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Site Specific Seismic Hazard Analysis At the DOE Kansas City Plant

Kansas City Division

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ABSTRACT

A site specific seismic hazard analysis is being conducted for the Kansas City Plant to support an on-going structural evaluation of existing buildings. This project is part of the overall review of facilities being conducted by DOE.

The seismic hazard was probabilistically defined at the theoretical rock outcrop by Lawrence Livermore National Laboratory. The U.S. Army Engineer Waterways Experiment Station conducted a subsurface site investigation to characterize in situ S-wave velocities and other subsurface physical properties related to the geology in the vicinity of the Main Manufacturing Building (MMB) at the Bannister Federal Complex. The test program consisted of crosshole S-wave, seismic cone penetrometer testing, and laboratory soil analyses. The information acquired from this investigation was used in a site response analysis by City College of New York to determine the earthquake motion at grade. Ground response spectra appropriate for design and evaluation of Performance Category 1 and 2 structures, systems, and components were recommended. Effects of seismic loadings on the buildings will be used to aid in designing any structural modifications.

INTRODUCTION

A seismic hazard analysis for the Kansas City Plant (KCP) has been performed for the U. S. Department of Energy (DOE). The purpose of this analysis was to reduce the apparently conservative 1991 Uniform Building Code (UBC) seismic hazard. The structural evaluation of the KCP identified overstresses using the 1991 UBC criteria. The cost to mitigate these overstresses was estimated at approximately $40 M. In an attempt to reduce this cost, an effort was undertaken by DOE to determine the site-specific seismic hazard for the KCP to learn if the use of a lower seismic demand could be justified. Such a conclusion would significantly reduce the number of overstresses and the cost of retrofit.

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SITE DESCRIPTION

The Bannister Federal Complex (BFC) is located at 2000 East 95th Street in Kansas City, Missouri (see Figure 1). This facility consists of a large main building approximately 1000 feet by 2000 feet in plan, together with several smaller surrounding buildings. It is occupied by the U. S. Department of Energy (DOE), U. S. General Services Administration (GSA), the Internal Revenue Service (IRS), and the U. S. Marine Corps. The DOE administers a manufacturing facility in the eastern portion of the building which is operated, under contract, by the AlliedSignal Aerospace Corporation.

The BFC is located on flood plain deposits of Indian Creek which flows easterly south of the plant. This creek joins the Blue River southeast of the plant with the resulting flow bordering the east property line. Previous studies have indicated that the site is underlain by approximately 40 feet of clay alluvium which is also underlain by a basal clay-gravel layer. Underlaying the clay-gravel layer is a shaly bedrock of the Pleasonton Group. The site is predominantly level with the exception being the bluff line on the northern portion of the site. All but two buildings in the BFC are supported on the clay alluvium layer. This clay alluvium including the underlying basal clay-gravel layer was expected to amplify seismic motion from the rock layer.

LLNL SEISMIC HAZARD ANALYSIS

The first step in the analysis was to have Lawrence Livermore National Laboratory (LLNL) generate the probabilistic hazard for the Kansas City Plant (Longitude -94.57 degrees and Latitude 38.96 degrees North)(Reference 1). Rock spectra were developed for three cases. Case A represents all earthquakes with magnitude greater than m_o= 3.75 at a return period of 500 years (annual exceedance probability = 0.002). Case B represents all earthquakes with magnitude greater than m_o= 5.00 at a return period of 500 years. Case C represents all earthquakes with magnitude greater than m_o= 5.00 at a return period of 1,000 years (annual exceedance probability = 0.001). These cases were chosen based on the fact that the spectrum used in the Uniform Building Code (UBC) is calculated using all earthquakes greater than m_o=4.00 and based on the return periods for Performance Category 1 and Performance Category 2 Structures, Systems, and Components (SSC) of 500 years and 1,000 years respectively. The resulting rock spectra for the KCP are contained in Chart 1.

CORPS OF ENGINEERS DYNAMIC SOIL TESTING

To determine the amplification of the rock motion the clay alluvium layer produces, dynamic properties of the material beneath the site were needed. Because this information did not currently exist, the Corps of Engineers at the Waterways Experiment Station (WES) was contracted to do soil testing and analysis for the Kansas City site.

The goal of this investigation was to determine the soil and bedrock S-wave velocities of the site. The WES/DOE test program consisted of crosshole S-wave, seismic cone penetrometer testing (SCPT), and laboratory soil analysis to provide the data necessary to complete the analysis of the buildings response to earthquake loadings (Reference 2). The location of the crosshole sets and SCPT pushes are shown in Figure 2. Laboratory tests on soil samples taken from the crosshole borings indicated that the alluvial material across the site is basically a lean clay of soil classification CL. Underlying the clay is a basal clay-gravel layer consisting of fine to coarse, semi-rounded to angular limestone gravel in a clay matrix. The bedrock belongs to the Pleasonton Group and is encountered at an approximate depth of 40 feet. The bedrock is described as a soft to moderately hard shaly siltstone with a greenish-gray to light brown color.

The SCPT was used to collect S-wave velocities, tip resistance, and sleeve friction measurements at 13 locations around the MMB. Tip resistance and sleeve friction measurements were used to make soil classification and N-values interpretations. The SCPT results indicated the presence of approximately 5 foot thick zones, between depths of 15 and 30 feet, that showed slightly higher tip resistance and sleeve friction values. SCPT S-wave results in the alluvium indicated values which increased with depth, ranging between 350 and 775 fps. Two of the pushes appear to have penetrated the clay-gravel layer, and the velocity for this layer is approximately 1100 fps. Averaged crosshole S-wave results indicate values ranging between 475 and 700 fps for the clay materials. The S-wave velocities showed an increase with depth. The average S-wave velocity for the shaly siltstone (bedrock) was 1900 fps. The SCPT and crosshole tests agreed favorably. The results of the testing can be seen in Tables 1, 2, and 3.

SITE RESPONSE ANALYSIS

The rock spectra developed by LLNL and the dynamic soil information from the WES report were given to Dr. Carl Costantino of City College of New York/Brookhaven National Laboratory to quantify the site response using a computer code entitled "Computer Analysis for Rapid Evaluation of Structures" (CARES)(Reference 3). This program analyzes the seismic response of a layered soil column subjected to upwardly propagating horizontal shear waves developed by a specified input seismic motion. The objective of this analysis was to develop site surface response spectra that can be used directly as input to building seismic response analyses.

In the site response calculations, soil column responses were computed for three different thicknesses of overburden: one of 41 feet, one of 46 feet, and an average thickness of 43.5 feet. Surface response spectra were generated for each column thickness, considering variability in measured shear wave velocity for each column depth, to determine the effect of depth variability on this response. Site response calculations indicate that earthquake ground motion at rock is amplified for frequencies greater than 1 Hertz with a maximum amplification of 3.7 from 3 to 4.5 Hertz. The envelopes of these surface response spectra are provided in Chart 2. The SA-1 envelope corresponds to LLNL's Case A, the SA-2 envelope corresponds to LLNL's Case B, and the SA-3 envelope corresponds to LLNL's Case C. A comparison of the SA-1 envelope to the spectrum used in the Uniform Building Code (UBC) is shown in Chart 3.

RECOMMENDED SPECTRUM

In choosing an appropriate spectrum, the intent was to envelope the site specific spectra using the broader standard spectral shape from UBC, as illustrated in Chart 4. This maintains some of the code conservatism without significantly over amplifying the values from the site specific information. The first step was to choose an appropriate peak ground acceleration value. The UBC base shear equation, which calculates the lateral force to be placed onto the building, uses a factor Z to represent the peak acceleration with an exceedance probability of 10% in 50 years. For the Kansas City area, Z = 0.15 g.

Other commonly used seismic zonation maps indicate much lower acceleration values at the same exceedance probability. The 1991 NEHRP Recommended Provisions map uses an acceleration value of 0.10g in this area. The 1990 USGS map shows a peak acceleration value of 0.04g for this region. The peak acceleration at grade calculated by the site response analysis for motion SA1 is 0.055g.

In developing the recommended spectrum, a peak ground acceleration (pga) of 0.06g was used. Although this value is lower than Z = 0.15g, it is considered acceptable because it envelopes values from the LLNL site-specific hazard analysis as well as the site response analysis. This value is also in agreement with the lower acceleration values indicated by the USGS and NEHRP maps.

In order to take into consideration the ground motion at a site, the UBC uses the term C. The equation $C = 1.25\ S/T^{2/3}$, where S varies depending on soil type, defines the shape of the response spectrum for a given pga. This shape was maintained in the development of the recommended spectrum, assuming a value of S = 1.5 to represent the soil condition at the Kansas City site. The use of this spectral equation is considered to maintain code conservatism.

The UBC sets a maximum value for C of 2.75. The use of 2.75 for the maximum spectral amplification in a standard spectral shape appears to be over conservative in terms of representing a median value. DOE-STD-1020 requires the use of median amplification. The Newmark-Hall standard spectrum (Reference 4) uses a maximum 5% damped spectral amplification factor of 2.12 with the value of 2.71 being associated with a one standard deviation value. The NEHRP spectrum uses a maximum amplification factor of 2.5. In developing the recommended spectrum, a maximum amplification factor of 2.5 was used (Reference 5). This value is consistent with the NEHRP Recommended Provisions and produces a spectrum which envelopes all of the site-specific information.

The progression of spectral acceleration values from the LLNL study to the recommended spectrum is shown in Table 4. The recommended spectrum is compared to the UBC and NEHRP design spectra appropriate for this soil condition and for the Kansas City area in Chart 5. Both of these design spectra use the maximum spectral amplification value for all periods lower than (or frequencies higher than) the point at which this maximum occurs. Therefore, for use as a design and evaluation spectrum, as shown in Chart 6, the recommended spectrum maintains the maximum amplification value of 2.5 for all periods lower than (frequencies higher than) the point at which the maximum occurs, similar to the UBC and NEHRP spectra.

EFFECT OF PERFORMANCE CATEGORY

The recommended spectrum discussed has been developed for an earthquake level with a hazard exceedance probability of 10% in 50 years, or a return period of about 500 years, which is the level referred to in the UBC code and the level recommended by DOE-STD-1020 for PC-1 facilities.

The level appropriate for a PC-2 facility has a hazard exceedance level of 1×10^{-3}, or a return period of 1000 years. Spectra were produced by the site response analysis for three different criteria. Chart 4 indicates that the recommended spectrum envelopes the SA-3 envelope, which was developed at the PC-2 hazard exceedance level. However, the SA-3 envelope was developed for all earthquakes greater than 5.0. Since the UBC is based on all earthquakes greater than 4.0, the SA-3 envelope would shift up beyond 0.15 for that condition.

Therefore, in order to use the recommended spectrum for a PC-2 facility, the same spectral shape should be used with a pga of 0.10g rather than 0.06g. This simply shifts the curve up to envelope the maximum expected values for PC-2 criteria. It is useful to note that the importance factor in the base shear equation still increases to 1.25 in the PC-2 application.

PEER REVIEW

EQE International performed an independent peer review of the KCP-specific seismic hazard analysis under contract to AlliedSignal Aerospace Company and with the permission of DOE (Reference 6). This review was conducted to verify that this seismic hazard analysis conforms to applicable DOE criteria and guidelines.

The significant findings of this peer review are as follows:

1. The methodology adopted, analysis inputs considered, analysis results obtained, and recommendations provided by the KCP-specific seismic hazard analysis are in general conformance with applicable DOE criteria and guidelines.
2. Use of a lower bound earthquake magnitude of 3.75 is conservative when random variability of ground motion parameters is included.
3. Defining the earthquake motion for rock at an outcrop of the shaly siltstone bedrock having an S-wave velocity of 1900 ft/sec underestimates the earthquake motion at the soil surface.
4. Use of UBC spectral amplifications results in a potentially very conservative design/evaluation spectra at frequencies less than about 2 Hz.

Based on the independent peer review, it was concluded that the ground response spectra that have been recommended by the site-specific seismic hazard analysis are adequate for seismic design and evaluation at the KCP. The conservatism associated with Finding 2 and unconservatism associated with Finding 3 are expected to cancel out. Slight reduction in the recommended design/evaluation spectra could be considered in response to Finding 4, if desired.

CONCLUSIONS

The use of the recommended spectrum significantly decreased and even eliminated some structural seismic overstresses caused by earthquake loading at the Kansas City Plant. This discussion provides justification for the use of this spectrum even though it represents a demand level lower than that of the Uniform Building Code. The justification can be summarized as follows:

- The recommended spectrum is based on site specific data.
- The recommended spectrum envelopes all site specific spectra developed by this study.
- The recommended spectrum retains conservatism from the UBC by using the formula $C = 1.25\ S/T^{2/3}$ and by maintaining the maximum spectral amplification at lower periods, lower than the point at which this maximum occurs.
- The recommended spectrum uses acceleration and amplification values similar to those used in the NEHRP Recommended Provisions.

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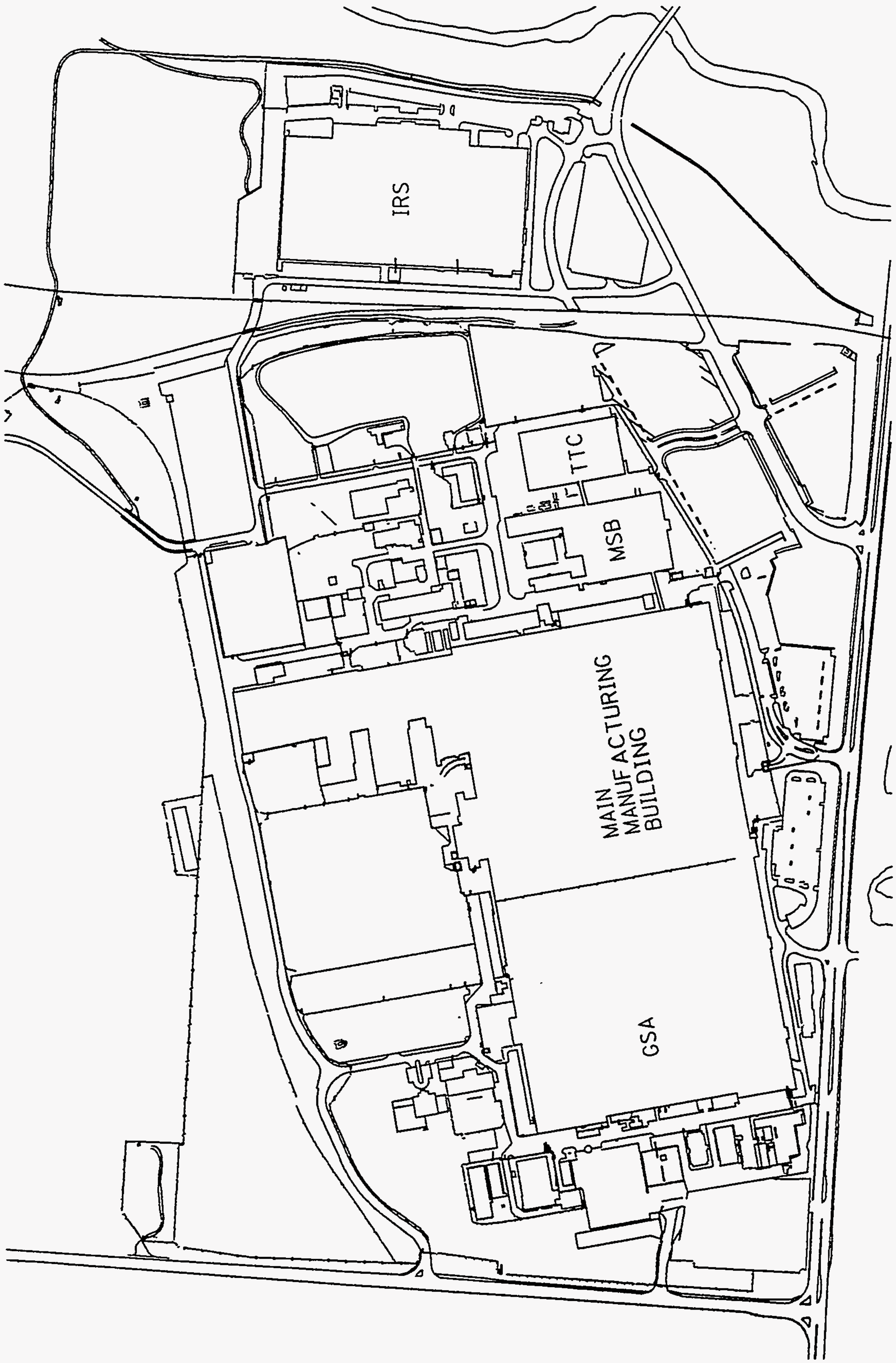
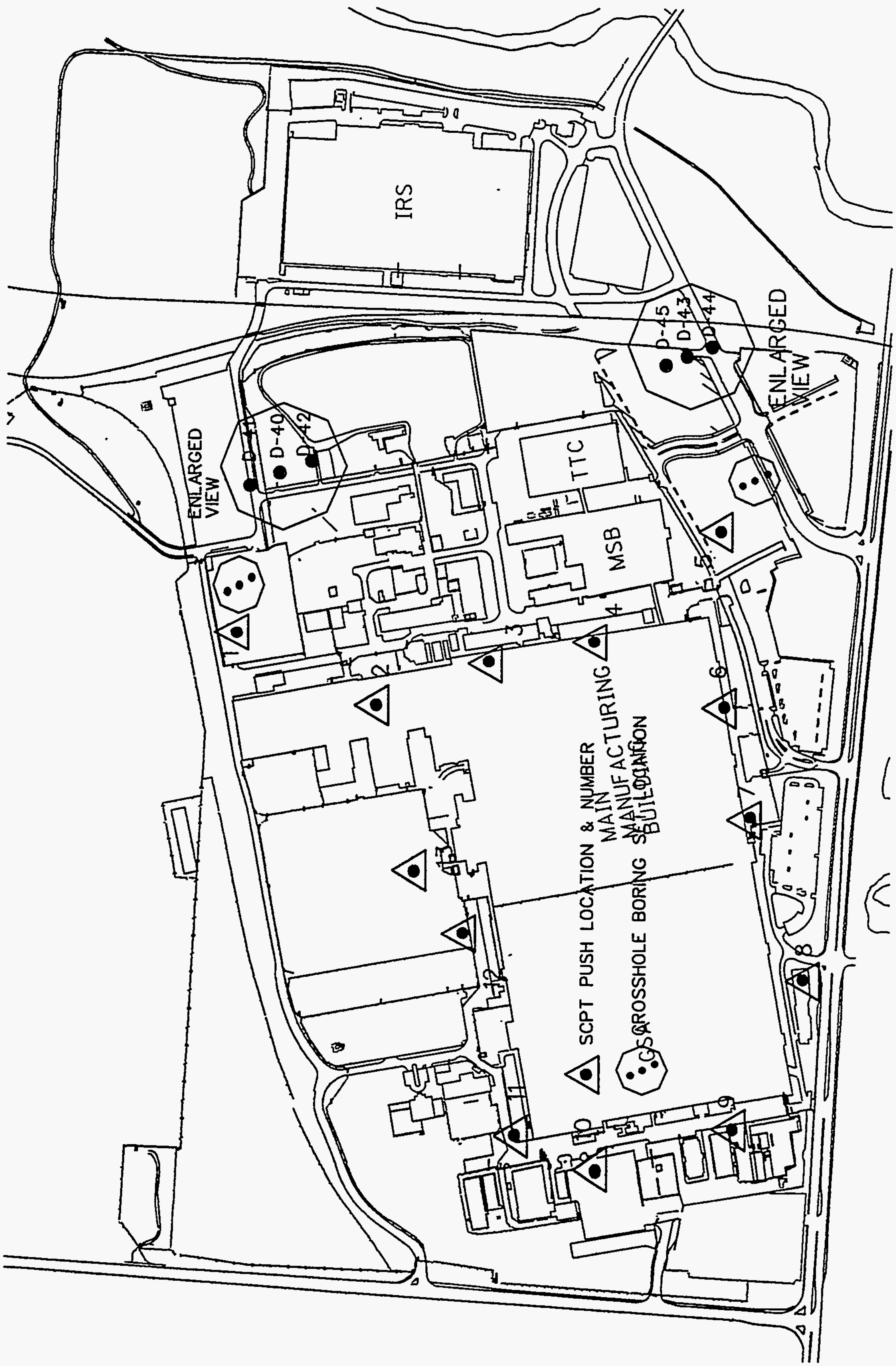
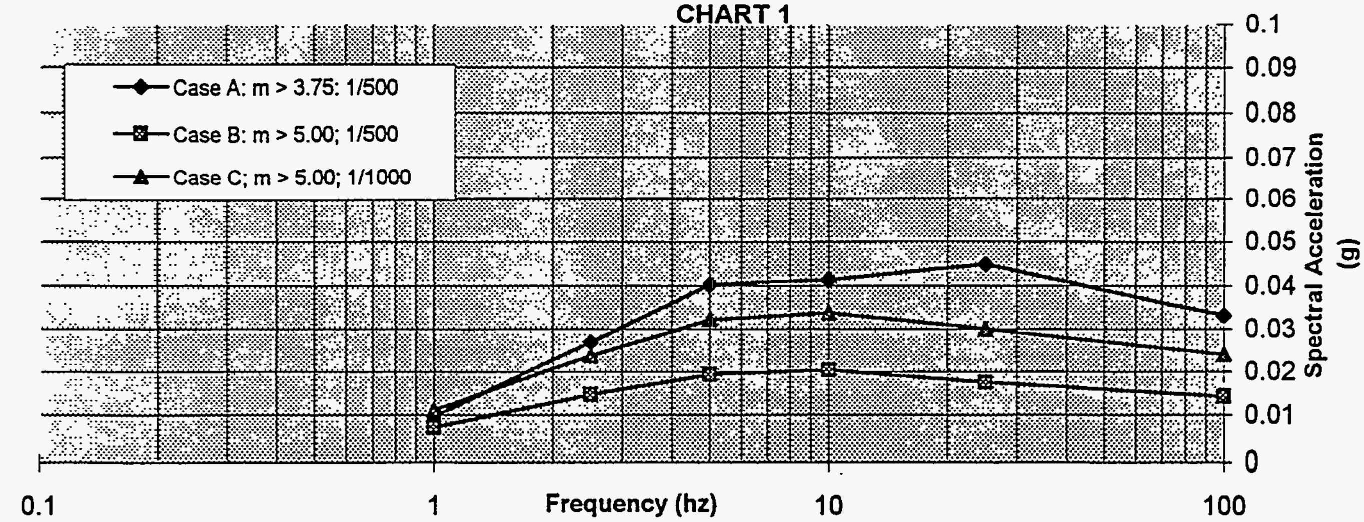


LOCATION PLAN

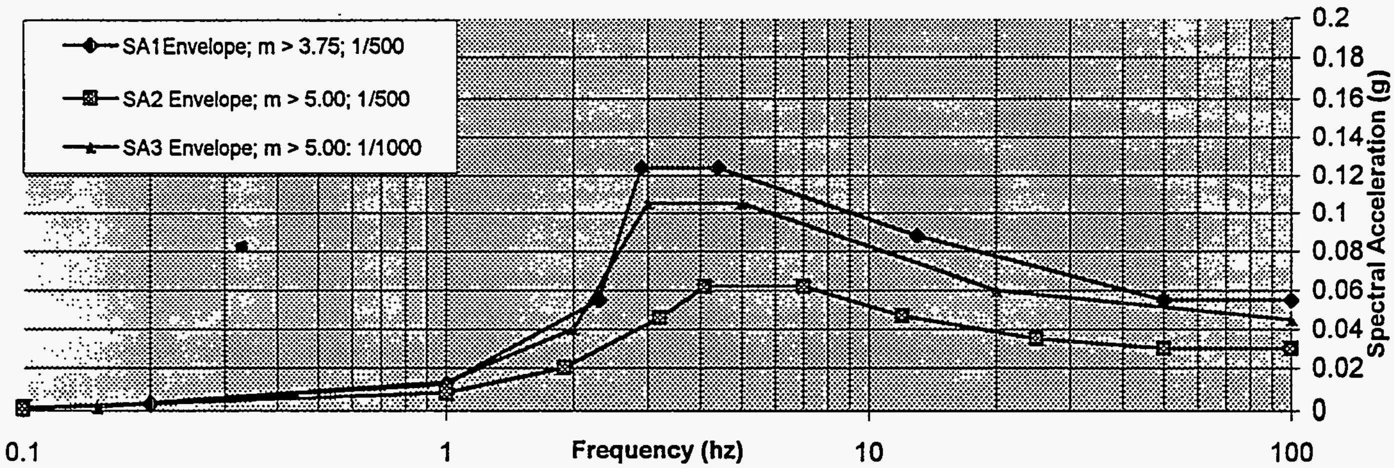


LOCATION PLAN

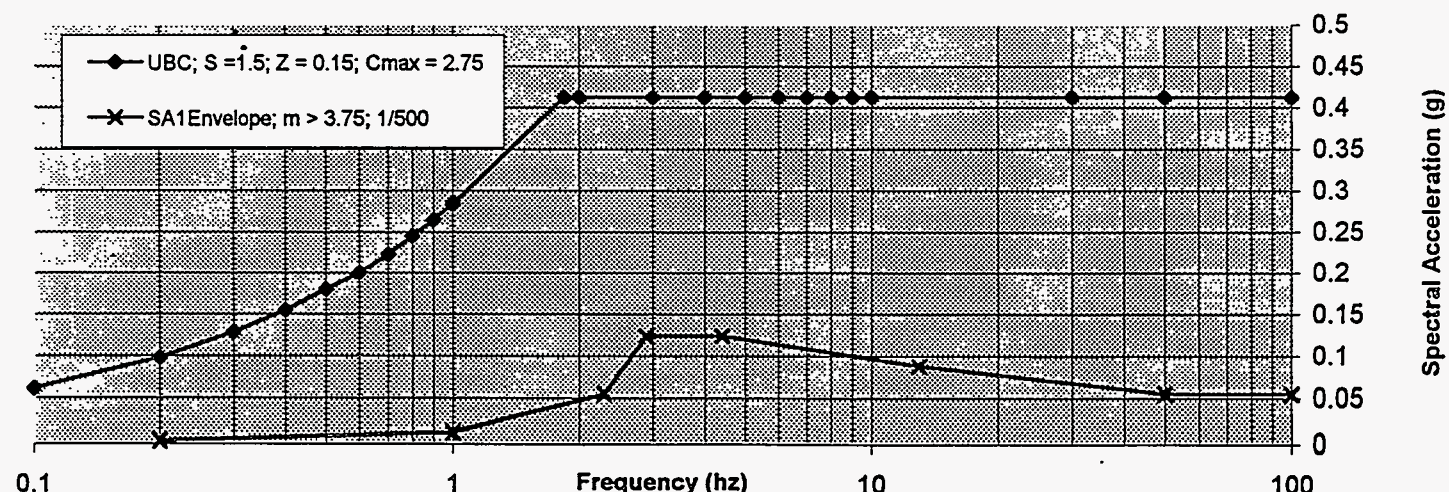
KANSAS CITY RESPONSE SPECTRA
Uniform Hazard Spectral Data From LLNL
Rock Surface
CHART 1

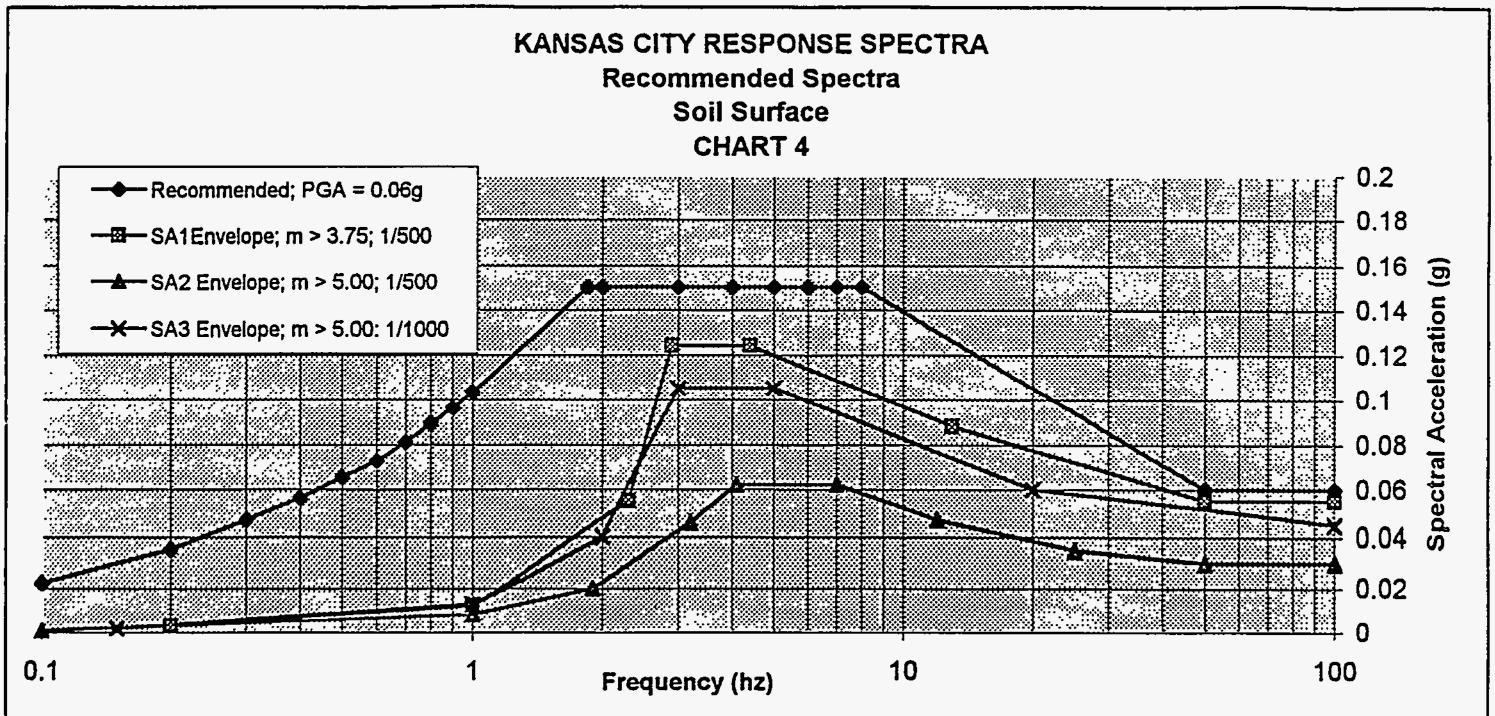


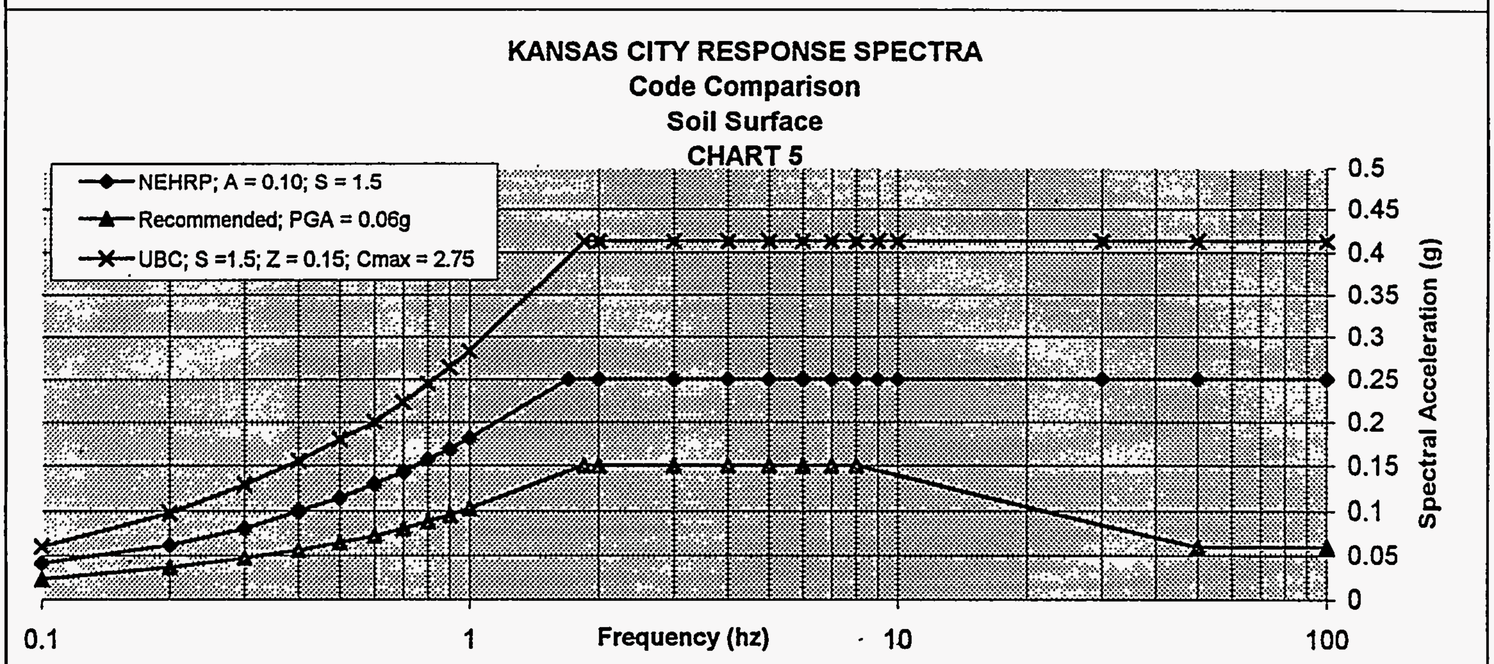
KANSAS CITY RESPONSE SPECTRA
Generated Envelopes
Soil Surface
CHART 2

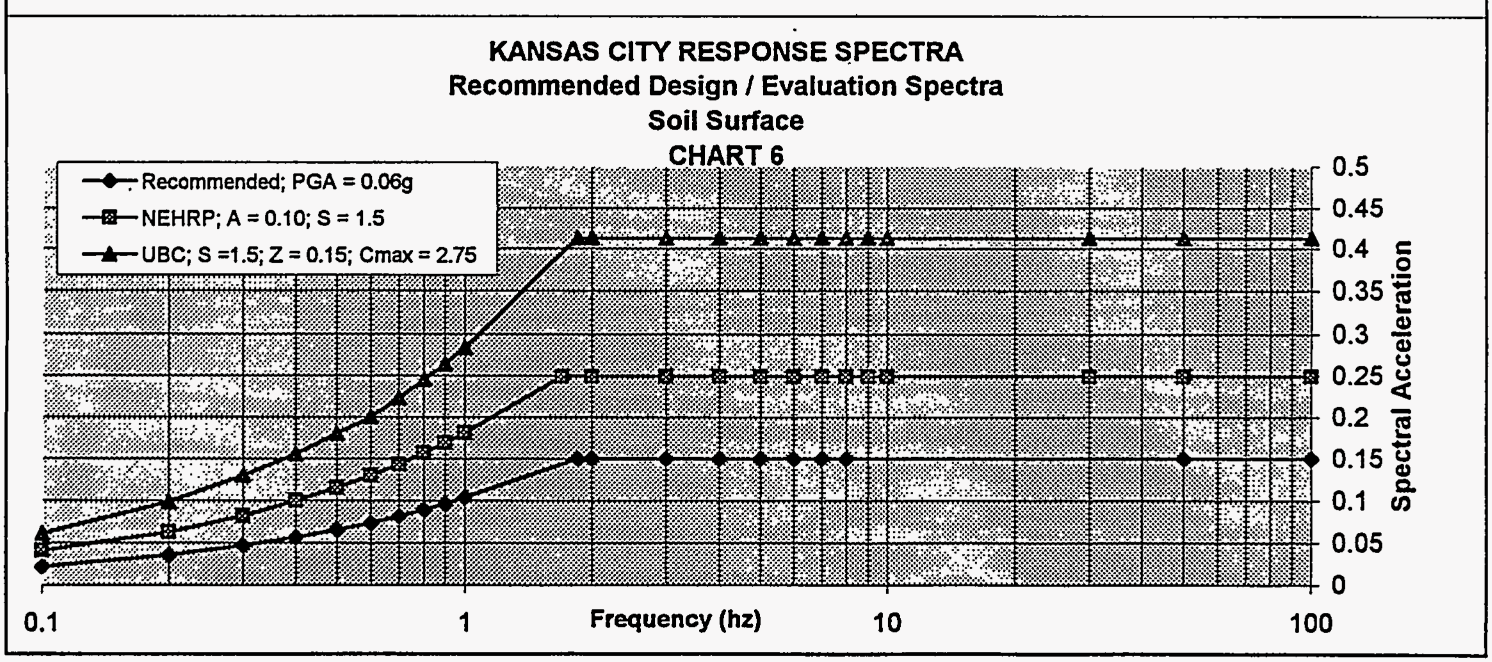


KANSAS CITY RESPONSE SPECTRA
Compare to Code
Soil Surface
CHART 3




KANSAS CITY RESPONSE SPECTRA
Recommended Spectra
Soil Surface
CHART 4
Recommended; PGA = 0.06g
SA1Envelope; m > 3.75; 1/500
SA2 Envelope; m > 5.00; 1/500
SA3 Envelope; m > 5.00: 1/1000
Spectral Acceleration (g)
Frequency (hz)
0.1
1
10
100
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2


KANSAS CITY RESPONSE SPECTRA
Code Comparison
Soil Surface
CHART 5
NEHRP; A = 0.10; S = 1.5
Recommended; PGA = 0.06g
UBC; S =1.5; Z = 0.15; Cmax = 2.75
Spectral Acceleration (g)
Frequency (hz)
0.1
1
10
100
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


KANSAS CITY RESPONSE SPECTRA
Recommended Design / Evaluation Spectra
Soil Surface
CHART 6
Recommended; PGA = 0.06g
NEHRP; A = 0.10; S = 1.5
UBC; S =1.5; Z = 0.15; Cmax = 2.75
Spectral Acceleration
Frequency (hz)
0.1
1
10
100
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

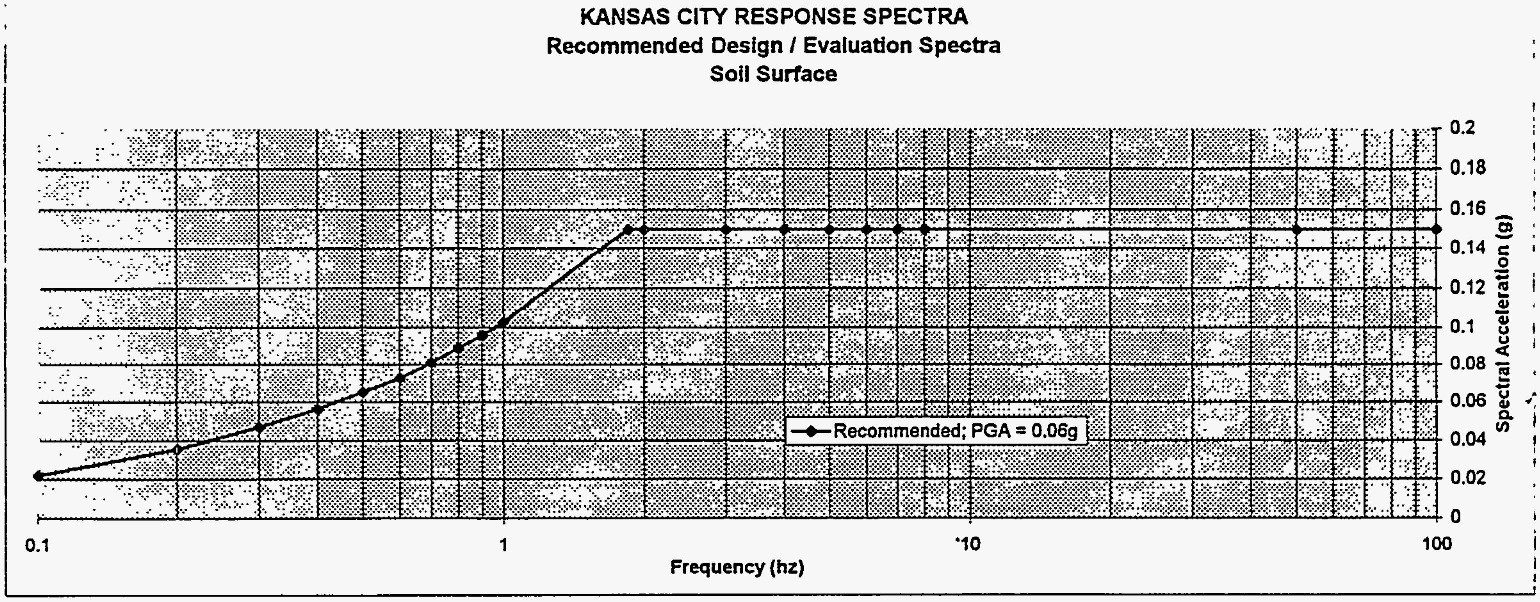


TABLE 1										
Summary of Laboratory Soils Testing-Boring D-40 - Northeast Parking Lot										
Sample	Depth, ft.	Net W%	LL	PL	PI	LI	% Retained on #200 Sieve	% Passing #200 Sieve	Blow Count	Classification
S-1	5.0 - 6.5	25	54	16	38	0.24	6.6	93.4	17	Very dark gray fat clay, CH
S-2	10.0 - 10.9	31.5	48	16	32	0.48	7.2	92.8	4	Dark gray and dark brown sandy clay, CL
S-3	15.0 - 16.5	29	43	18	25	0.44	8.2	91.8	8	Dark brown sandy clay, CL
S-4	20.0 - 21.5	30.6	39	15	24	0.65	7.8	92.2	4	Very dark gray lean clay, CL
S-5	25.0 - 26.4	31.5	40	18	22	0.61	7.7	92.3	5	Very dark gray lean clay, CL
S-6	30.0 - 31.5	26.6	53	19	34	0.22	5.8	94.2	18	Mottled gray and rust fat clay with some sand, CH
S-7	35.0 - 36.5	24.6	41	16	25	0.34	25.5	74.5	8	Dark brown clayey sandy gravel
S-8	40.0 - 40.3		30	15	15					Note: Speciman too small for 4-point Atterberg.

TABLE 2										
Summary of Laboratory Soils Testing-Boring D-40 - Southeast Parking Lot										
Sample	Depth, ft.	Net W%	LL	PL	PI	LI	% Retained on #200 Sieve	% Passing #200 Sieve	Blow Count	Classification
S-1	5.0 - 6.5	26	45	17	28	0.32	7.3	93.4	17	Very dark gray fat clay, CH
S-2	10.0 - 11.5	26.8	38	17	21	0.47	7.2	92.8	4	Dark gray and dark brown sandy clay, CL
S-3	15.0 - 16.5	26.7	38	17	21	0.46	5.9	91.8	8	Dark brown sandy clay, CL
S-4	20.0 - 21.5	27.2	35	16	19	0.59	5.7	92.2	4	Very dark gray lean clay, CL
S-5	25.0 - 26.3	32.3	42	18	24	0.60	4.7	92.3	5	Very dark gray lean clay, CL
S-6	30.0 - 31.5	34.9	42	17	25	0.72	4.2	94.2	18	Mottled gray and rust fat clay with some sand, CH
S-7	35.0 - 36.3	28.5	46	17	29	0.40	8.0	74.5	8	Dark brown clayey sandy gravel
S-8	40.0 - 41.5	30.4	41	16	25	0.58	8.2			Note: Speciman too small for 4-point Atterberg.
S-9	45.0 - 45.4		33	16	17					

TABLE 3		
Average Crosshole S - wave Velocities		
Depth Range, ft.	Average S-wave Velocity, fps	Material
5 to 12	475	Clay-alluvium
12 to 21	600	Clay-alluvium
21 to (37-46) bedrock	700	Clay-alluvium
(37 - 46) to ?	1900	Shaly Siltstone - Bedrock

TABLE 4						
	Spectral Acceleration (g)					
Model	Frequency (hz)					
	1	2.5	5	10	25	pga
LLNL SA 1	0.01	0.03	0.04	0.04	0.05	0.03
BNL Soil SA 1	0.01	0.07	0.12	0.1	0.08	0.06
Recommended Spectrum	0.11	0.15	0.15	0.15	0.15	0.06

LL= Liquid Limit
PL= Plastic Limit
PI = Plasticity Index