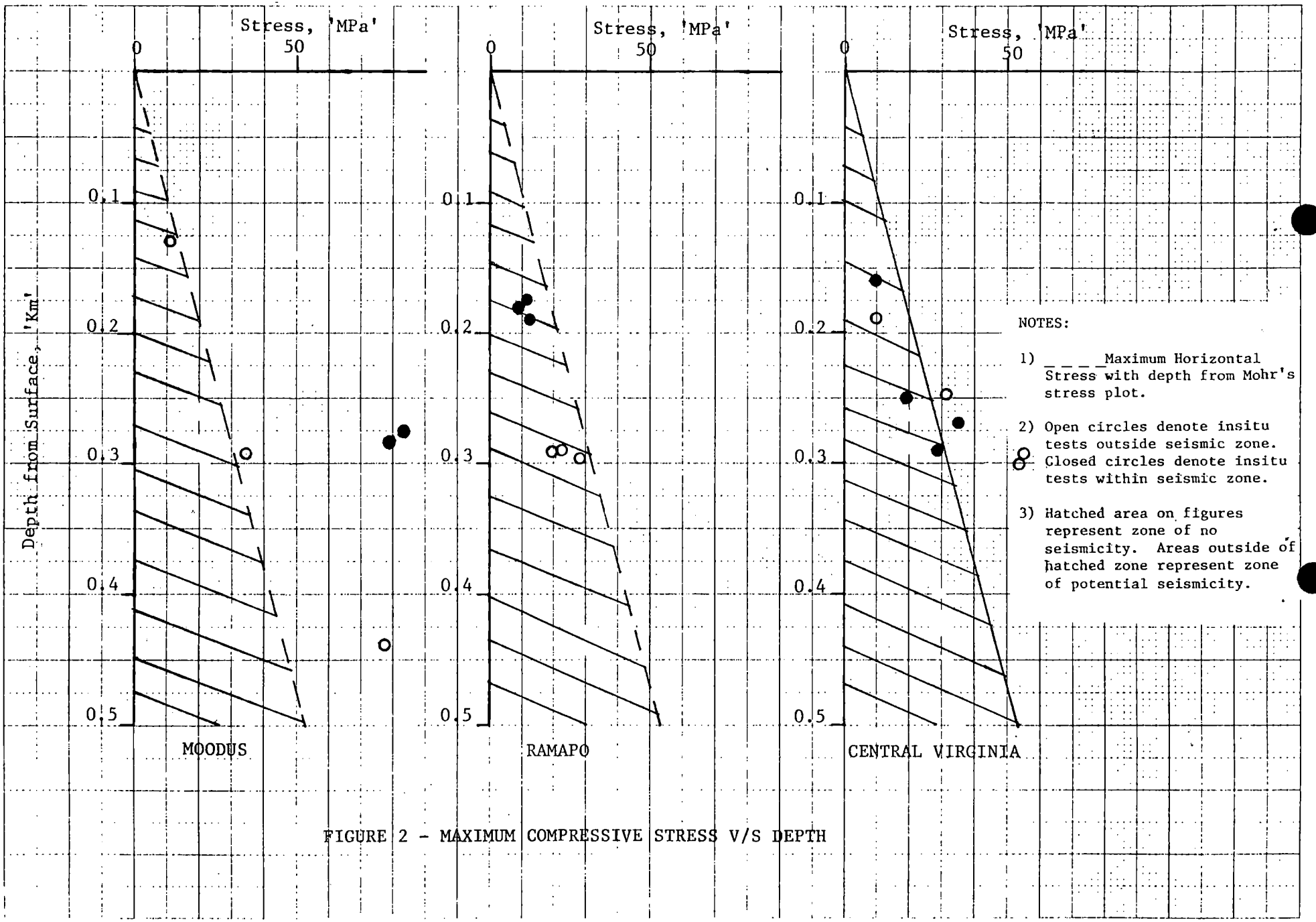

FIGURE 2 - MAXIMUM COMPRESSIVE STRESS V/S DEPTH

Table 1 Stress Measurement Summary

Seismic Zone (Test Proximity)	Hole Number	Test Depth, ft Test Elevation	Test Depth, ft Below Mean Sea Level	Min. Horiz. Stress, psi σ_h	Max. Horiz. Stress, psi σ_H	Vert. Stress, psi σ_v	Max Horiz. Stress(σ_H) Direction
Moodus	3	931	(-781)	5,985	12,200	1,100	N48°W
(within zone)		945	(-795)	5,560	11,700	1,115	
Moodus	4	422	(-412)	1,050	1,675	500	
(Outside Zone)	4	939	(-929)	2,605	5,100	1,110	N75°W
		1432	(-1432)	5,802	11,580	1,690	
Ramapo	1	568	(-318)	920	1,755	630	
(Near Zone Boundary)		594	(-344)	830	1,585	660	N69°E
		637	(-387)	1,050	1,855	700	
Ramapo	5	941	(-561)	1,725	3,215	1,110	
(Outside Zone)		951	(-571)	1,670	3,140	1,125	N72°E
		979	(-599)	2,270	4,170	1,155	
Ramapo	2	- No usable test results obtained -					
Central Virginia	6	538	(-388)	930	1,490	635	
(within zone)		831	(-681)	1,560	2,830	908	N74°W
		882	(-732)	2,480	5,190	1,040	
		940	(-790)	2,410	4,230	1,110	
Central Virginia	7	629	(-279)	980	1,495	740	
(Outside Zone)		820	(-470)	2,605	4,605	970	N74°E
		969	(-619)	4,270	8,370	1,145	
		997	(-647)	3,730	7,930	1,175	

1,432-foot borehole probably extended into the hypocentral depth of some of the seismicity, and it can be assumed that the measured stress direction is reliable. Unfortunately there are no focal plane solutions of the seismicity at Moodus available at the present time to verify the field data.

SUMMARY AND CONCLUSIONS

(1) In a general way, the stress measurements reported indicate that the area east of the Appalachians belongs to the same stress province as the mid-continent of the United States, where the predominant stress direction ranges from eastnortheast to east. Some of the stress measurements, however, deviate from this direction, particularly at Moodus where a consistent westnorthwest to northwest direction was measured. The difference may be due to the type and orientation of geologic structures at Moodus.

(2) The in situ stress measurements show that complete reliance cannot be placed on a uniform regional stress pattern throughout the Eastern United States. Site specific stress orientations and magnitudes must also be taken into account in assessing the seismic and surface faulting potentials at a site.

(3) Stress magnitudes measured at all three sites were high, indicating seismically active areas. The measurements support the hypothesis that shallow reverse faulting is the predominant mechanism for seismicity at the sites.

(4) No consistent difference in stress magnitude has been found between measurements inside and outside of the seismic zones (Fig. 2). This suggests that local inhomogeneities or zones of weakness determine the location of seismicity rather than changes in stress levels.

(5) RES is considering the merits of additional research in the following areas: More measurements of in situ stress may help to resolve questions on the causes of seismicity in the Eastern United States. Stress measurements at greater depths would be particularly desirable. Measurements of crustal strain are being considered as another means of analyzing the causes of seismicity that should be pursued concurrently with stress measurements.

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Enclosure: List of References

REFERENCES

Zoback, M. D. and Zoback, M. (1980), "State of Stress in the Continental United States," Journal of Geophysical Research, V. 85, pp 6113-6156.

Rundle, T. A., Singh, M. M., and Baker, C. H., (1986), "In Situ Stress Measurements in the Earth's Crust in the Eastern United States," NUREG/CR-4623.

Quittmeyer, R. C., Statton, C. T., Mrotek, K. A., Houlclay, M., (1985), "Possible Implications of Recent Microearthquakes in Southern New York State," Earthquake Notes, Vol. 56, No. 2, April-June 1985.

Memorandum, P. Sobel and R. McMullen to R. Jackson, NRR, December 8, 1983.