DESIGN GROUND MOTIONS FOR COOPER RIVER BRIDGE
MARK CLARK EXPRESSWAY
CHARLESTON, SOUTH CAROLINA

G.N. Richardson[I] and W.B. Wright[II]

ABSTRACT

As part of the Cooper River Bridge Study, three synthetic earthquake ground motion time-histories wre generated for use in evaluating liquefaction potentials and dynamic lateral pile capacities. Earthquake recurrance relationships for this region were used to establish probabilistic ground motion characteristics of the ground motions consistent with the assumed design life of the structure. Synthetic ground motions were developed consistent with the peak response characteristics defined by the probabilistic ground motion study and with the bridge design spectra defined by ATC-06.

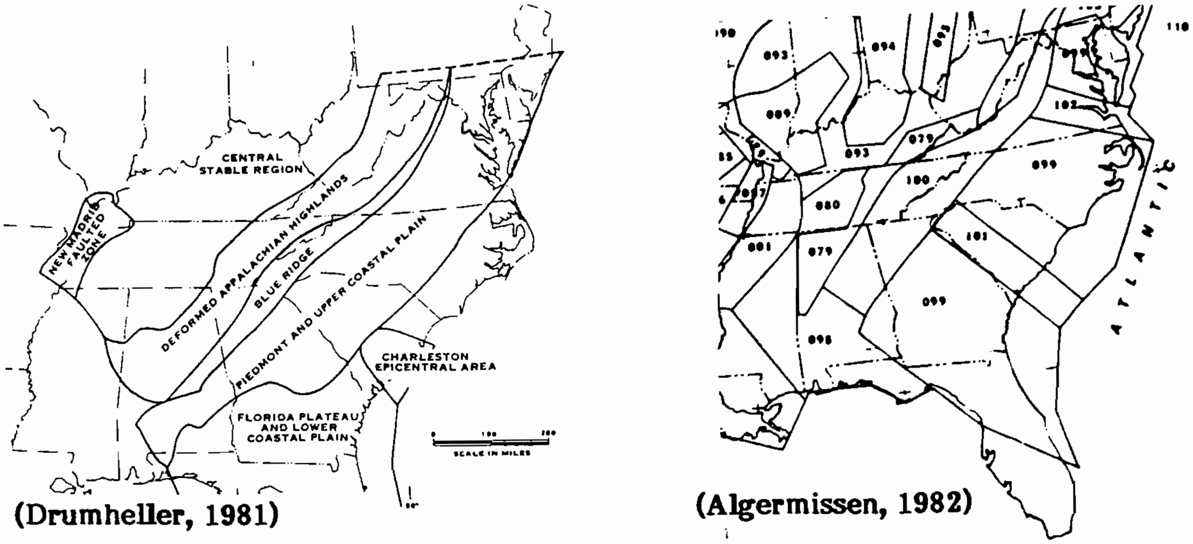
INTRODUCTION

Construction of the Mark Clark Expressway (I-526) from Interstate I-26 in North Charleston to U.S. Highway 17 in Mt. Pleasant requires oonstruction of significant bridge spans over both the Cooper and Wando Rivers. The Cooper River Bridge will have a total length of approximately 26,700 feet and is dominated by the "main span" over the navigational channel of the Cooper River. The "main span" will provide a 155 foot vertical clearance above mean high tide over a 800 foot horizontal span. The Wando River Bridge will have a total length of 7,900 feet and will, in turn, be dominated by a "main span" over the Wando that provides clearances of 138 feet above mean high tide over a horizontal span of 400 feet. Bridge segments were analyzed using ATC-6 methods. The "main span" of the Cooper River Bridge exceeds the 400-foot clear span limitation inherent in the ATC-6(1) guidelines and, therefore, required a more rigorous multimode spectral analysis.

In the absence of indentifiable active faults or active seismic structures, the use of seismotectonic regions characterized by consistency of geological structure and historical seismicity has been proposed(2,3) to evaluate seismic potential. The maximum possible earthquake in a seismotectonic regions is assumed to be defined by the largest that has occurred within this region in historical times. For the Charleston region, this would be the Great Charleston earthquake of 1886. Purposed seismotectonic regions within the southeastern United States are shown on Figure 1 based on two recent studies.

I. Corporate Engineer, Soil & Material Engineers, Inc., Raleigh, North Carolina

II. Branch Manager, Soil & Material Engineers, Inc., Charleston, South Carolina



(Drumheller, 1981)

(Algermissen, 1982)

Figure 1 Seismotechtonic Regions

Three synthetic earthquakes were generated during this study for use in the evaluations of liquefaction potentials and the lateral response of piles during seismic ground motions consistent with that used for the bridge designs. Two earthquake time histories are presented for gound motion characteristics for a 90% probability of occurrence within 100 years. A third synthetic time history was generated using the ATC-6 normalized site corrected acceleration spectra and the ground motion for the maximum credible historic event, namely the Great Charleston Earthquake of 1886. Generation of earthquake time histories requires defining limiting ground motion parameters such as peak acceleration, peak velocity, ground motion duration, and frequency distribution envelops. Maximum peak bedrock and ground accelerations for use in scaling the design spectrum are presented for recurrence periods of 50 to 250 years base on historical seismicity within the Charleston seismotectonic region.

HISTORICAL SEISMICITY

The known seismicity of the Charleston seismotectonic region is dominated by the earthquake of 1886(4). Having a maximum intensity of X MM, (Modified Mercalli), this event is two intensity levels higher that the next largest event to occur since this region was settled in 1670. Microfilm files of early newspapers were reviewed(5,6) by previous investigators to define the seismicity of this region prior to the 1886 event. These studies resulted in identification of 18 probable earthquakes between 1698 and 1886. Newspaper accounts of these events frequently indicate that the shock "accompanied by a rumbling noise" or that a single jolt or heavy jar was accompanied by an explosive sound. Louderback(7) suggested that these audible sounds imply the fracturing of fresh rock under high stresses rather than movement along established faults.

On August 31, 1886, the Charleston region was struck by the largest earthquake recorded on the east coast of the United States. A maximum MM intensity of X for the epicentral region has been suggested(4) by a recent evaluation of intensity reports gathered by Dutton(8) immediately following the event. Recent epicentral maps for the 1886 event generally encompass the Rivers Avenue and Cooper River portion of the proposed bridges. Within this region, Talwani(9) indicates that 65% of all brick buildings suffered damage compared to only 7% of all wood frame buildings. The preferential damage of higher frequency brick buildings and the historical "rumbling noise" associated with seismic events in this region suggest the presence of great energies at higher frequencies.

Instrumental studies of the seismicity of the Charleston regions have been conducted since 1972. Unfortunately, no major seismic events have occurred since installation of this network. A reveiw of instrumentally recorded South Carolina earthquakes from 1973 through 1979 indicates that no seismic event occurred having a magnitude (M) greater than 3.8 (Richter Scale).

Extensive geophysical studies(11)(12) performed within the Charleston-Summerville region over the past 15 years have failed to conclusively delineate active faults capable of the 1886 Charleston earthquake. The general agreement in trends indicated by magnetic, gravity, and seismic surveys is surprisingly poor and forces the use of probabilistic measures to evaluate design seismic ground motions.

PROBABILISTIC GROUND MOTION CHARACTERISTCS

For the Charleston region, the determination of capable faults was not possible due to the thick surface layer of Pleistocene sediments that obfuscate the underlying crystalling bedrock. Regional seismicity, however, is evaluated based upon historical records of earthquake occurrence and intensity (MM). Catalogs of earthquakes are maintained by various organizations(13)(14) and the catalog for the South Carolina region has recently undergone extensive updating(5)(10)(11).

The regional seismicity was determined by examining the earthquakes that have occurred within the Charleston seismotectonic region and establishing a magnitude or intensity recurrence curve for this region. Recurrence relationships are established in terms of earthquake intensity (MM) due to the preponderance of historical data obtained prior to the availability of instumental recordings. Such historical accounts are poor scientific records that are affected by the low density and distribution of population during the settlement of this region. A recurrence relationshiip for the Charleston seismotectonic region was previously established(15) during an investigation for a proposed expressway bridge at James Island. Two additional recurrence relationships were established(10) by the Geological Survey (USGS) based on records of 436 earthquakes over the period of 1754 to 1975. Both the James Island and USGS recurrence relationships are shown on Figure 2. The USGS recurrence relationships are presented for both South Carolina exclusive of the Charleston-Summerville region and for the Charleston region inclusively. There is good agreement between the James Island and USGS South Carolina recurrence relationships.

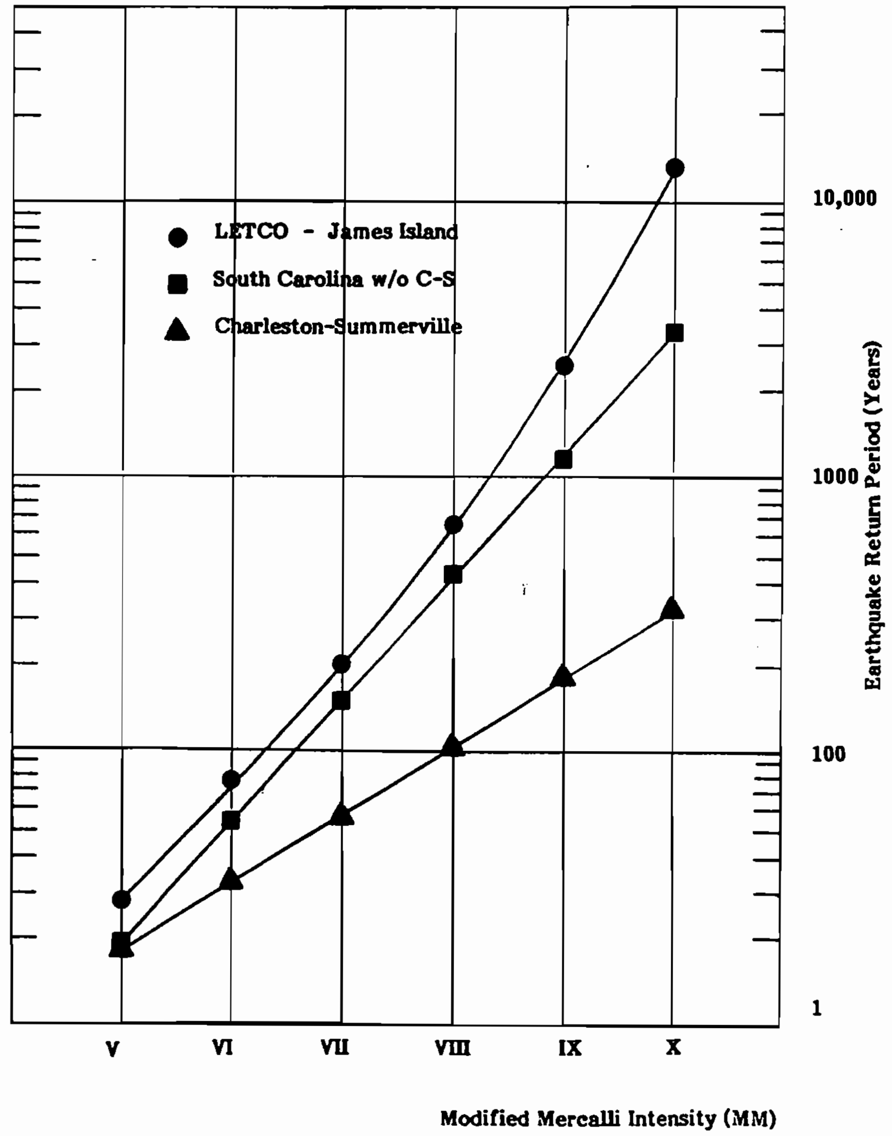


Figure 2 Earthquake Recurrence Relationships

To estimate the probability of occurrence , it is assumed that earthquakes occur randomly in time and that a Poisson distribution is applicable$^{(16)}$. Using a Poisson distribution, the probability of occurrence that X number of events will occur over a span of time t is given by:

$-\lambda t$

$$P_x(x) = \frac{(\lambda t)e^{\lambda - t}}{x!} \qquad x = 0,1,2,3 ----\infty$$

Where λ is equal to the inverse of the recurrence interval for a particular intensity (MM) event. The application of Poisson distribution to the USGS recurrence relationships provides estimates of the probability of earthquake occurrence which can be represented as shown on Figure 3. Assuming Poisson theory to be valid, the Charleston-Summerville data can be interpreted to indicate that an earthquake of intensity VI+MM has 90% probability of at least one occurrence within a time of 100 years. The impact of the three

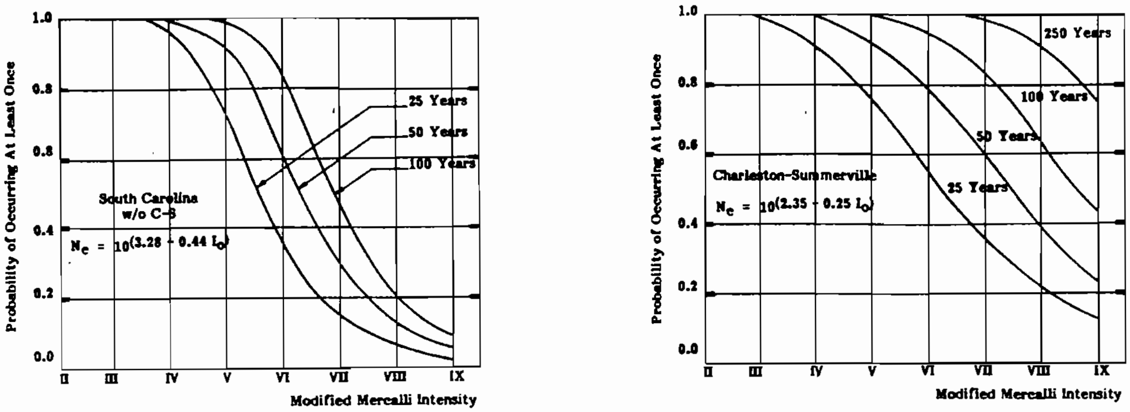


Figure 3 Poisson Recurrence Curves

different recurrence relationships on the resulting probability of occurrence is shown on Figure 4 for a recurrence period of 75 years.

The next step in the development of probabilistic ground motion characteristics is the conversion of a probable earthquake intensity to ground or bedrock peak acceleration and velocity value for use in the design process. Earthquake intensities (MM) are related to earthquake magnitudes (Richter) here using the following relations$^{(11)}$.

$$M = 1 + 2/3 \; I_0$$

Where M is magnitude and I_0 intensity. Estimates of peak bedrock accelerations and velocities were obtained using relationships proposed by Nuttli and Herrmann for earthquakes occurring in the eastern United States. These and two additional magnitude versus peak ground motion relationships are shown on Figure 5. The values present by Housner$^{(17)}$ are found to be on the high side with actual earthquakes in the western United States producing smaller values. The Computer Science Corporation$^{(18)}$ relationship is based on a computer evaluation of nearly 1,600 earthquake accelerograms from around the world. Design values of peak acceleration and velocity are a function of the assumed design life span: the longer the design life span the larger the design values for peak acceleration and velocity. Peak design accelerations velocities for a 90% possibility of occurrence are developed on Figure 6 for design life spans of 50, 100, and 250 years.

Development of synthetic ground motions also required estimates of both ground motion duration and the freefield ground motion spectra. The duration of the 1886 Charleston earthquake has been reported to range from 35 to 70 seconds. A general relationship for earthquake duration verses magnitude as proposed by Housner$^{(19)}$ was adjusted to agree with this historical observation as shown on Figure 7. The normalized response spectra, as defined by ATC-6 for soil profile Type I, stiff soil, and Type III, soft clays, are shown on Figure 8. These spectra were used in the design of the bridge supersturcture and were therefore selected for use as target freefield ground motion spectra.

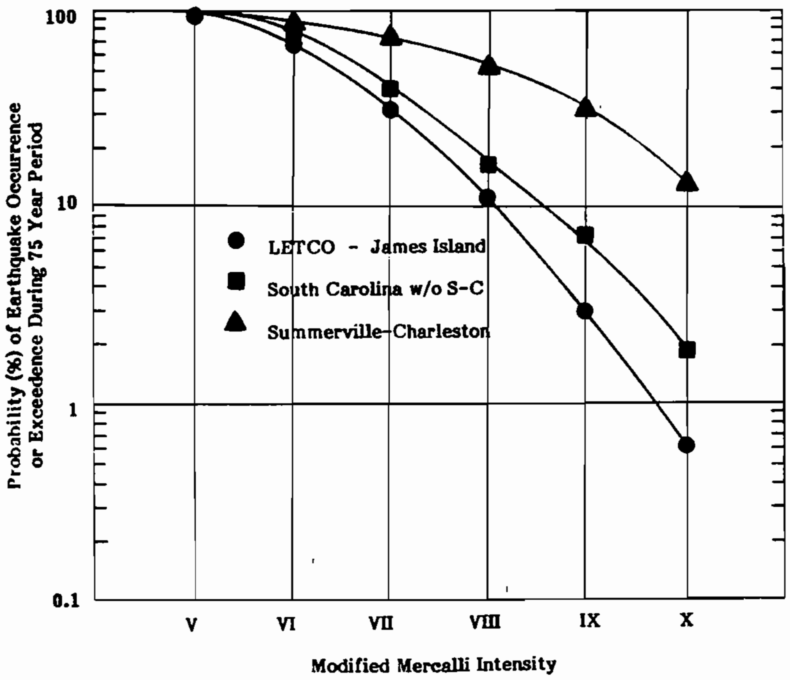


Figure 4 75 Year Recurrence Curves

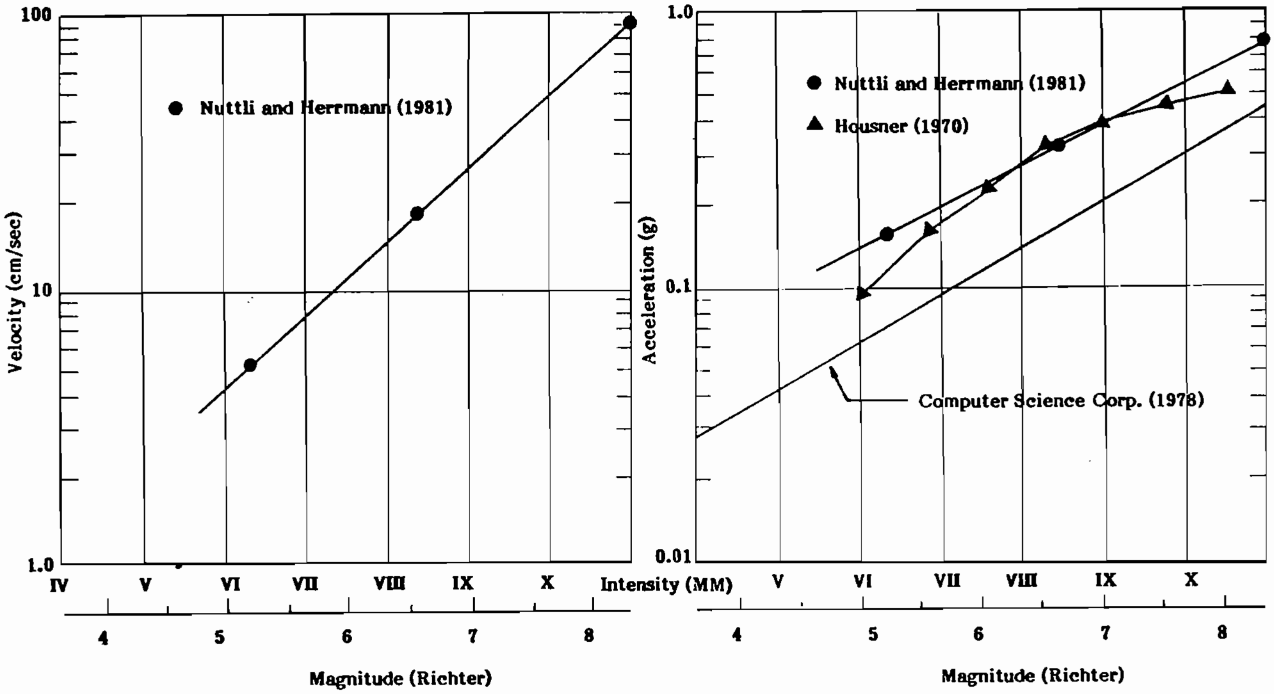


Figure 5 Peak Ground Motion vs. Magnitude

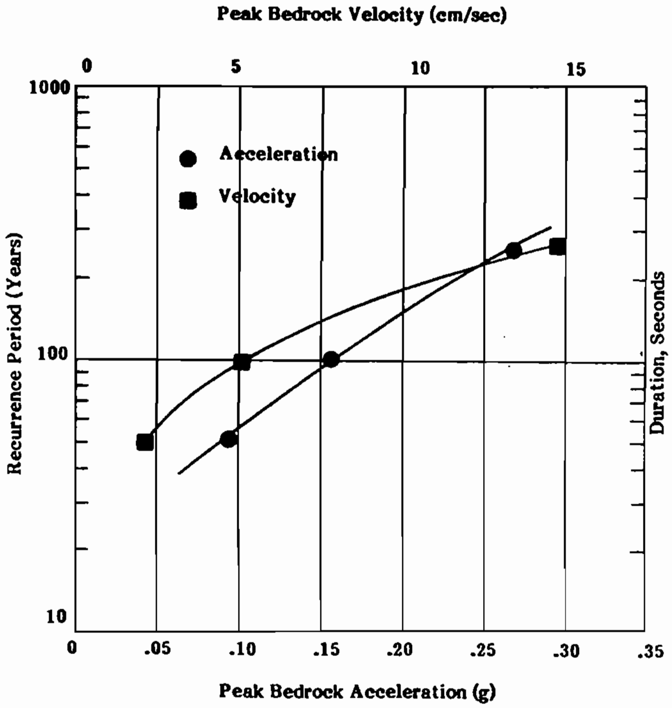


Figure 6 Peak Ground Motion vs. Recurrence Period

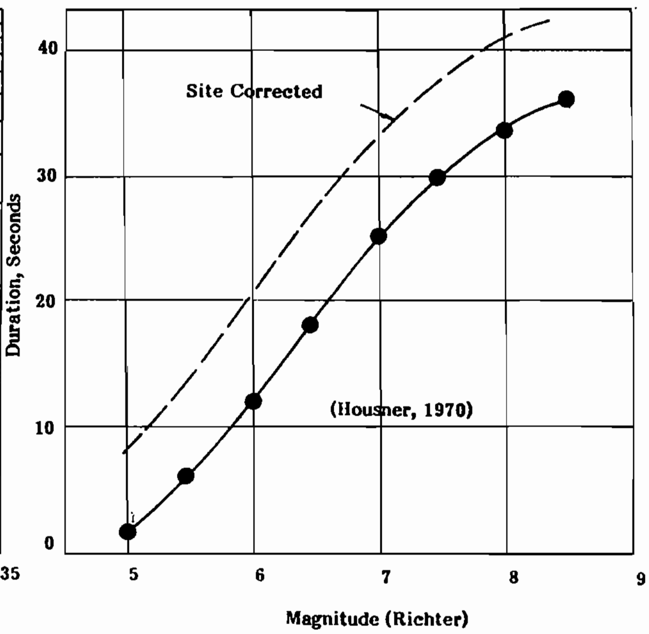


Figure 7 Ground Motion Duration vs. Magnitude

GENERATION OF SYNTHETIC GROUND MOTIONS

The method used for generation of the artifical motion is based(19,20) on the ability to model any periodic function as a series of sine waves such as:

$$x(t) = \sum A_n \sin(Wn^t + \phi_n)$$

Where A_n is the amplitude and ϕ is the phase angle of the nth contributing sinusoid. A random number generator is used to produce a string of phase angles having a uniform distribution over the range of 0 to 6.28 radians.

Each sinusoid contributes power to the proportional to A_n squared. Thus, the total power of the steady state motion is proportional to

$$X(t) = \sum A_n^2 \sin(Wn^t + \phi_n)$$

An actual acceleration time history will, of course, contain an infinite range of sinusoids, each contributing to the total power of the motion. The series simulation used in the generation of synthetic ground motions uses only a finite number of discrete harmonics. Allowing the number of sinusoids in the motion to become very large, the total power in the synthetic motion will approach that of the actual target motion.

The series solution used in building the synthetic ground motion maintains a constant frequency content with time, referred to as a stationary frequency distribution. In actual earthquakes, however, the frequency content is not stationary so that the relative contribution (or amplitude) of a given sinusoid will change with time. To simulate the transient character of real earthquakes, the stationary motions produced by the series solution are multiplied by a deterministic intensity function. For the earthquake generated as part of this report, a trapezoidal intensity function was used. The intensity function simply indicates that the levels of vibration will be zero initially and increase with time to some maximum value. This maximum value will continue for a discrete period of time and then the energy will decrease and finally cease. Thus, the intensity function provides a beginning and an ending to the infinite series used to model the ground motion.

Generated time-histories and response spectra curves for the three synthetic ground motions are shown on Figures 9 to 11. The first two synthetic motions are intended to model that motion that would reasonable be expected to occur during the design life of the proposed bridge structures. These synthetic motions correspond to magnitude (MM) VI event having a 10% probability of occurrence in 100 years. Based on the relationships presented on Figure 6, each event has a peak acceleration of 0.15g and a duration of 14 seconds. However, the motion time-histories differ in that the motion shown on Figure 10 satisfies the ATC-6 design spectra for Type I soil profiles while that presented on Figure 11 satisfies the soil Type III design spectra. The influence of the soil profile on the resulting time-history is quite apparent. The third synthetic ground motion is an attempt to simulate the maximum historical seismic event, namely the 1886 Great Charleston Earthquake.

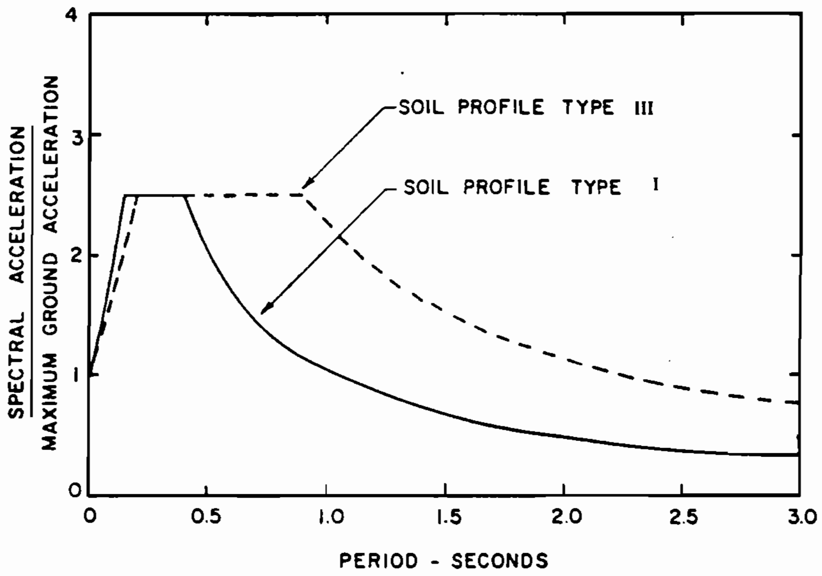


Figure 8 ATC-6 Target Spectra

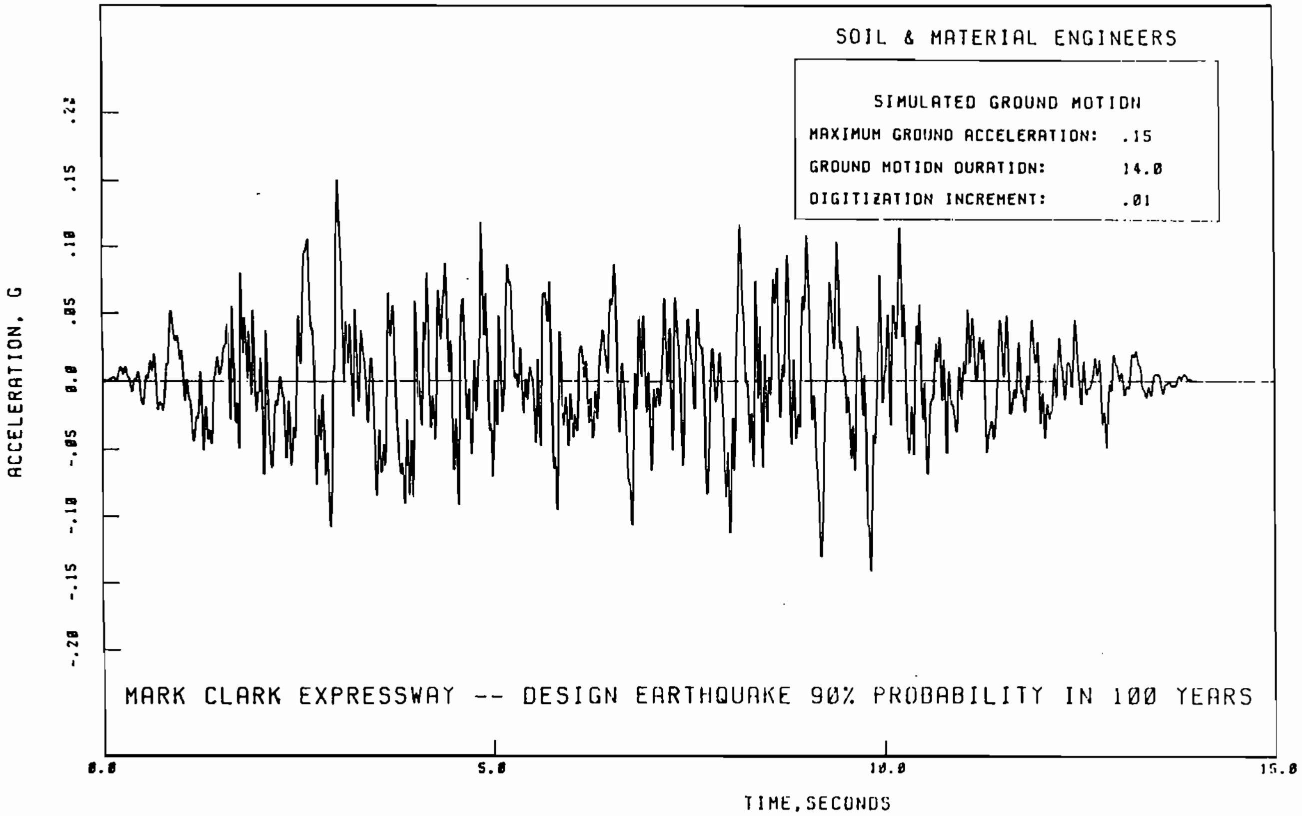


Figure 9 Ground Motion ATC-6 Type 1 Profile

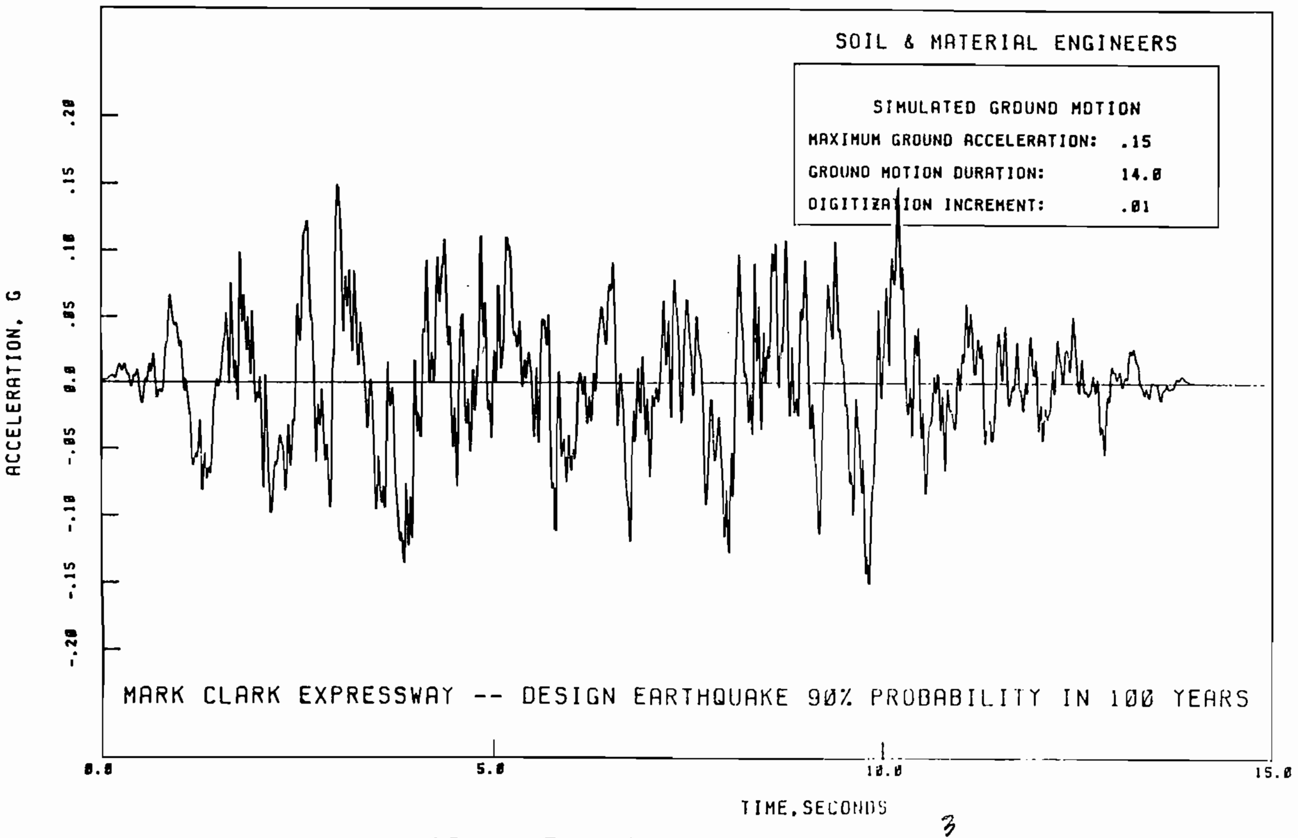


Figure 10 Ground Motion ATC-6 Type ~~5~~ 3 Profile

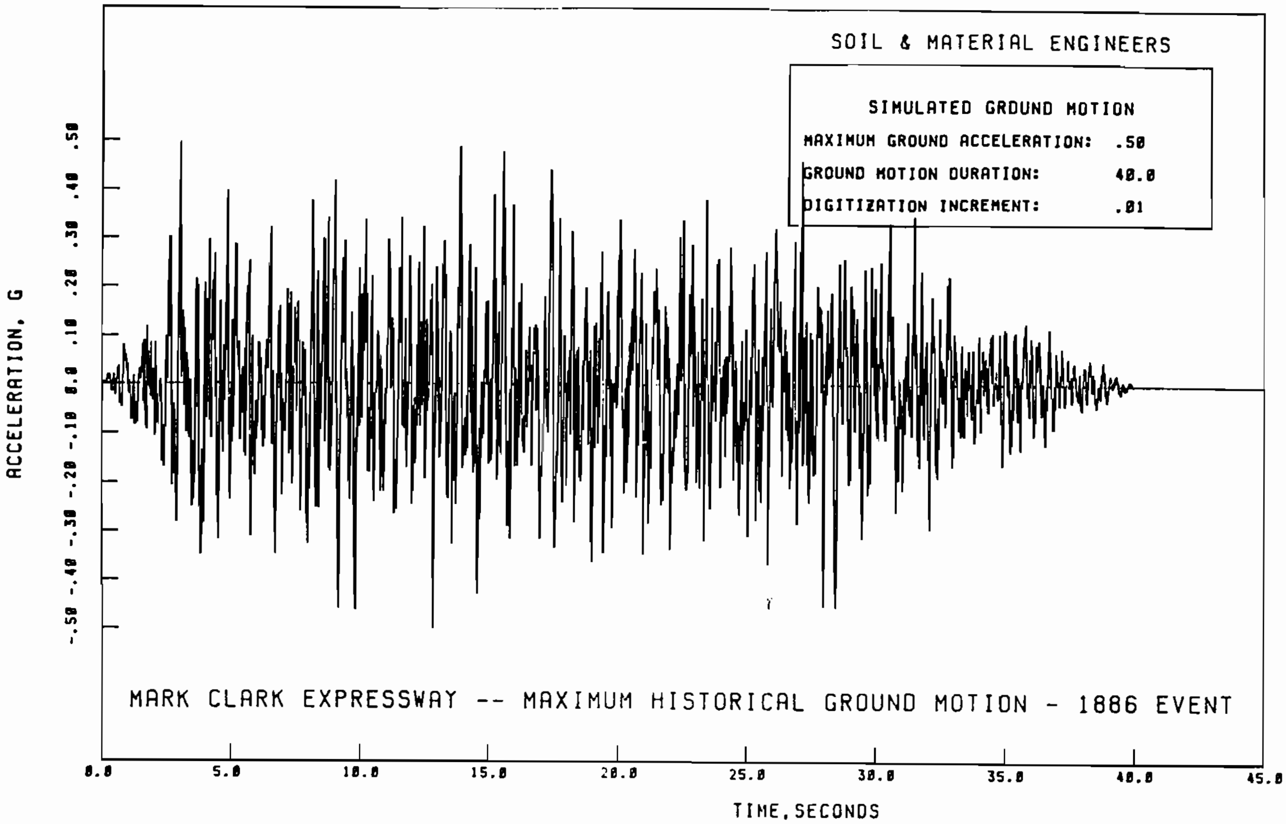


Figure 11 **Ground Motion - Maximum Credible Event**

REFERENCES

(1) ATC-6, Seismic Design Guidelines for Highway Bridges, Applied Technology Council, Berkeley, California, 1981.

(2) Drumheller, Joe C., et al, "Delineation of Seismotectonic Regions in the Southeastern United States," Proceedings of Earthquakes and Earthquake Engineering: The Eastern United States, Knowxville, TN, 1981.

(3) Algermissen, S. T., et al Probabilistic Estimates of Maximum Acceleration and Velocityin Rock in the Contiguous United States, United States Geological Surcey, Open-File Report 82-1033, 1982.

(4) Bollinger, G. A. "Reinterpretation of the Intensity Data for the 1886 Charleston, South Carolina Earthquake," United States Geological Survey, Professional Paper 1028-B, 1977.

(5) Bollinger, G. A. and Visvanthan, T. R., "The Seismicity of South Carolina Prior to 1886, "United States Geological Survay, Professional Paper 1028-C, 1977.

(6) Taber, Stephen, "Seismic Activity in the Atlantic Coastal Plain near Charleston, South Carolina," Seismological Society Bulletin., Vol. 4, No. 3, 1914.

(7) Louderback, G. D., "The Personal Record of Ada M. Troter of Certain Aftershocks of the Charleston Earthquake of 1886," Seismological Society of America Bulletin, Vol. 31, No. 4, 1941.

(8) Dutton, C. E., The Charleston Earthquake of August 31, 1886, United States Geological Survey, Ninth Annual Report, 1887-1988.

(9) Robinson, Andrew and Talwani, Pradeed, "Building Damage at Charleston, South Carolina Associated with the 1886 Earthquake," Bulletin of the Seismological Society of America, Vol. 73, No. 2, April, 1983.

(10) Tarr, Arthur C., "Recent Seismicity Near Charleston, South Carolina, and its Relationship to the August 31, 1886, Earthquake," United States Geological Survey, Professional Paper 1028-D, 1977.

(11) Tarr, Arthur C., and Rhea, Susan, "Seismicity near Charleston, South Carolina, March, 1973, to December 1979," United States Geological Survey, Professional Paper 1313-R, 1983.

(12) Leland, Timothy Long, et at, "Bouger Gravity Map of the Summerville-Charleston, South Carolina, Epicentral Zone and Tectonic Implication," United States Geological Survey, Professional Paper 1028-K, 1977.

(13) "United States Earthquakes, 19XX," United States Department of Commerce, Coast and Geodetic Survey, Washington, DC.

(14) "Listing of Hypocenters from Southeastern U.S. Seismic Network", Bulletins No. 1-10, Seismological Observatory, Virginia Polytechnic Institute, Blacksburg, VA 1983.

(15) "Final Report of Geologic/Seismic Analysis of James Island Expressway Site", Law Engineering and Testing, Project Numbers MF8503.01 and CO-374, 1979.

(16) Benjamin, Jack, R. and Cornell, C. Allin, Probability Statistics and Decision for Civil Engineers, McGraw-Hill, New York, 1970.

(17) Housner, G. W., "Strong Ground Motion", chapter within Earthquake Engineering, Edited by Robert Wiegel, Prentice-Hall, Englewood Cliffs, NJ, 1970.

(18) Murphy, J. R., et al, Analysis of a Worldwide Strong Motion Data Sample to Develop and Improved Correlation, etc., Computer Sciences Corporation, Arlington, VA, 1978.

(19) "SIMQKE - A program for Artificial Motion Generation," Dept. of Civil Engineering, Massachusetts Instutute of Technology, November, 1976.

(20) "PSEQGN - Artigicial Generationof Earthquake Accelerograms" College of Engineering, University of California, Berkeley, California, March, 1969, Report No. EERC 69-3.