Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

TIMES-HISTORY FINITE ELEMENT DYNAMIC ANALYSIS - SOIL NAIL WALL - SAN MANUEL CASINO - HIGHLAND, CALIFORNIA

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ABSTRACT

The site of the proposed Phase II Parking Facility at the San Manuel Resort Casino, Highland, California, is on a sloped terrain where there is a 35 ft. grade differential from the north to the south end of the planned structure. PB&A, Inc. was selected to design a 12,000 square foot Soil-Nailed wall with a maximum height of 37 ft. to protect the Parking Structure from the soil pressures resulting from sloping ground conditions at the site. The project site is located within 100 feet of the San Andreas Fault in the highly seismic Southern California region, characterized by numerous active faults and high level seismic activity.

The alignment of the Soil-Nailed wall is located at the edge of the Alquist-Priolo Earthquake Fault Zone. The proximity of the Soil Nail Wall to this major seismic fault necessitated the preparation of a dynamic analysis to better assess the behavior of the wall during a seismic event.

The main objective of this analysis was to determine the maximum deformation the Soil-Nailed Wall would undergo during an earthquake so that an adequate separation could be defined between the structure of the parking garage and the Soil-Nailed Wall. In addition, vertical soil nails (V-Nails) were to be installed directly behind the shotcrete facing of the wall to provide localized surface stability during construction. The effect of the V-Nails was to be studied in relationship to the overall performance of the wall.

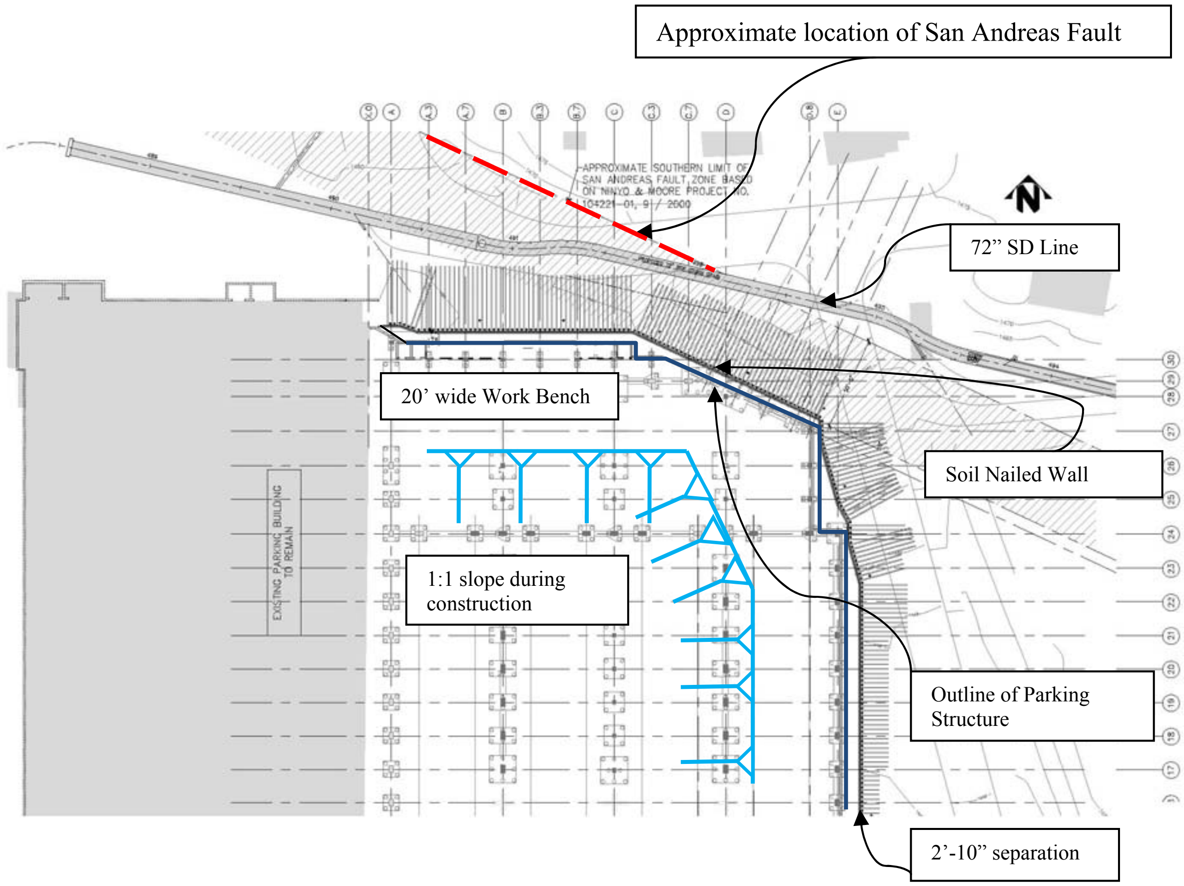
The Geotechnical Engineer of Record, Kleinfelder, provided three sets of spectra-matched outcropping acceleration time histories from three representative earthquakes: Duzce earthquake, Turkey (11/12/1999), Landers earthquake, United States (06/28/1992) and Chi-Chi earthquake, Taiwan China (09/20/1999).

Using the information gleaned from these time histories, PB&A constructed a half-space model in PLAXIS, a Finite Element software application widely used in the industry. To construct the model, engineers used the "Mohr-Columb" soil model applied to layers of soil at the project site. The soil strength and stiffness parameters were based on the recommended values outlined in the Geotechnical Report and the shotcrete wall and soil nails were modeled with the plate (Beam) and ground anchor element, respectively. It was necessary to transform the acceleration time histories to the proper depth at the bottom of the PLAXIS model, as the acceleration time histories were recorded as the outcropping motions,. To accomplish this, the deconvolution process was performed in the SHAKE91 program. In the staged construction calculation, the horizontal and vertical displacement, velocity and acceleration are recorded at the top and the bottom of the wall in each step.

INTRODUCTION

In the mid-1980s, the San Manuel Band of Mission Indians (SMBMI) invested in a casino complex near Highland, CA.. The casino operation is enormously successful and due to the high demand for extra parking, a seven-story, 1,190-spaces Phase II parking structure was proposed. The primary purpose is to provide a more comfortable and enjoyable facility for patrons and improve pedestrian safety.

Figure 1: Schematic Plan View



The site of the Phase II parking facility lays east of Victoria Avenue, adjacent to the Phase I parking facility within the SMBMI Reservation. The finished grades slope from north to south by approximately 35 feet, hence the necessity to construct a permanent Earth Retention System behind the parking structure saving the Lateral Load Resisting System of the structure from the lateral soil pressures, including seismic soil pressures. (See Figure 2: Schematic Plan View).

The Phase II parking facility has seven levels of parking, with two of these levels below grade at the northern end of the structure. In order to maintain the alignment of the proposed fire lane and new utilities along the northern and western perimeter, it was necessary to place engineered fill of up to 16 feet to bring the grade to the desired elevation at the northern part of parking structure. The Fill was placed with a 20' wide work bench from the face of the wall with a 1:1 slope down to grade. (See Figure 3: Schematic Plan View) The purpose of the work bench was to provide space for construction equipment maneuverability and facilitate the top-down construction of the soil nail wall.

A permanent Soil-Nailed wall system, designed by PB&A, was constructed to provide separation between the soil material and the parking structure, thereby eliminating the exertion of static and seismic lateral earth pressures on the structure. The high seismicity in Southern California region and close proximity to the San Andreas Fault, combined with the complex soils make-up at the site, required that a state-of-the-art dynamic analysis be prepared on the permanent Soil-Nailed wall system.

GEOTECHNICAL CONSIDERATIONS

The project site is located within the influence of several fault systems considered to be active or potentially active. The fault closest to the site is the San Andreas Fault which is a right lateral strike slip fault, having a slip rate of 24+/-6 mm/year and a maximum magnitude of 7.5 based on the updated 002 California Geological Survey (CGS) fault data base. The portion closest to the Soil-Nailed wall at the northern part of site is within 100 feet of this fault, the Alquist-Priolo Earthquake Fault Zone. A special study is required by the State of California to address the potential for surface fault rupture.

According the geotechnical investigation performed by the geotechnical engineer of record, Kleinfelder, ten borings were advanced to depths ranging from approximately 51 to 101 feet below existing grades. The number of blows necessary to drive the sampler is

typically recorded at an interval of 5 feet. Various depths of undocumented fill soil from 3 feet to 10 feet were encountered in all borings. Below the fill the alluvium consists of inter-bedded layers of silty sand (SM), sand (SP and SW), sand with silt (SP-SM and SW-SM), and sandy gravel (GP) with cobbles and boulders. Occasional layers of sandy clay (CL) and clayey sand (SC) were also encountered. Groundwater was found in only one boring at a depth of 71 feet below the existing grade, the effect of which on the excavation and the permanent Soil-Nailed wall can be neglected.

PERMANENT SOIL-NAILED WALL SYSTEM

The concept of Soil Nailing, also referred to as "In Situ Reinforced Earth", is to strengthen a slope or an excavation wall consisting of existing ground using the installation of steel rods ("Soil Nails") into grouted holes.

The first known soil nail wall constructed in the United States was the temporary shoring wall for Good Samaritan Hospital in Portland, Oregon in 1978. The second soil nail wall was constructed as a temporary shoring wall in Walnut Creek, California, 1983, designed by PB&A and built by Kulchin Assoc.

The Nails are installed in the pattern of a matrix with spacing not-to-exceed 6 feet by 6 feet. The length of the Nails is typically between approximately 80% and 120% of the height of the excavation. When the Nails are installed a homogeneous and reinforced mass of soil is created, acting much the same as a gravity earth dam to resist the lateral pressures of the soil behind the boundaries of the Soil Nails. The passive reinforcements develop their strengthening action as the ground deforms during wall construction. Soil Nailing uses a "top-down" construction technique with excavations taken in lifts and installation of soil nails by rows. Compared with the soldier beam method, Soil Nailing has the advantage of economy, ease of construction, accelerated construction schedule and greater system redundancy.

A typical section of a 29 feet high Soil-Nailed wall was selected for the stability analysis. The soil consists of one layer of engineered backfill, a thickness of 22 feet, and underlain by the native soil. The strength parameters recommended by Kleinfelder are shown in *Table 1*. Five rows of soil nails were installed with a spacing of 5 feet on center, horizontally. The nails were placed in 8 inch diameter drilled holes and are ASTM 615 Grade 75, No. 8 (1 inch diameter) threaded bars with double corrosion protection. In order to mitigate localized surface instability during construction, vertical nails (V-nails) with the same specifications as the soil nails were installed immediately behind the shotcrete face of the wall, at 2'-6" spacing, in between the soil nails.

Computer program "Winslope", developed by PB&A and Dr. Toorak Zokaie, was used to carry out this computational effort. The analysis is based on limit equilibrium procedure and adopts the traditional slope stability analysis method calculating the factor of safety against the most critical failure plane. The soil nail lengths were determined by a trial and error method in order to achieve a factor of safety of 1.50 or better in the permanent static condition, with a 1.1 factor of safety for seismic. The maximum nail length in this case was 35 feet for the top two rows. The factor of safety calculated was 1.63 for static condition. A horizontal pseudo-static force equivalent of 40% of the weight of the mass of the soil in front of the assumed failure plane (seismic coefficient =0.40 g) was applied in the same model. The calculated factor of safety was 1.38, which is satisfactory according to the recommended value of 1.1 or better from the FHWA Technical Manual for Soil Nail Walls (FHWA0-IF-03-017 Geotechnical Engineering Circular No. 7).

The effect of V-nails was neglected in the limit equilibrium analysis.

Table 1. Input Soil Strength Parameters for "Winslope"

Soil Strata	Unit Weight γ (pcf)	Cohesion c (psf)	Friction Angle φ (deg)	Pullout Strength μ (psf)
Eng. Fill	125	200	30	1500
Native Soil	125	200	35	1500

PLAXIS DYNAMIC ANALYSIS

The site is located within an Alquist-Priolo Earthquake Fault Zone where special studies addressing the potential for surface fault rupture are required by the State of California.

"Winslope" computer program, as well as other commercially available software programs such as SNAIL, treat the analysis of Soil-Nailed Walls as a slope stability problem and are based on limit-equilibrium methods. No displacement is allowed and only forces and moments are calculated to satisfy the equilibrium in this method. Further, the affects of "V-Nails" were not accounted for in these analyses.

"Plaxis" is finite element software program developed in Holland for the two and three-dimensional analysis of Geo-structures and Geotechnical Engineering problems. It includes from the most basic to the most advanced constitutive models for the simulation of the linear or non-linear, time-dependent and anisotropic behavior of soil and/or rock. Plaxis is also equipped with features to deal with various aspects of complex structures and study the soil-structure interaction effect. In addition to static loads, the dynamic module of Plaxis also provides a powerful tool in modeling the dynamic response of a soil structure during an earthquake.

The typical section of a 29 feet high wall for the "Winslope" analysis is modeled in Plaxis. The model was simulated assuming plane-strain conditions. The finite element mesh boundary conditions were set using horizontal restraints for the left and right boundaries and total restraints for the bottom boundary. The soil stratigraphy was assumed to be uniform across the site. In addition to the Engineering Fill layer, the native soil was classified into three layers to account for the soil hardening effect with an increasing depth: Silt Sand (SP/SM/SC), Silty Sand (SP/SM) and Silty Sand (SP/SM/Gravel).

The soil model used to characterize the site was the elasto-plastic Mohr-Columb model. Table 2 shows the initial values of the basic Mohr-Columb input parameters for the four layers of soil. The soil-nailed wall was modeled as a linear elastic material with a composite modulus calculated to account for the thickness of the 12 inch permanent shotcrete facing of the Soil-Nailed Wall. The stiffness of the V-nails was included in the stiffness of the shotcrete facing. However the stiffness of the V-nails was adjusted to account for their 2.5 ft. spacing.

The soil nails are steel thread bars placed in the drilled holes filled with grout at a horizontal spacing of 5 feet on center. They are modeled as a line element with an axial stiffness EA and no bending stiffness. Interface elements were placed between soil and structural elements for the interaction effect. *Table 2* summarizes the parameters used to model the structural elements.

The calculations were carried out by six intermediate phases to simulate the staged construction of the soil-nailed wall in the field. In each phase, finite element clusters were removed to simulate the excavation lifts and structural elements were activated to simulate the installation of the soil nails along with application of the shotcrete facing. A uniformly distributed surcharge of 300 psf was applied on the retaining side to simulate the traffic surcharge.

Phi-c reduction is a special type of plastic calculation. In the Phi-c reduction approach the strength parameters (φ) and C of the soil are successively reduced until failure of the structure occurs and a factor of safety (F.O.S.) is achieved. The *Phi-c* reduction step is added after the final excavation stage is achieved. In this case the purpose was to calculate the global stability F.O.S. for comparison with the result of the "Winslope" analysis.

Table 2: Properties of Structural Elements

Element Type	Normal Stiffness EA (lbf/ft)	Flexural Stiffness EI lbf*ft2/ft	Weight w (lb/ft/ft)	Poisson Ration
Shotcrete Facing	4.32E+8	3.60E+7	150	0.2
Soil Nail	4.52E+6	-	-	-

Fig. 3 shows the computed deformed mesh of the Plaxis model. The extreme horizontal displacement occurs in the mid depth of the excavation, which is 0.11 inch. The global stability F.O.S. is calculated as 2.03 for the permanent static condition, which is larger compared with the F.O.S =1.63 from the "Winslope" analysis. This can be explained by the fact that in the "Winslope" analysis, the failure planes that are searched all go through the toe of the soil-nailed wall, and ignore the affects of the V-Nails. In Plaxis, the affects of the V-Nails are taken into account and suppress the most critical failure plane to a greater depth and generate a higher F.O.S. The allowable deformation within the soil body reduces the active pressures on the structural elements as well as thr contribution of the V-Nails increasing the global stability.

The site is classified as Type D, provided in the Geotechnical Investigation report by Kleinfelder and based on the Table 16-J of the 2001 California Building code (CBC). The California Geological Survey Probabilistic Seismic Hazard Mapping indicates that the design basis earthquake (DBE) has a peak horizontal acceleration of 0.8g for 10% probability of exceedance in 50 years, which translates to a return period of 475 years. A probabilistic seismic hazard analysis (PSHA) procedure was used to estimate the peak ground motions corresponding to the DBE level. The PSHA approach is based on the earthquake characteristics and its causative fault.

The effects of site soil conditions and mechanism of faulting are accounted for in the attenuation relationships. Three sets of times histories were selected from Pacific Earthquake Engineering Research (PEER) Strong Motion Database as references based on the closet similarity of seismological and geological features: 375 Lamont station in Duzce, Turkey (11/12/1999), 24 Lucerne station in Landers (06/28/1992) and TCU065 in Chi-Chi, Taiwan (09/20/1999). The above selected horizontal motions were spectrally matched to the targeted horizontal uniform hazard spectral (UHS), and the vertical motions spectrally matched to the target vertical UHS.

It should be noted that these spectrum-matched acceleration time histories are corresponding to an outcropping condition. To obtain the input motion at the bottom of the Plaxis model, we have used SHAKE91 (Idriss et al., 1991) to perform the deconvolution process. SHAKE91 is a widely used computer program developed for the one-dimensional ground response analysis of layered sites with the equivalent linear approach. The actual nonlinear hysteretic stress-strain behavior of cyclically loaded soils can be approximated by equivalent linear soil properties.

These properties were estimated by information provided in the geotechnical investigation report along with engineering judgment.

The input ground motions at appropriate depths are defined by means of the dynamic multipliers. These multipliers are a set of scaling factors on the prescribed unit displacement, applied on the bottom of model, to produce the actual dynamic load magnitudes such as displacements, velocities and accelerations. In the dynamic calculation, the time-displacement and time-acceleration curves are recorded at the top (Point A) and bottom (Point B) of the soil-nailed wall. Also the time-acceleration curve is generated at the bottom of the mesh (Point C) to verify the input motions. See Fig. 2 for the detailed locations of the points.

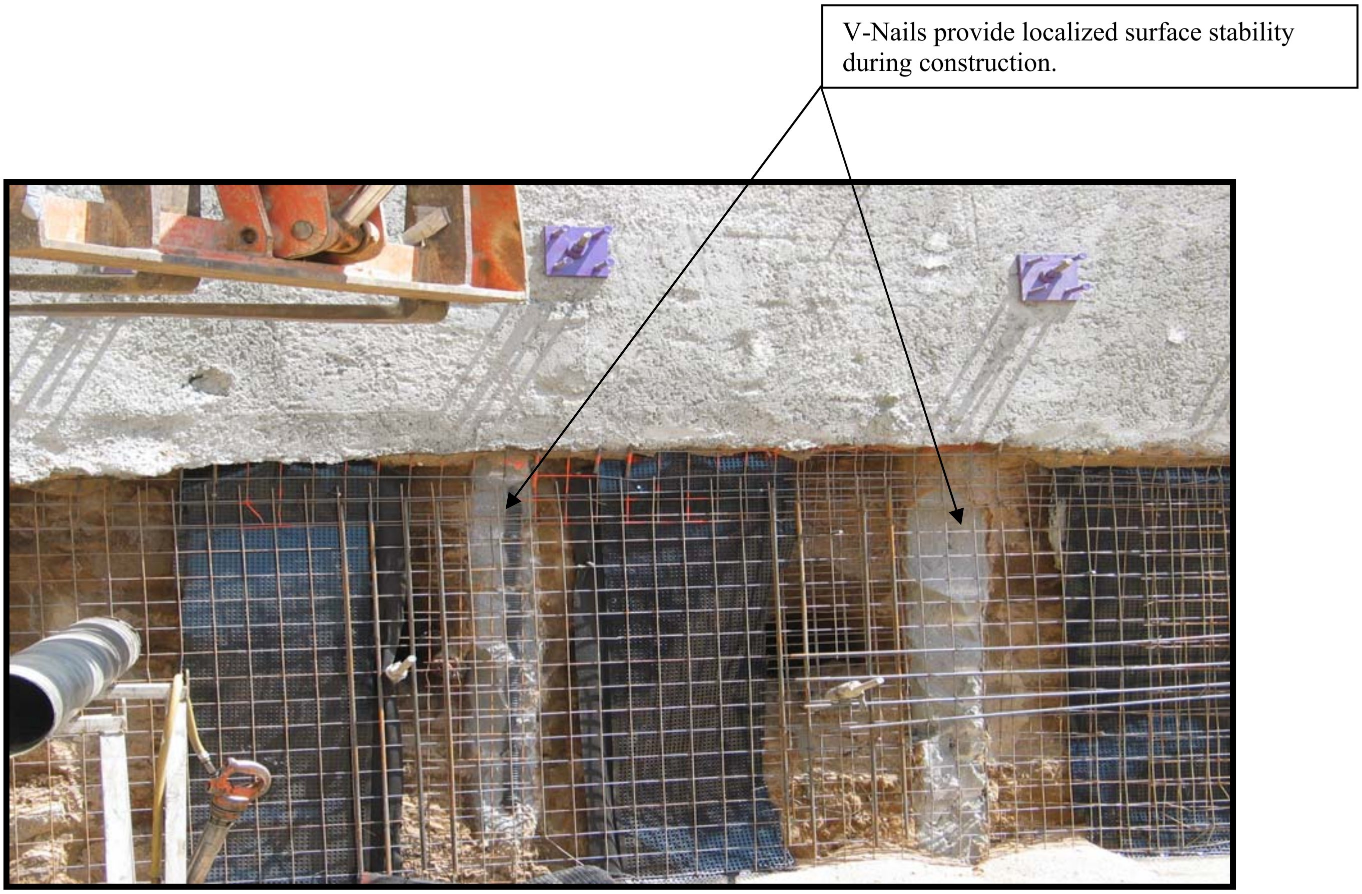


Table 1: Input Parameters of Mohr-Columb model

Soil Strata	Unit Weight γ (pcf)	Cohesion c (psf)	Friction Angle φ (deg)	Young's Modulus E (psf)	Poisson Ratio n
Eng. Fill	110	200	30	6.5E+6	0.3
Silty Sand (SP/ SM/SC)	110	200	35	1.0E+7	0.3
Silty Sand (SP/SM)	110	20	36	1.4E+7	0.3
Silty Sand (SP/SM/ Gravel)	110	200	36	2.1E+7	0.25

The results are shown in Fig. 5 through Fig. 7. The "Plaxis" Finite Element Analysis has determined that the soil-nailed wall as designed will remain stable during the prescribed earthquake events. The output accelerations in all three earthquakes from Point C, which is recorded at the bottom of the mesh, match the input motions. The absolute horizontal displacements at the top of the wall during three earthquakes are 2.81 feet (Duzce earthquake), 2.71 feet (Landers earthquake) and 2.32 feet (Chi-Chi earthquake), respectively.

As a result of these investigations the soil nail wall that was originally located only 8 inches away from the structure was realigned so as to maintain a 2'-10" separation.

Figure 2: Plaxis Input Model

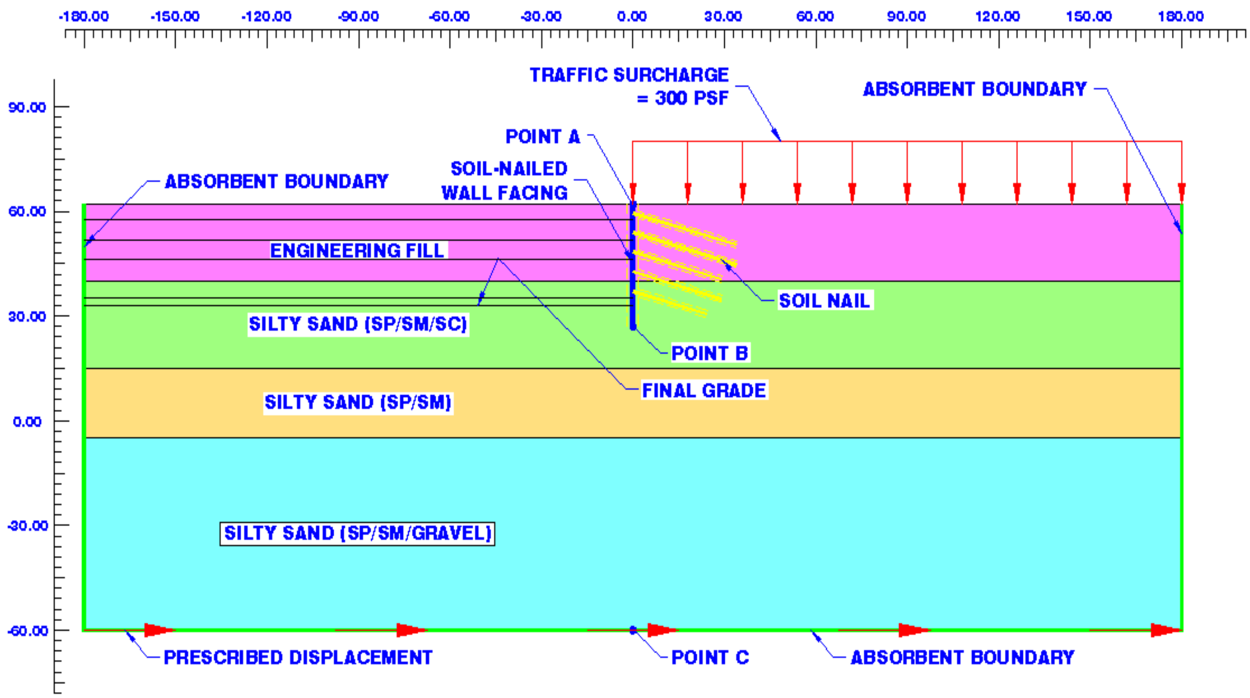


Figure 3: Deformed Mesh for the Final Excavation

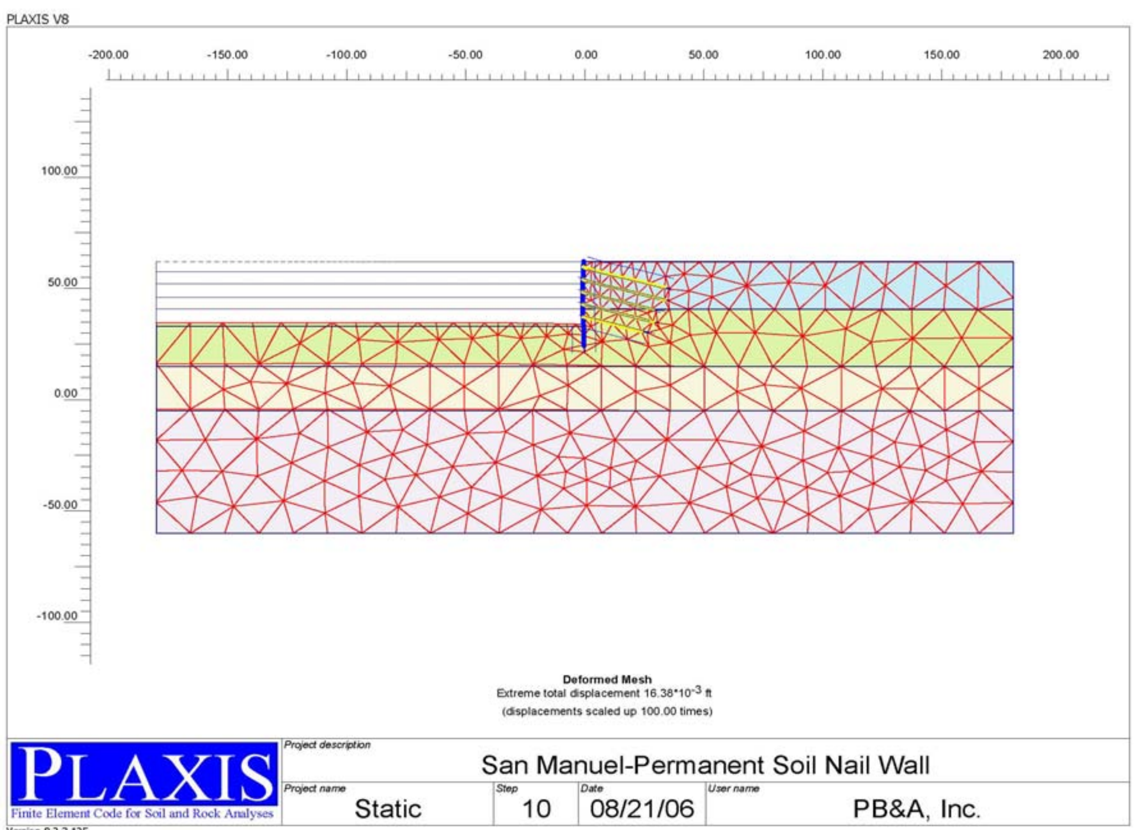


Figure 4: Global Stability Analysis by Phi-c reduction

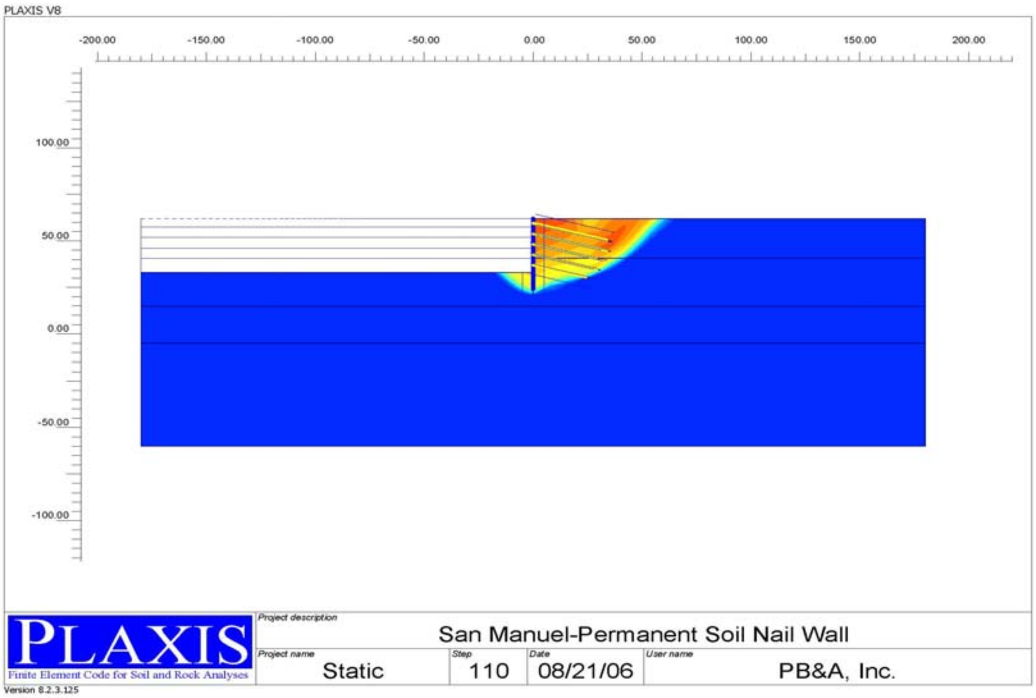
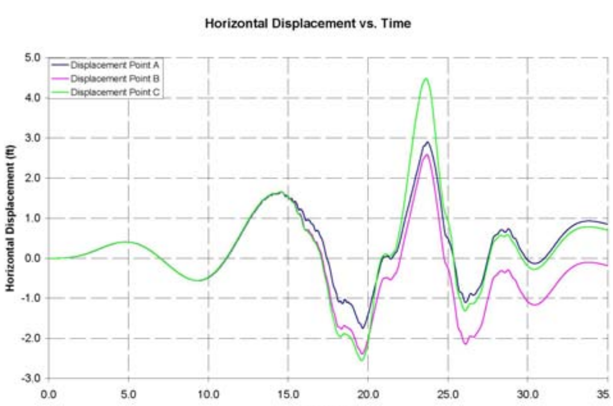


Figure 5: Time-Displacement and Time- Acceleration
Curve for Ducze, Turkey Earthquake (11/12/1999)



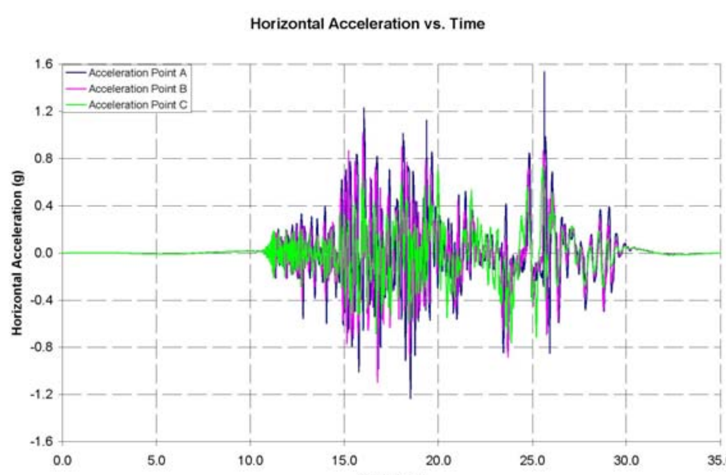


Figure 6: Time-Displacement and Time- Acceleration Curve for Landers, US Earthquake (06/28/1992)

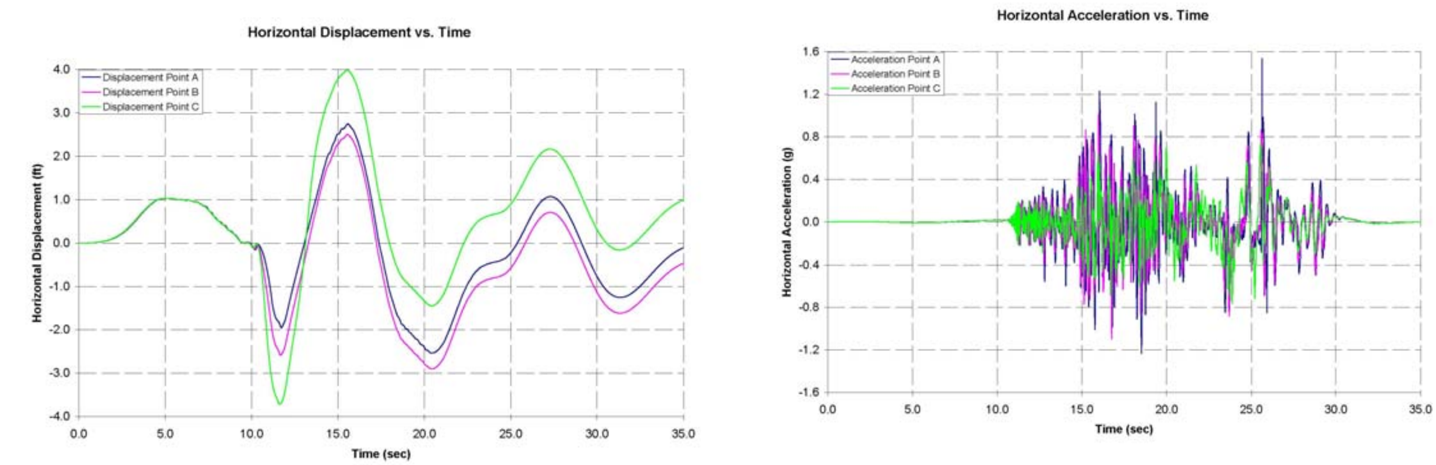
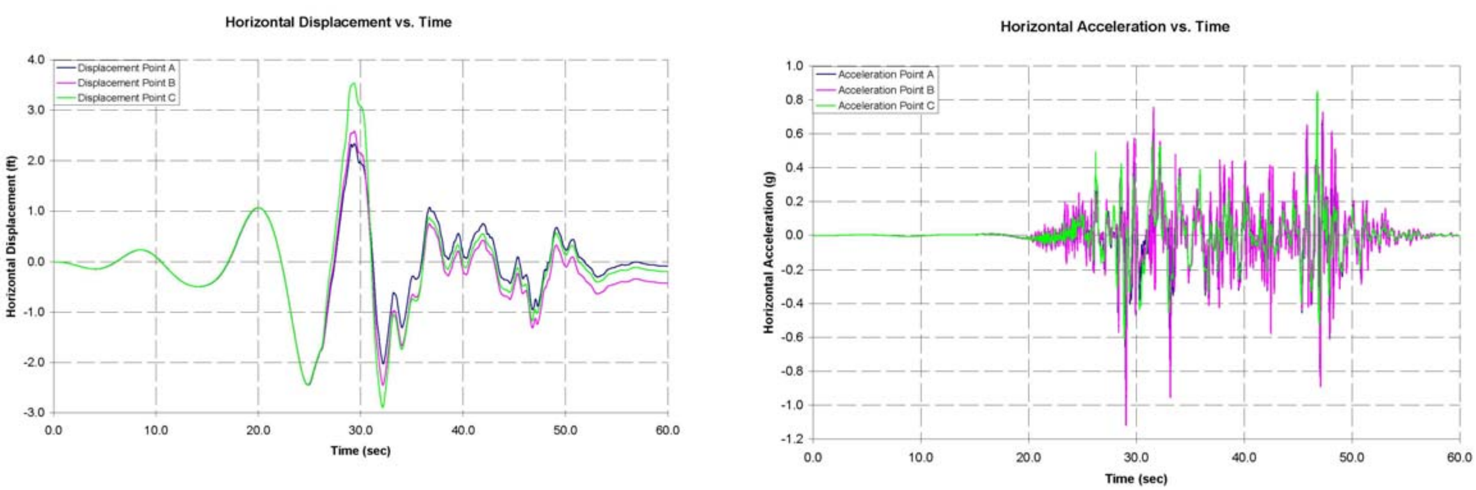


Figure 7: Time-Displacement and Time- Acceleration Curve for Chi-Chi, Taiwan, China Earthquake (09/20/1999)



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