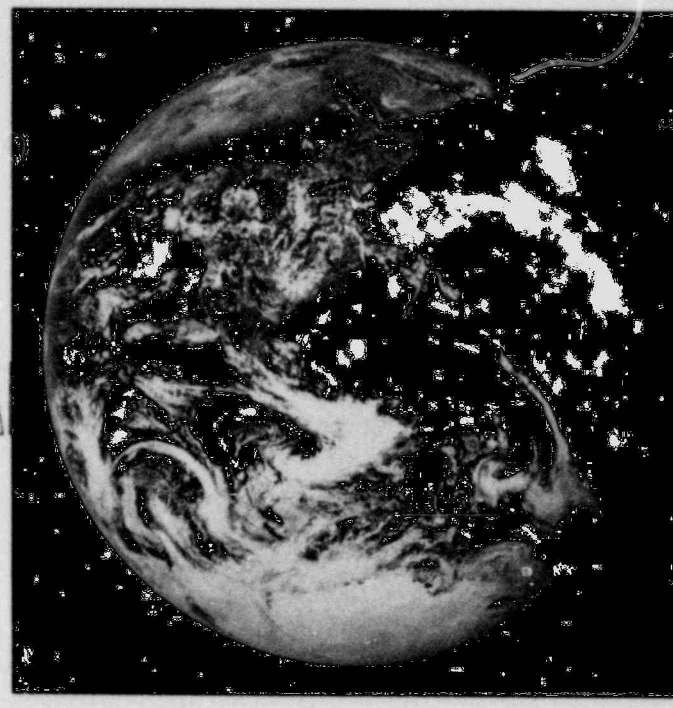

RESPONSE TO NRC CONCERNS ON LIQUEFACTION POTENTIAL AT LACROSSE BOILING WATER REACTOR (LACBWR) SITE NEAR GENOA VERNON COUNTY, WISCONSIN

Prepared for
Dairyland Power Cooperative
LaCrosse, Wisconsin 54601

Contract Number
11166-003-27

Prepared by

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March 2[illegible], 1980

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March 21, 1980

LaCrosse Boiling Water Reactor
Dairyland Power Cooperative
Post Office Box 135
Genoa, Wisconsin 54632

Attention: Mr. R. E. Shimshak
Plant Superintendent

Gentlemen:

We have enclosed 40 copies of our report, "Response to NRC Concerns on Liquefaction Potential at LaCrosse Boiling Water Reactor (LACBWR) Site, Near Genoa, Vernon County, Wisconsin," for your use. This report includes:

a) Brief summaries of all previous liquefaction analyses performed at LACBWR site and related background studies;

b) A re-evaluation of the seismicity at LACBWR site;

c) Summaries of reviews of the D&M report of September 28, 1979, by Dr. H. Bolton Seed; and

d) Our conclusions based upon re-evaluation of our earlier findings in light of Dr. Seed's review.

We have concluded that the factors of safety against liquefaction potential under the containment building at the LACBWR site are higher than those presented in our September 28, 1979, report for the free-field conditions.

This report was transmitted to you in draft form for your review on March 14, 1980, and your review comments were received during a telephone conversation between your Mr. Shimshak and Dr. Nataraja of Dames & Moore.

If you have any further questions or comments regarding the contents of this report, please do not hesitate to call us.

It has been a pleasure working for Dairyland Power Cooperative and we look forward to our continued association with you.

Very truly yours,

DAMES & MOORE

Harch Singh

Harch Singh, Ph.D.
Partner

M S Nataraja

Mysore Nataraja, Ph.D., P.E.
Senior Engineer and Project Manager

HS/MN:ev

Enclosure

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1.0 INTRODUCTION

1.1 BACKGROUND

In 1973, Dames & Moore (D&M) performed a Geotechnical Investigation of Geology, Seismology, and Liquefaction Potential at the LaCrosse Boiling Water Reactor (LACBWR) site (Ref. 1). This study was conducted for Gulf United Nuclear Fuels Corporation. D&M's report was submitted to the U.S. Nuclear Regulatory Commission (NRC) in 1974, as part of the application for an operating license for the LACBWR plant (Ref. 2). In the study, D&M concluded that the LACBWR plant had adequate factors of safety against potential for liquefaction under the design Safe Shutdown Earthquake (SSE) corresponding to a peak ground surface acceleration of .12 g.

NRC initiated a review of the LACBWR site and plant under its Systematic Evaluation Program (SEP) in 1978. As a part of SEP, the U.S. Army Engineer Waterways Experiment Station (WES) was requested by NRC to review the 1973 D&M soils investigation. After reviewing the data and analyses presented by D&M, WES performed its own analyses based on interpretations of the same data. The WES report, submitted to NRC and made public in 1978 (Ref. 3), concluded that the factors of safety against liquefaction potential were considerably lower than those calculated by D&M for a peak ground surface acceleration of .12 g.

Upon request of the Dairyland Power Cooperative (DPC), D&M reviewed the WES report and reevaluated its 1973 report in view of the WES analyses. Based on this effort, D&M presented to NRC a position whicn was essentially consistent with its 1973 study. It was decided during the meeting with NRC on February 9, 1979, that a written report should be prepared summarizing the meeting, the reviews made, and the various analyses on liquefaction potential for the LACBWR site. Accordingly, a report (Ref. 4) was submitted to NRC in which D&M reiterated its earlier stand that the LACBWR site had adequate factors of safety against potential for liquefaction under the design SSE. However, certain questions raised by NRC regarding the lack of test data on undisturbed samples and the lack of continuous standard penetration test (SPT) results could not be satisfactorily answered with the existing data. Therefore, DPC agreed to perform further field and laboratory investigations and analyses.

In its March 1979 report (Ref. 4), D&M recommended a program consisting of a minimum of four test borings, undisturbed sampling, and cyclic triaxial testing and analyses. After review of the D&M report, NRC approved the proposed geotechnical program and suggested minor modifications (Ref. 5).

D&M performed a field and laboratory testing program which included:

- Carefully controlled standard penetration tests
- "Undisturbed sampling" using state-of-the-art procedures and techniques
- Measurements of cyclic shear strength using state-of-the-art testing techniques.

D&M performed an in-depth analysis of liquefaction potential at the LACBWR site utilizing the results of the field and laboratory testing program and all available procedures. These findings were documented in a report submitted to NRC on September 28, 1979 (Ref. 6), which concluded that there was no threat of seismic liquefaction at the LACBWR site due to an acceleration of .12 g at the ground surface.

Based on a review and interpretation of the data presented in the September 28, 1979, report, NRC and its consultant (WES) concluded that the foundation material below the water table down to a depth of approximately 40 feet could strain badly if an earthquake with peak acceleration of .12 g occurs. NRC also made an initial estimate, based on a review of probabilistic studies, of a return period of at least 1000 years for an earthquake producing an acceleration of .12 g at the site. This estimate led NRC to conclude that there is a low seismic hazard for the facility during the period required to complete evaluation of seismic design parameters of the site (Ref. 7).

A meeting was subsequently held between representatives of DPC and their consultant D&M, and NRC and their consultant WES, on October 7, 1979. The purpose of the meeting was to discuss the contents of the September 1979 report. NRC and WES reasserted their conclusion that liquefaction potential exists for the soils below the water table to a depth of at least 35 feet, based upon a more conservative interpretation of the data presented by D&M. It was contended by NRC and WES that densification during sampling and testing was not adequately accounted for in the D&M analysis, and that correlations with SPT data at Niigata, Japan, show factors of safety against liquefaction of less than 1. The NRC staff agreed that the site is in a seismically stable region, and indicated that the study to determine an appropriate design acceleration level should be complete by early 1980. DPC requested a written summary of NRC concerns in order to adequately respond to them, to which NRC agreed (Ref. 8).

On November 2, 1979, NRC and their consultants met with DPC and their consultants to discuss the concerns raised in the meeting of October 17. NRC and WES believed that the soil samples used for laboratory analysis could be densified up to 3-4 pounds per cubic foot (lb/ft^3) from the in situ condition, and contended that this densification was not adequately accounted for in the D&M analysis. On the basis of the effect of this density increase, and an independent comparison of SPT data with that of Niigata, Japan, NRC and WES concluded that liquefaction potential exists at the site for peak accelerations of .08 g or higher. DPC was requested to submit a plan to NRC by November 30, 1979, for mitigating liquefaction at the site (Ref. 9).

In accordance with NRC's request, an assessment of various methods to mitigate liquefaction potential at the LACBWR site was prepared and a report dated November 29, 1979 (Ref. 10), was submitted to NRC. This report tentatively concluded that a dewatering system appeared to be the most feasible means of reducing the potential for liquefaction at the site, and presented preliminary details for such a plan.

Following submittal of the dewatering plan, an independent review of the September 28, 1979, report prepared by D&M was sought and obtained by DPC. Dr. H. Bolton Seed, professor of Civil Engineering at the University of California at Berkeley and an internationally recognized expert on liquefaction, and Dr. Sukhmander Singh, an in-house D&M specialist on soil properties pertaining to liquefaction, performed the review. Dr. Seed has developed procedures for performing liquefaction analysis, and these procedures were used by both D&M and WES. In his technical review Dr. Seed evaluated the data using both an analysis-testing approach and an empirical approach based on past performance of different sandy sites during earthquakes. His conclusion was that the site is safe against liquefaction during a local earthquake producing maximum horizontal ground surface acceleration of .12 g, with five equivalent uniform cycles of shaking (Ref. 11).

Dr. Seed's conclusions were discussed during a conference telephone call among Dr. Seed and representatives of DPC, D&M, NRC, and WES on January 18,

1980. During the conference call the NRC expressed its concerns about the following:

- Increase of measured N-values as suggested by Dr. Seed to account for special considerations given to minimize rope and pulley friction during sampling in this project and to compare results so obtained with N-values obtained by more common techniques
- Selection of appropriate earthquake magnitude curves to be used in the empirical analysis developed by Dr. Seed
- Increase in density during sampling and testing.

On the issue of soil densities, Dr. Seed said that there were several counter-balancing influences during sampling, freezing, thawing and testing, and therefore it was inappropriate to reduce arbitrarily the strengths to account for lowered densities. Also, by accounting for the presence of piles under the containment vessel, which was not considered in the D&M free-field analysis, it could be shown that the conclusions of the D&M analysis are valid without modification. Even on the basis of Dr. Seed's review of December 27, 1979, and the telephone discussion of January 18, 1980, the liquefaction issue at the LACBWR site remained unresolved.

As a result of the review of the D&M report of September 28, 1979, and the ensuing technical discussions, NRC issued to DPC on February 25, 1980, an "Order to Show Cause" why DPC should not plan and implement a site dewatering system to preclude liquefaction in the event of an earthquake with peak ground surface accelerations of .12 g or less (Ref. 12). NRC's conclusion that liquefaction can occur down to a depth of 40 feet was based on a comparison of the LACBWR site with other sites where liquefaction has occurred and on the use of laboratory strength data.

1.2 PURPOSE AND SCOPE

The purpose of this report is to show that, in our opinion, there is no threat of liquefaction under the designated earthquake conditions, and to show that there is no need for any mitigative measures.

The remaining sections of this report will present technical issues not discussed in detail in earlier reports and answer the concerns of NRC and their consultant WES.

2.0 SEISMICITY AT LACBWR SITE

After a careful evaluation of all possible sources of earthquake motion and their possible effects on the LACBWR site, D&M concluded in 1973 (Ref. 1) that the Safe Shutdown Earthquake (SSE) should be considered as the occurrence of an MM Intensity VI shock with its epicenter close to the site. Using the procedures available in 1973, D&M estimated that the maximum horizontal ground acceleration induced by such an event would be 12 percent of gravity at the ground surface. According to the detailed discussions on the historical seismicity of the central stable region (CSR) presented in the 1973 report, the SSE and the ground surface acceleration corresponding to the SSE were considered conservative. However, the NRC has not yet assigned an SSE for the LACBWR site and is expected to do so in the spring of 1980. All the liquefaction analyses performed during the SEP for the LACBWR site have been performed for a given range of ground surface acceleration due to the SSE. For this reason, the NRC staff has made an estimate of the probability of exceeding a range of peak accelerations at the LACBWR site in order to make an estimate of the hazard associated with the liquefaction potential (Ref. 7).

A seismicity study of the Central United States performed by TERA Corporation for Lawrence Livermore Laboratory (Ref. 13) is being used by NRC to arrive at an SSE for the LACBWR site. Based on the TERA review of several probabilistic studies, the return period for an earthquake resulting in .12 g ground surface acceleration would be <u>at least 1000 years</u>. This peak acceleration (.12 g), according to NRC, corresponds to MM Intensity VII when utilizing the relationship proposed by Trifunac and Brady. It should be noted that D&M had assigned an SSE of MM Intensity VI which, according to Trifunac and Brady's relationship, corresponds to a peak acceleration of only .06 g, a value half as much as the one designated for liquefaction analysis in 1973. The TERA study for NRC also reveals that the actual return period for a .12 g level earthquake <u>could be larger by an order of magnitude</u> than the calculated return rate of 1000 years. Based on these estimates of return periods NRC concluded that the general level of seismic hazard at the LACBWR site was sufficiently low that the operation of the plant for the next 12 months would not endanger the health and safety of the public.

We have reviewed the three-volume study by TERA Corporation which was used by NRC to conclude that the seismic hazard at the LACBWR site was low.

We have examined the assumptions and methodology on which the TERA analysis is based, and made appropriate modifications.

The TERA study concludes that the best estimate of peak single-component horizontal ground acceleration at the LaCrosse site is as follows:

Acceleration	Return Period	Annual Probability of Exceedance
6% g	200 years	.005
11% g	1,000 years	.001
18% g	4,000 years	.00025

Ranges of estimates are also given; for example, a range of 7% g to 16% g is indicated for the 1,000-year return acceleration.

We discuss below some of the differences in approach we have taken to arrive at the return periods and seismic risk for the LACBWR site.

2.1 EARTHQUAKE SOURCES

The TERA report determines that the seismic hazard at LaCrosse results primarily from two sources of earthquakes: the New Madrid region; and the so-called Central Stable Region (CSR). The former contributes mathematically to the probability of exceeding accelerations of 10% g to 20% g at LaCrosse, but we do not feel that earthquakes originating in the New Madrid area could cause liquefaction at the site. The distance involved is some 700 to 800 km; for comparison, the largest reported epicentral distance of liquefaction effects during Japanese earthquakes is about 350 km during a magnitude 8 event (Ref. 14). During the December 1811 New Madrid earthquake the estimated Modified Mercalli Intensity (MMI) in the area of the LACBWR site was V (Ref. 15). Thus we feel it is appropriate to exclude the New Madrid region during an analysis of liquefaction hazard at the LaCrosse site.

Earthquakes are assumed in the TERA study to occur throughout the Central Stable Region (CSR), with epicenters equally likely at all points; this is a reasonable assumption for assessing seismic hazard. The largest earthquake thought possible by the experts polled had associated MMI's ranging from about VI to XII (an approximate conversion from magnitude M_b to MMI is necessary for these comparisons), with an average of about VIII½. The largest historical events in the CSR have associated MMI's of VII½ (one MMI VIII event in northern Michigan can be attributed to a mine collapse on the basis of the felt area and descriptions of effects). We believe it is conservative to assume a maximum MMI of VIII for the CSR, for the purposes of seismic hazard analysis. The large number of historical MMI VII's in the CSR support this assumption and imply that a maximum MMI of VII½ (instead of VIII) might be supported on statistical grounds. This would change the results presented here (reduce the indicated hazard) only slightly; the assumption of maximum MMI of VIII in any case is more conservative.

The TERA study uses the following relations among epicentral intensity MMI_e, body wave magnitude M_b, and local magnitude M_L:

$$MMI_e = 2 M_b - 3.5 \tag{2.1}$$

$$M_L = 1.34 M_b - 1.71 \tag{2.2}$$

With these relations, the maximum MMI of VIII corresponds to $M_L = 6.0$. We conclude that the liquefaction hazard at the LACBWR site is caused by small earthquakes ($M_L \le 6$); larger events ($M_L > 6$) can occur only at distant sources and will not generate ground motions at the site great enough to cause liquefaction.

The TERA results are calculated on the basis of a lower bound MMI of 4.25 (the Arabic scale is used by TERA). Using the above equations, this lower bound corresponds to a magnitude (M_L) of 3.5. Such small earthquakes, while contributing mathematically to the acceleration hazard, are not considered capable of inducing liquefaction because of their short duration. Therefore we consider it reasonable to determine the seismic hazard from earthquakes in the CSR of magnitude $M_L \ge 5.0$, which corresponds to MMI = 6.5. We have calculated a rate of occurrence for these events based on the historical seismicity as reported by TERA.

2.2 ATTENUATION OF ACCELERATION

The TERA study uses an attenuation of acceleration derived from MMI attenuation and a relationship among MMI, acceleration, and distance. This is slightly different from other attenuations which have been used. (We have ignored any differences in site conditions for which the curves have been proposed; many researchers, including TERA, find an insignificant dependence of acceleration on site geology.) The TERA curves generally give somewhat larger accelerations at long distances and somewhat lower accelerations at short distances. At around 30 to 50 km for magnitudes 5 to 6, the accelerations predicted by TERA are close to those of the other investigators. Not surprisingly, the seismic hazard analysis is not sensitive to which set of mean curves is used.

2.3 UNCERTAINTY OF PREDICTED ACCELERATIONS

An important aspect of hazard analysis is the uncertainty associated with the predicted acceleration. TERA models the uncertainty with a lognormal distribution (which is appropriate) with a standard deviation σ of ln (acceleration) equal to ($\sigma_{\ln a} = .9$), a coefficient of variation of 1.1. We feel that a lower standard deviation is more appropriate for two reasons. First, the available attenuation functions indicate similar accelerations in the magnitude and distance range critical to seismic hazard assessment at the LACBWR site. Second, data on intensity attenuation and intensity-acceleration correlations are almost universally derived by treating MMI as a discrete variable, whereas seismic hazard analysis is usually done (and is done here) by treating MMI as a continuous variable. Thus, a discrete MMI of VII is represented in the hazard analysis as a range of intensities (e.g., 6.5 to 7.5) which in itself induces scatter in the predicted accelerations. We therefore feel that an attentuation uncertainty represented by $\sigma = .6$ (coefficient of variation of .66), which is typical of California attenuation functions, is appropriate.

2.4 GROUND MOTION HAZARD

With the assumptions mentioned above we have determined the seismic ground acceleration hazard at the LACBWR site. Other methods and assumptions used are generally those adopted by TERA, except that uncertainty in predicted acceleration was not truncated at two standard deviations, as was done by TERA. Truncation at two standard deviations is not easily justifiable, although it is logical that attenuation uncertainty be truncated at some level; we use an untruncated distribution here because it is conservative.

2.5 SUMMARY

The following summary represents the seismic hazard associated with the LACBWR site.

Acceleration	Return Period	Annual Probability of Exceedance
5%g	1,000 years	10^{-3}
8%g	4,000 years	.00025
12%g	10,000 years	10^{-4}

These results were obtained using a computer program developed by R. McGuire to perform seismic risk analysis (Ref. 16). For purposes of checking, the program was first run using the assumptions of TERA, and virtually identical results were obtained to those of TERA for this test case.

The difference between the above results and those of TERA derives predominantly from two sources: events with magnitudes less than 5 are not included in the D&M analysis; and a smaller uncertainty in attenuation is used. Both of these differences are justified and result in more accurate estimation of seismic hazard for the purposes of determining liquefaction risk. To a lesser degree, several other differences also contribute: no consideration of New Madrid Region is given, and a maximum MMI of VIII is assumed for the CSR. We believe that a more detailed analysis would indicate an even lower hazard in the range of 10^{-4} to 10^{-5} annual probability for .12 g acceleration (i.e., a return period of 10,000 to 100,000 yrs).

Therefore, we conclude that, with the very low seismic risk associated with the LACBWR site, liquefaction analysis using the designated seismic parameters should lead to conservative conclusions.

3.0 CONCERNS RELATING TO LIQUEFACTION POTENTIAL

As presented in the "Order to Show Cause," NRC's conclusion of liquefaction potential under the designated seismic conditions is based on two concerns: that of apparently low SPT N-values and that of inadequately conservative interpretation of laboratory test strengths. Each of these concerns is addressed below as related to the evaluation of liquefaction potential for the site.

3.1 SPT BLOW COUNT DATA

The empirical approaches to evaluation of liquefaction potential used by both D&M and WES depend on the availability of SPT blow counts (N-values) representative of the site being evaluated. These N-values are compared with those at other sites where liquefaction has been observed either to occur or not to occur under known seismic conditions (Ref. 17). Based on these past performances, a prediction can be made as to whether liquefaction will occur for the postulated seismic event at the site. In applying these correlations with the N-values for the LACBWR site presented in the D&M report of September 28, 1979 (Ref. 6), the following points must be considered:

- o Depth of the foundation for reactor containment vessel (3.1.1)
- o SPT techniques used at this site as compared to common practice (3.1.2)
- o Increase in density and earth pressure coefficient in soils under the reactor containment vessel due to pile-driving (3.1.3).

Each of these considerations and its effect on liquefaction evaluation is discussed below.

3.1.1 Depth of Foundation

The borings which provided the SPT data and soil samples for the present analysis were drilled from the existing ground surface at elevation +639 feet. However, the foundation piles for the reactor containment vessel, installed in 1962, were driven from an excavated surface at approximately elevation +609 feet (Ref. 18). The reactor vessel was then placed and the excavation backfilled to present ground level of +639 feet. Therefore, the soils of concern under the reactor are those below about elevation +609, or 30 feet below existing ground surface.

3.1.2 SPT Technique

Although the procedure of the "standard" penetration test is specified by the American Society of Testing Materials (ASTM), the type of equipment to perform the test is not, and variations in field N-values can occur with different techniques and equipment used in performing the tests. The N-values used for this analysis were produced by a rope and pulley system for raising the drop weight, with frequent oiling of the rope to minimize friction between the rope and pulley. Dr. Seed observed that the commonly used techniques for collecting blow count data on which the correlations of N-values and field performance are based did not involve this procedure to minimize friction as used by D&M. To compensate for the reduced friction in the system used, he felt it appropriate to increase the measured blow counts by about 20 percent. These increased N-values were then corrected to an overburden pressure of 1 ton/ft^2 and applied in the empirical evaluation. The judgement to use these increased values was based on Dr. Seed's compilation of data from many sources used in development of his empirical approach to liquefaction evaluation (Ref. 17).

These corrected and increased N-values are tabulated as they vary with depth in each of three borings near the reactor containment vessel (Table 1). Also shown are the original blow counts corrected to 1 ton/ft^2 overburden. Values have been shown for depths of 30 to 45 feet, as these are the depths for which the concern for liquefaction has been raised by NRC. The earlier analyses presented by D&M had not taken into account such increase in N-values.

3.1.3 Increase in Density and Earth Pressure Coefficient

The SPT data correction and all analyses to date for the LACBWR site have been for free-field conditions; that is, for the relatively unaffected soils away from the reactor vessel and other structures (all SPT borings were 13 feet or further from the exterior wall of the reactor vessel). However, the soils beneath and around the reactor foundation have been significantly affected by the driving of piles from approximately elevation +609 feet to a depth of 30 feet or more. Use of driven piles is an accepted means of compacting soils; the degree of effectiveness depends on pile spacing, type of piles, and method of driving. A recent D&M project (Ref. 19) quantified and documented predictions of the effects of pile-driving on the soils beneath a structure, which were then verified by a field testing program. A brief discussion of the project is warranted here, as the project involved a major structure built on sands and silts in which liquefaction potential was a concern.

The project involved a proposed addition to a hospital in South San Francisco which was built before California introduced a stringent new seismic design code. The new code required a building to withstand ground motions up to .5 g in rock at the site. Because the proposed addition was a major one, it was necessary to evaluate liquefaction potential for the site soils under such seismic conditions. D&M proposed and carried out a study in which the increases in SPT blow counts due to the effects of pile-driving and placement of fill were predicted and subsequently verified through a test boring program.

In order to predict the increases in N-values, a relation was assumed between confining pressure, relative density and overconsolidation ratio as developed by Marcuson and Bieganousky (Ref. 20) as follows:

$$N = 9.4 + 3.0\,(OCR) + .23\,(\bar{\sigma}_v) + .0046\,(D_r)^2 \tag{3.1}$$

where

N = SPT blow counts

OCR = overconsolidation ratio

$\bar{\sigma}_v$ = vertical effective stress (lb/in^2)

D_r = relative density (percent)

Pile-driving was assumed to increase the horizontal soil stress resulting in a change of the at-rest earth pressure coefficient, K_o, which has a value of .4 to .5 under normal depositional conditions. The effect of displacement piles would increase the horizontal stresses so that the earth pressure coefficient would rise to approximately 1.0. Using data of Seed and Peacock (Ref. 21) relating the horizontal pressure coefficient to overconsolidation ratio, it was assumed that the changed conditions would be equivalent to an increase in overconsolidation ratio from 1 to 4. The change in relative density due to pile-driving was more difficult to predict but was assumed not to exceed about 10 percent because of the wide spacing of the piles.

Based on these assumptions and on SPT data from the site before construction of the original hospital, predictions of increased N-values were made according to Equation 3.1. A field program was then carried out in which borings were drilled close to the existing building for comparison of blow count data. The results compared very well with the predicted values, especially in clean sands, thereby justifying this approach to prediction of increased N-values at the hospital site (Ref. 19).

A similar approach can be taken to predict the effects of pile driving at the LACBWR site. An updated form of Equation 3.1 was used to estimate relative densities under existing free-field conditions (Refs. 3, 26):

$$D_r = 11.7 + .76\left[\left|221\,N + 1600 - 53\bar{\sigma}_v - 50\,C_u\,2\right|\right]^{1/2} \tag{3.2}$$

where

D_r = relative density (percent)
N = SPT blow counts
$\bar{\sigma}_v$ = vertical effective stress (lb/in^2)
C_u = uniformity coefficient

Changes in density and lateral stress conditions as a result of pile driving were then assumed and applied to estimate the increase in N-values. At-rest earth pressure coefficients were chosen as equal to 1.0, a conservative assumption in this case because of the close spacing of the piles (3.5 ft on centers). This increase in K_o corresponds to an overconsolidation ratio of approximately 4, according to data presented by Seed and Peacock (Ref. 21) and relationships developed by Sherif et al. (Ref. 22) and Schmertmann (Ref. 23). (Recommended OCR values in the literature corresponding to K_o of 1 vary from 4 to 8; for conservatism the smallest value was chosen.) Density increase was estimated simply on the basis of displacement of soil by the 232 piles which yielded an increase of between 3 and 6 lb/ft^3 for the area under the reactor vessel. For conservatism, an increase of 3 lb/ft^3 was assumed. (Note that the report submitted by WES to NRC (Ref. 3) had not accounted for this density increase attributed to pile driving. The WES report had estimated this density increase to be as low as 1 lb/ft^3.)

These changed parameters were applied in an equation developed from tests on overconsolidated sands (Ref. 26):

$$D_r = 12.2 + .75\left[\left|222\,N + 2311 - 711\,(OCR) - 53\bar{\sigma}_v - 50\,C_u\,2\right|\right]^{1/2} \tag{3.3}$$

where

D_r = relative density (percent)

N = SPT blow counts

OCR = overconsolidation ratio

$\bar{\sigma}_v$ = vertical effective stress (lb/in^2)

C_u = uniformity coefficient

This yields estimates of N-values which should represent the soil conditions under the reactor. These estimates are shown as a function of depth below the reactor as N_1* in Table I. In this table the predicted N-values are based on the measured free-field values rather than those increased by 20 percent as discussed above in order to consider the two effects independently. Under actual field conditions the effects would be expected to act concurrently and would be cumulative.

The effect of increasing the earth pressure coefficient by pile driving should also be reflected in the analysis-testing approach to liquefaction evaluation. Under conditions of normal deposition, a correction factor of about .57 would be applied to cyclic triaxial test results to represent in situ soil conditions, as was done in the D&M analysis for the LACBWR site. However, for a K_o approximately equal to 1.0, this correction factor increases to a value between .9 and 1.0 (Ref. 17). Japanese work published subsequent to the completion of the D&M analysis in 1979 (Ref. 24) also indicates that the cyclic shear stress ratio is a function of K_o and approximately the square root of the OCR. If K_o is assumed to be 1.0 and the OCR to be about 4, application of Ishihara's relationship and the .57 correction to field conditions yields a cumulative correction factor of 1.14. This clearly indicates that using a correction factor of .57 as done in D&M analyses is extremely conservative. For this re-evaluation of liquefaction potential, however, a more realistic yet conservative correction factor of .9 will be used.

3.2 DENSITY CHANGES DURING SAMPLING AND TESTING

Although soil samples for the D&M cyclic triaxial test program were obtained using state-of-the-art techniques, questions have been raised concerning density changes during sampling and testing. We have contended that while some densification of samples could have occurred during sampling and testing, it was more than counterbalanced by other influences, as discussed earlier. The earlier analyses presented by D&M have not taken credit for the increased density under the containment building due to the presence of driven piles. Therefore, we believe that there is no need to reduce the measured cyclic shear strengths to account for the possible increase in density during sampling and testing.

4.0 RE-EVALUATION OF LIQUEFACTION POTENTIAL

As discussed in the D&M report of September 28, 1979, there are two basic approaches for evaluating the liquefaction potential of a deposit of saturated sand when it is subjected to earthquake loading. The first approach uses the information available on the performance of various sand deposits during past earthquakes. This approach is essentially empirical, and the response of the soil to earthquake loading is not evaluated by any direct means. Simplified methods of analysis, with known limitations, proposed by various investigators, are normally used in this approach.

In the second approach, stress conditions in the field are evaluated by using an analytical technique, such as the one-dimensional wave propagation analysis. Laboratory investigations are conducted to determine the cyclic shear stresses required to cause liquefaction at various depths. At a given depth, a factor of safety against liquefaction can be evaluated by dividing the cyclic shear stress required to cause liquefaction by the cyclic shear stress induced by the design earthquake.

Methods based on these two approaches were used in the September 28, 1979, analysis to assess the liquefaction potential of the granular soils at the LACBWR site. Each approach has been re-evaluated in light of the influences discussed in preceding sections, and a new assessment of liquefaction potential by each approach has been made. (A third approach, a semi-empirical one which uses a combination of the above two approaches, is the Japanese procedure used in the D&M analysis of September 1979. This procedure yielded higher factors of safety than the empirical approach and therefore will not be presented again in this report.)

4.1 EMPIRICAL APPROACH

In the first approach the cyclic shear stress ratio that is induced at any depth by the design earthquake was computed using a simplified procedure (Ref. 25). The procedure recommended by Seed (Ref. 17) was then used to estimate the cyclic shear stress required to cause liquefaction. In the September 1979 analysis, average design N-values were chosen for different depths and were corrected for overburden pressure. These corrected N-values were then compared to curves of lower bounds of the cyclic shear stress ratios that have caused liquefaction in the field under different magnitudes of earthquakes. By plotting data from the

LACBWR site onto such lower bound curves corresponding to different magnitudes of earthquakes, D&M concluded that there was no liquefaction potential under the designated earthquake conditions. WES and NRC staff, however, took two exceptions to D&M procedure: the use of average N-values; and the use of magnitude curves other than the 7 1/2 magnitude curve. WES and NRC staff preferred to use the measured N-values rather than the average N-values, and also did not accept the extrapolated magnitude curves presented by Seed (Ref. 17) which include $M \approx 6$, $M \approx 8\ 1/4$, in addition to $M \approx 7\ 1/2$.

In his review of the D&M analysis, Dr. Seed concurred with the use of an average N-value for each depth. However, a concern was raised by NRC about the scatter of N-values from the chosen averages. Therefore, in this re-evaluation, blow counts from each SPT boring have been considered individually. These individual N-values have been corrected to account for the presence of piles under the containment vessel at the LACBWR site using the procedures discussed in Section 3.1.3. Figures 1, 2 and 3 show cyclic shear strengths for soils under the reactor containment vessel. These strengths were calculated using the estimated N-values increased by pile-driving, based on blow counts from the three nearby SPT borings (DM-7, DM-8, and DM-10). The plots show that the predicted effect of pile-driving yields high factors of safety against liquefaction at all depths of concern below the reactor containment vessel. A similar effect would be expected beneath other structures founded on driven pilings at the LACBWR site. The comparison with past performance is made here, even including $M \approx 7\ 1/2$ curve as suggested by WES and NRC staff. It should be remembered that if a 20-percent increase in N-values is assigned, as recommended by Dr. Seed, the margin of safety would be even higher than that reflected in Figures 1, 2 and 3.

4.2 ANALYSIS-TESTING APPROACH

This approach uses more rigorous methods and site-specific data from sophisticated laboratory results. During the September 1979 D&M analysis, seismic response analysis was performed to estimate the stresses, strains, and accelerations at different depths within the soil profiles resulting from the design earthquake loading at the LACBWR site. Several cyclic triaxial tests were performed on undisturbed (frozen and thawed) samples to define their behavior under cyclic loading. In the current re-evaluation of liquefaction potential, an effect has been included which was not considered in the previous analysis. This is the effect of pile-driving on the correction factor, C_r, which is used to convert laboratory results to field conditions.

As discussed in Section 3.1, the driving of piles has a significant effect on the properties of soils surrounding the piles. The test results presented in the September 28, 1979, report were for samples out of range of the major influence of the piles. Therefore, as discussed above, it is appropriate to apply a correction factor of .9 rather than .57 to correct the cyclic triaxial test strengths to represent field conditions. The conservative value of .9 was chosen for this re-evaluation and all other interpretations were unchanged. Factors of safety against liquefaction were recalculated using this higher strength to represent soil strengths beneath the reactor vessel, and are shown in Table 2 in the column, "Under Reactor."

5.0 SUMMARY AND CONCLUSIONS

Under the current Systematic Evaluation Program for the LACBWR site, liquefaction potential has been one of the main issues discussed at length during several NRC meetings and in several reports prepared by D&M. Two points have been emphasized repeatedly by D&M: the LACBWR site is located in the Central Stable Region where the historic seismic activity has been very low; and under the designated earthquake conditions, there is no potential for seismically induced soil liquefaction. NRC and their consultants, however, have held a different view as far as the liquefaction potential issue is concerned. NRC has agreed that the LACBWR plant site is situated in a zone of very low seismicity, and that the designated SSE for the plant site has a return period of at least 1000 years and possibly much more. However, if an earthquake occurs that results in a .12 g ground surface acceleration at the site, NRC and their consultants believe that the soils at the LACBWR site will experience large strains up to a depth of about 40 feet below the existing ground surface.

D&M has performed extensive field and laboratory investigations using state-of-the-art techniques to demonstrate that an adequate margin of safety exists under the containment building in the event of a highly unlikely occurrence of the design earthquake at the LACBWR site. It should be remembered that the designated SSE has been the result of very conservative interpretation of the historic seismicity data of the Central Stable Region. All the liquefaction analyses performed so far by D&M have resulted in the same conclusion, that an adequate margin of safety exists against potential for liquefaction.

NRC consultants have used two arguments to conclude that the LACBWR site is unsafe against a .12 g earthquake: the apparently low measured SPT blow counts; and unaccounted effects of densification during sampling and testing. None of the analyses presented to NRC to date took into account, in a quantitative way, the following facts which enhance the calculated safety factors against liquefaction:

- Considerable increase in density due to the hundreds of closely spaced driven piles under the reactor containment vessel and throughout the site area

- Increase in the lateral coefficient of earth pressure due to the driving of piles which increases resistance to liquefaction

- Counterbalancing effects of structural disturbance and increase in densities of soil resulting from sampling, handling and testing
- The technique of minimizing friction by frequently oiling the rope and pulley while performing standard penetration tests which results in fewer blow counts as compared to the normally used procedures of the SPT data compiled for the empirical approach.

In this report, which is essentially a response to the show cause order issued by NRC to DPC, D&M has once again come to the same conclusion regarding the liquefaction potential at the LACBWR site. However, D&M now believes that the factors of safety against liquefaction potential under the containment vessel at the LACBWR plant are significantly higher than those presented in the report of September 28, 1979, in which calculations were made for free-field conditions only. The arguments presented in this response contain: a fresh look at the seismicity at the LACBWR site, which indicates that the return period for a .12 g earthquake at the site could be on the order of 10,000 years and possibly more; an endorsement of the D&M analysis and conclusions by Dr. H.B. Seed, an internationally-renowned expert; and a logical way to quantify the effects of driven piles supported by a verified case study.

In order to address the two specific issues of the SPT blow counts and the densification of samples during sampling and testing, the following approach was taken. D&M used the measured N-values rather than the average values, as desired by NRC staff and WES, and upgraded them to account for the presence of driven piles. Using these upgraded N-values in Seed's empirical approach, it was concluded that the soils under the containment vessel at the LACBWR site will not liquefy even under a magnitude 7 1/2 earthquake (NRC and WES preferred to be conservative and use only M ≃ 7 1/2 curves and no other extrapolated magnitude curves recommended by Dr. Seed). D&M has contended that the density changes during sampling, freezing, thawing and consolidating the test specimen have been more than counterbalanced by the fact that the samples obtained away from the driven piles are less dense by 3 to 6 lb/ft^3 than the soils under the containment. Therefore, D&M believes that it is not appropriate to decrease the cyclic triaxial test strengths further to account for the changes in densities as pointed out by NRC and WES.

The factors of safety presented in this response to the Order to Show Cause are higher than any other values presented so far and high enough to convince us that no measures for mitigation of seismic liquefaction potential are required for seismic conditions producing a peak ground surface acceleration of .12 g at LACBWR site.

In summary, as a result of our extensive studies during 1973, 1978, and 1979 of the geology, seismology and liquefaction potential at the LACBWR site, we conclude that:

- The LACBWR site is located in the Central Stable Region where historically the seismic activity is very low.
- The SSE corresponding to a peak ground surface acceleration of .12 g designated for the LACBWR plant site is a result of very conservative interpretation of the historical seismicity of the area within a 200-mile radius of the plant site.
- Probabilistically speaking, the seismic risk corresponding to the SSE producing .12 g peak ground surface acceleration at the LACBWR site is very low, and the estimated return period of more than 10,000 years is very long in comparison to the remaining life of the plant.
- The predicted SPT blow counts under the containment building are so high that there is no potential for liquefaction even during a Magnitude 7.5 earthquake, using the empirical approach.
- The estimated cyclic shear strength under the containment building is so high that it produces very high factors of safety against the potential for liquefaction under a peak acceleration of .12 g, using the analysis-testing approach.
- The soil conditions throughout the site are more or less uniform, and driven piles are present over much of the site area. The SPT N-values, the in-place densities, and the cyclic shear strengths of soils below pile-supported structures other than the containment building are also likely to be higher than the reported free-field values. This suggests an overall adequate margin of safety against potential for liquefaction under an earthquake producing a peak ground surface acceleration of .12 g at the LACBWR site.

Based on our conclusions as outlined above, we strongly believe that a mitigative measure to preclude liquefaction is unnecessary.

TABLE I

VARIATION OF SPT BLOW COUNTS WITH DEPTH
EMPIRICAL APPROACH

DM-7

Elevation (ft)	Depth (ft)	N	N_1	$1.2 N_1$	N_1*
+608.5	30.5 (top of reactor foundation)	13	12	14	95
604	35	—	—	—	—
599	40	13	10	12	62
594	45	—	—	—	—

DM-8

Elevation (ft)	Depth (ft)	N	N_1	$1.2 N_1$	N_1*
+608.5	30.5 (top of reactor foundation)	10	9	11	82
604	35	13	11	13	62
599	40	14	11	13	64
594	45	16	11	13	50

DM-10

Elevation (ft)	Depth (ft)	N	N_1	$1.2 N_1$	N_1*
+608.5	30.5 (top of reactor foundation)	10	9	11	82
604	35	14	12	14	64
599	40	17	13	16	61
594	45	17	12	15	51

N = measured blow count from SPT.

N_1 = N corrected for overburden pressure.

N_1* = N corrected for effect of pile-driving and for overburden pressure.

TABLE 2

SUMMARY OF LIQUEFACTION ANALYSIS

ANALYSIS-TESTING APPROACH
ACCELERATION = .12 g

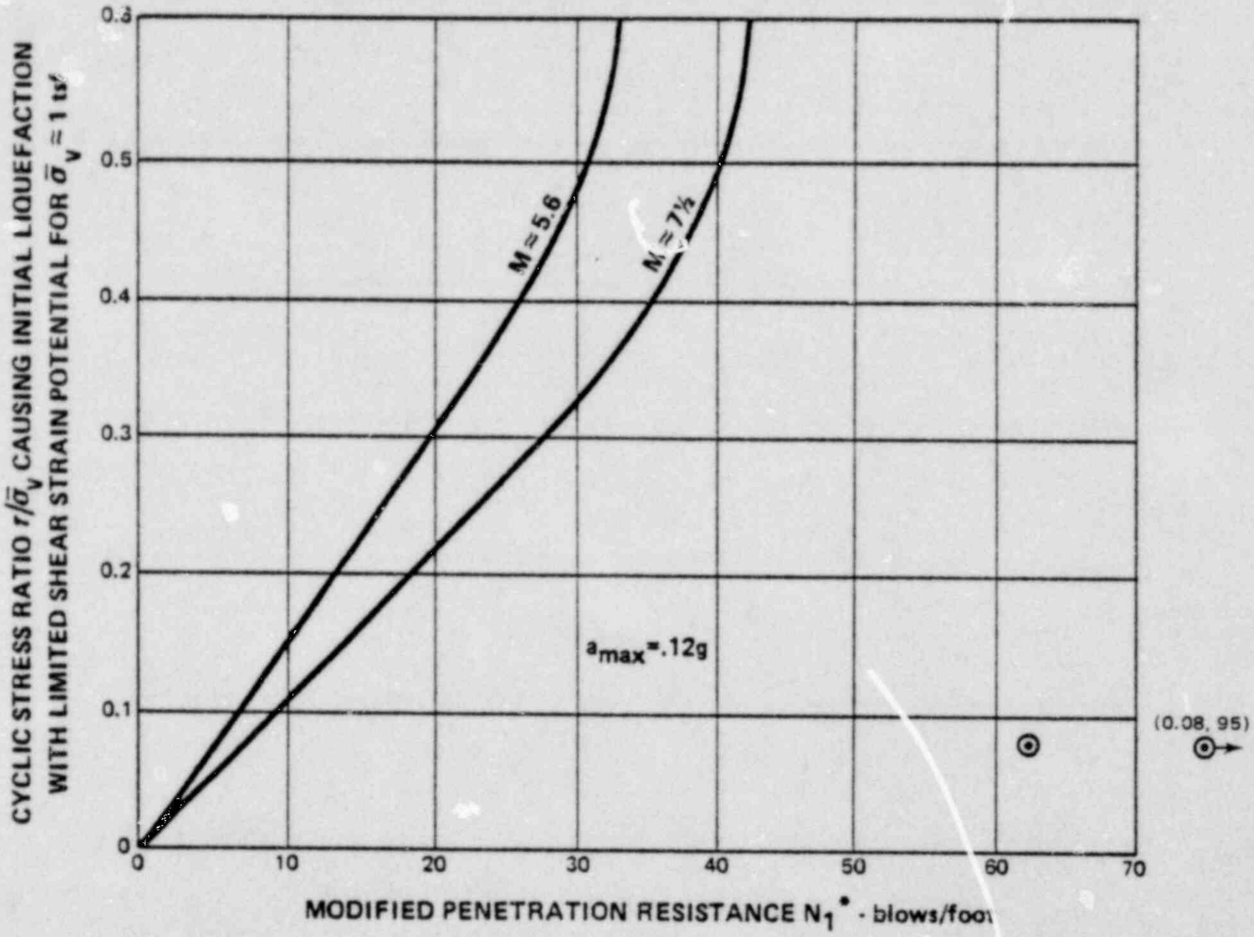
		Free-Field		Under Reactor	
Depth (ft)	τ_{av} (lb/ft^2)[1]	τ[2]	FS[3]	τ[4]	FS[3]
30 (top of reactor foundation)	233	350	1.50	550	2.36
35	265	410	1.55	650	2.45
40	290	480	1.66	750	2.59
45	315	540	1.71	840	2.67

1. τ_{av} = average cyclic shear stress = (maximum cyclic shear stress from one-dimensional analysis) x (0.65)

2. τ = cyclic shear strength under field conditions = (triaxial cyclic shear strength) x (0.57)

3. FS = factor of safety against liquefaction

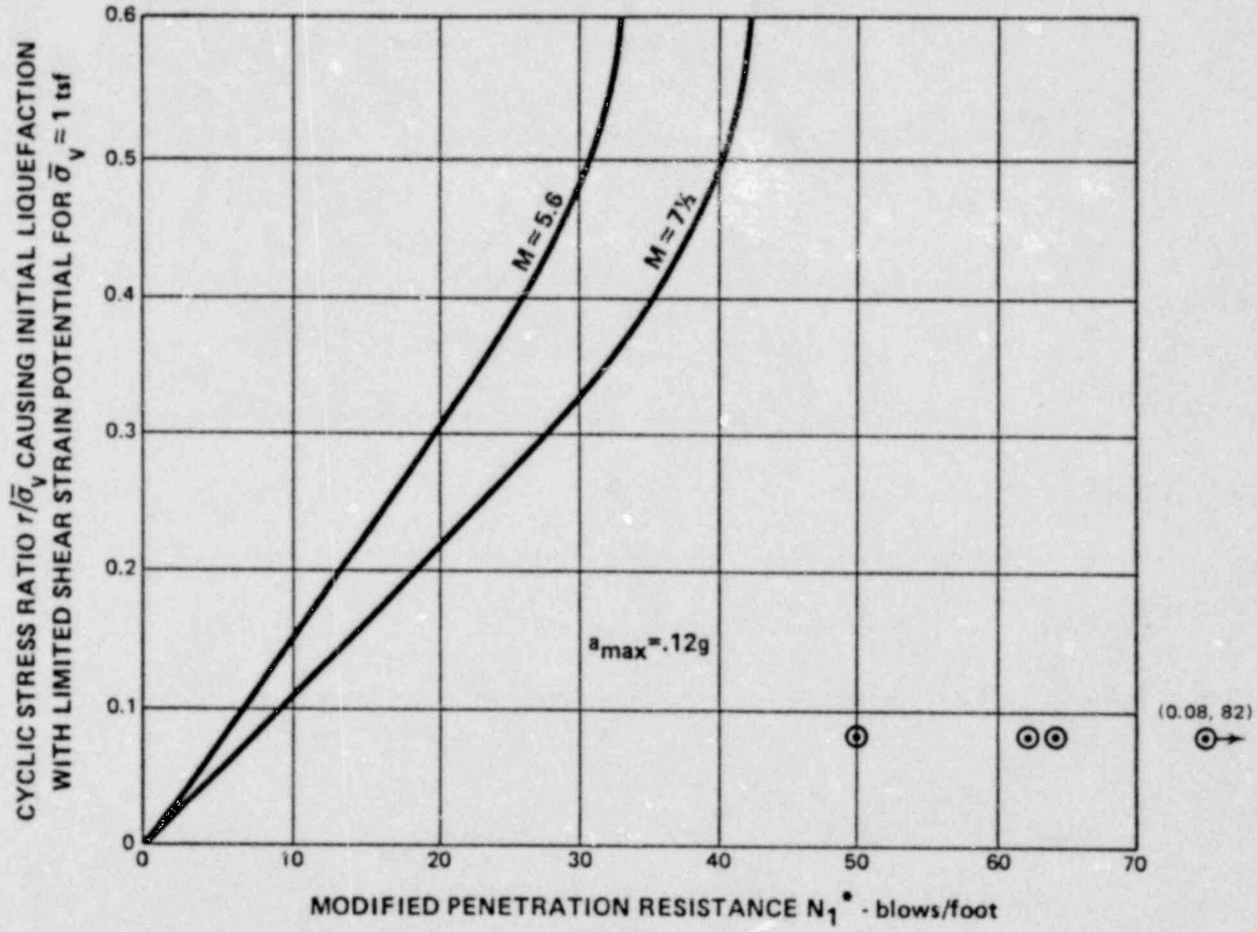
4. τ = (triaxial cyclic shear strength) x (0.9)



CORRELATION BETWEEN PREDICTED PENETRATION RESISTANCE UNDER REACTOR AND FIELD LIQUEFACTION BEHAVIOR OF SANDS FOR LEVEL GROUND CONDITIONS
BORING DM-7

DAMES & MOORE

FIGURE 1

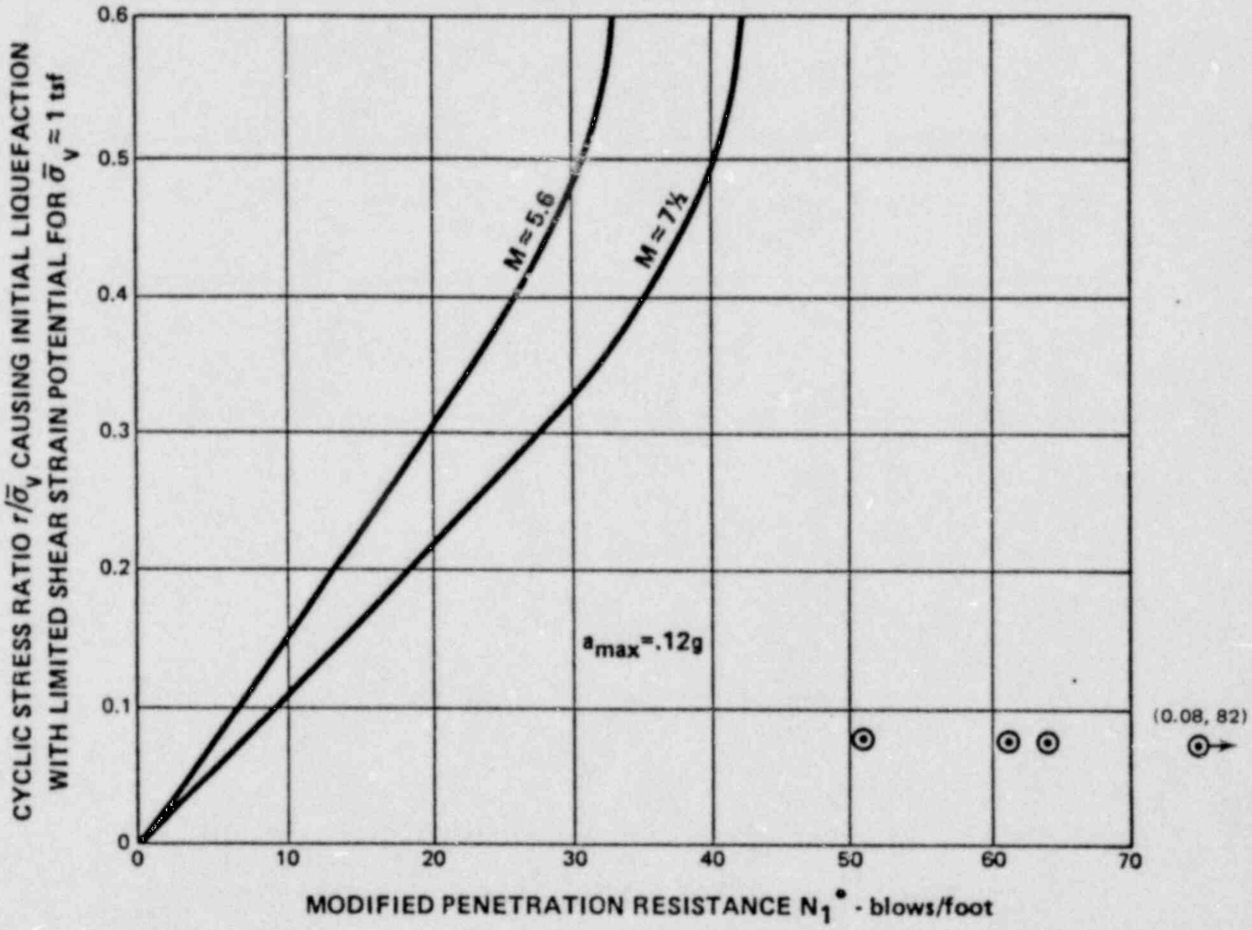


CORRELATION BETWEEN PREDICTED PENETRATION RESISTANCE UNDER REACTOR AND FIELD LIQUEFACTION BEHAVIOR OF SANDS FOR LEVEL GROUND CONDITIONS

BORING DM-8

DAMES & MOORE

FIGURE 2



CORRELATION BETWEEN PREDICTED PENETRATION RESISTANCE UNDER REACTOR AND FIELD LIQUEFACTION BEHAVIOR OF SANDS FOR LEVEL GROUND CONDITIONS
BORING DM-10

DAMES & MOORE

FIGURE 3

REFERENCES

1. Dames & Moore, Geotechnical Investigation of Geology, Seismology, and Liquefaction Potential, LaCrosse Boiling Water Reactor (LACBWR) Near Genoa, Vernon County, Wisconsin (October 1973).

2. Dairyland Power Cooperative, Application for Operating License for the LaCrosse Boiling Water Reactor, Report to the U.S. Nuclear Regulatory Commission (1974).

3. Marcuson, W.F., and W.A. Bieganousky, Liquefaction Analysis for LaCrosse Nuclear Power Station, U.S. Army Engineer Waterways Experiment Station, Report to the U.S. Nuclear Regulatory Commission (December 1978).

4. Dames & Moore, Review of Liquefaction Potential, LaCrosse Boiling Water Reactor (LACBWR) Near Genoa, Vernon County, Wisconsin, Report to the Dairyland Power Cooperative (March 1979).

5. U.S. Nuclear Regulatory Commission, letter of April 30, 1979 (Docket No. 50-409), to Dairyland Power Cooperative's General Manager.

6. Dames & Moore, Liquefaction Potential at LaCrosse Boiling Water Reactor (LACBWR) Site Near Genoa, Vernon County, Wisconsin, Report to the Dairyland Power Cooperative (September 28, 1979).

7. U.S. Nuclear Regulatory Commission memorandum of October 25, 1979, to D. Crutchfield, Chief, DOR, Systematic Evaluation Program Branch.

8. U.S. Nuclear Regulatory Commission memorandum of October 29, 1979 (Docket No. 50-409), summarizing meeting of October 17, 1979.

9. U.S. Nuclear Regulatory Commission memorandum of November 26, 1979 (Docket No. 50-409), summarizing meeting of November 2, 1979.

10. Dames & Moore, Draft Preliminary Report: Proposed Measure to Mitigate the Potential for Liquefaction at LACBWR Site Near Genoa, Wisconsin, Report to the Dairyland Power Cooperative (November 29, 1979).

11. Seed, H.B., letter of December 27, 1979, to Dames & Moore.

12. U.S. Nuclear Regulatory Commission, Order to Show Cause (Docket No. 50-409), February 25, 1980.

13. TERA Corp., Draft Seismic Hazard Analysis: A Methodology for the Eastern United States; Seismic Hazard Analysis: Solicitation of Expert Opinion; and Draft Seismic Hazard Analysis: Site Specific Response Spectra Results (August 1979).

14. Kukibayashi, E., and F. Tatsuoka, "Brief Review of Liquefaction During Earthquakes in Japan," Soils and Foundations, Vol. 15, No. 4 (December 1975).

15. Nuttli, O.W., "The Mississippi Valley Earthquakes of 1811 and 1812: Intensities, Ground Motion and Magnitudes," Bulletin of the Seismological Society of America, Vol. 62, No. 1 (February 1973).

16. McGuire, R.K., Fortran Computer Program for Seismic Risk Analysis, USGS Open-File Report 76-67 (1976).

17. Seed, H.B., "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Proceedings Paper 14380 (February 1979).

18. Sargent and Lundy, Containment Vessel Pile Driving Operations for 50 MWe Boiling Water Reactor at Genoa, Wisconsin (February 25, 1963).

19. Dames & Moore, Report: Liquefaction Potential Study, South San Francisco Medical Center, South San Francisco, California, for Kaiser Foundation Hospitals (August 11, 1978).

20. Marcuson, W.F., and W.A. Bieganousky, "Laboratory Standard Penetration Tests on Fine Sands," Journal of the Geotechnical Engineering Division, ASCE, Vol. 103, No. GT6 (June 1977).

21. Seed, H.B., and W.H. Peacock, "Test Procedures for Measuring Soil Liquefaction Characteristics," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM8 (August 1971).

22. Sherif, M.A., I. Ishibashi, and D.E. Ryden, Coefficient of Lateral Earth Pressure at Rest, Soil Engineering Report No. 9, University of Washington (1974).

23. Schmertmann, J.S., "Measurement of In Situ Shear Strength," Proceedings of the Conference of In Situ Measurement of Soil Properties, Specialty Conference of the Geotechnical Engineering Division, ASCE, Vol. II.

24. Ishihara, K., and H. Takatsu, "Effects of Over Consolidation and K_o Conditions on the Liquefaction Characteristics of Sands," Soils and Foundations, Vol. 19, No. 4 (December 1979).

25. Seed, H.B., and I.M. Idriss, "Simplified Procedure for Evaluating Soil Liquefaction Potential," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM9, Proceedings Paper 8371 (September 1971).

26. Marcuson, W.F., and W.A. Bieganousky, "SPT and Relative Density in Coarse Sands," Journal of the Geotechnical Engineering Division, ASCE, Vol. 103, No. GT11 (November 1977).