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INVESTIGATION OF GROUND CRACKING AT THE
VAN GOGH STREET SCHOOL, GRANADA HILLS, CALIFORNIA

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ABSTRACT

The Van Gogh Street School, located in the northern portion of the San Fernando Valley in the City of Los Angeles, suffered damage from the January 17, 1994 Northridge earthquake having a moment magnitude of 6.7. The school experienced significant cracking in some of the building walls and asphalt paving. The school, located approximately 7 miles from the epicenter, was within a zone of surface cracking coincident with the east-northeast to northeast trending Mission Hills syncline. There was speculation that either fault rupture, liquefaction and/or seismic settlement may have occurred at the school site.

A geotechnical investigation was performed to evaluate the ground cracking at the school. The comprehensive exploratory program consisted of mapping and shallow trenching of the surface cracks, closely spaced cone penetration tests (CPT's) and borings to characterize the stratigraphy of the underlying alluvial materials, and high resolution seismic reflection surveys to map the underlying geologic structure and determine if faults were present within the bedrock. This combination of exploratory tools was utilized simultaneously to provide the necessary data to accurately evaluate the shallow and deep structural and stratigraphic conditions beneath the school site.

KEYWORDS

Northridge earthquake, ground shaking, regional uplift, cone penetrometer testing, seismic reflection

INTRODUCTION

This study was conducted to evaluate the surface cracking at Van Gogh Street School in the Granada Hills district of the City of Los Angeles resulting from the January 17, 1994 Northridge earthquake (moment magnitude 6.7) and to develop an opinion as to the cause of distress to the structures from a geologic and geotechnical standpoint. The investigation consisted of a review of available literature and onsite explorations which included surface mapping, exploratory trenching and borings, cone penetration testing, and geophysical surveys. The explorations were performed to determine if the ground cracking at the school site was a result of either primary fault rupture, liquefaction, or seismic settlement due to the earthquake.

The school was originally constructed in 1968 in an area known as Bee Canyon. Prior to the school development, the majority of the Bee Canyon area, was occupied by an orchard. During the development of the school, several feet of fill material was reportedly placed to create a level pad. Although the grading was relatively minor, the as graded elevations were not significantly changed from the original topography.

The school sustained damage as a result of the February 9, 1971 San Fernando earthquake. According to Fugro (1971), the main building sustained an eastward lateral shift in the north half of the building, bulging the lower portion of the east-facing walls and the slabs east of the main building toward the kindergarten facility. Long arcuate cracks were observed within the asphalt paving in the play area south of the main building which exhibited both compressional and extensional features. Based on their investigation, the cracks in the asphalt could be traced several feet into the alluvial soils. Most of these cracks were determined to be "simple tension fractures with little evidence of displacement parallel to the crack." Additionally, "although most of the cracks have formed
for the first time during the recent (1971) earthquake, it is clear that some are coincident with former cracks developed during an earlier event." It was concluded that the cause of damage to the school was ground shaking, and a redistribution of the alluvial soils beneath the site; damage was not attributed to fault displacement or surface fault rupture.

The Earthquake Engineering Research Institute (EERI, 1994 and Hall, 1995) reported two broad zones of concentrated ground cracking and breakage as a result of the Northridge earthquake, one within the northern San Fernando Valley (including Granada Hills) and the other within Santa Clarita Valley. These zones of ground cracking were generally oriented in a west-northwest direction. The damage to the school site was identified and included in one of these zones of cracking.

Recent publications indicate that approximately 40 centimeters of uplift occurred in the vicinity of the school site as a result of the Northridge earthquake (Hodgkinson et al., 1996).

**GEOLOGIC SETTING**

The school is located in Los Angeles, California at the northern end of the San Fernando Valley at the base of the Santa Susana Mountains. A review of historic topographic maps prepared by the U.S. Geological Survey (1933) indicates that the property is located within a fairly narrow east-west-trending valley on a southeast-sloping alluvial fan at the mouth of Bee Canyon, which is separated from the main San Fernando Valley by the Granada Hills.

The site is underlain by a thin veneer of artificial fill soils which are in turn underlain by both Holocene and Pleistocene age alluvial sediments derived from the adjacent Santa Susana Mountains. These alluvial sediments are in turn underlain by sedimentary bedrock units of the Plio-Pleistocene age Saugus Formation.

The major geologic structural feature within the Bee Canyon area is the Mission Hills Syncline (Saul, 1979). Beds within the Plio-Pleistocene age Saugus Formation have been folded into a broad syncline. The axial trace of the syncline has been mapped by Barrows et al. (1974) traversing the southern portion of the school site in an northeast-southwest direction; additional mapping by Saul (1979) places the syncline in the central portion of the school trending in a similar direction. The trend of the syncline is roughly parallel to the southern terminus of the active Santa Susana fault zone, located approximately 0.5 mile to the west-northwest.

**EXPLORATIONS**

An exploratory program was developed to evaluate the potential for fault rupture or other fault-related hazards at the school site; the investigation included a variety of exploratory tools because any given single method would not be sufficient to provide an adequate evaluation. Detailed mapping of the ground cracks and shallow trenching of the shallow subsurface materials was performed to evaluate if the cracks occurred as a result of primary fault rupture. A combination of closely spaced cone penetration tests and exploratory borings were performed to assess the stratigraphy and engineering characteristics of the alluvial materials. Furthermore, high-resolution seismic reflection surveys were conducted to map the subsurface geologic structure and to determine if faults were present within the deeper alluvial sediments and bedrock units. This combination of exploratory tools was utilized to provide data to evaluate the structural and stratigraphic conditions beneath the site. The compilation and correlation of this data was intended to provide a more complete representation of the subsurface conditions, including detailed stratigraphy within the upper 20 to 40 feet and a more general representation of the geologic structure and stratigraphy at depth. The locations of the explorations with respect to the school site are shown on Fig. 1. Site Plan.

**Site Reconnaissance & Mapping**

The site reconnaissance was performed to identify zones of cracking and damage. An east-west-trending zone of cracking was observed along the northern portion of the school site. This zone could be traced west from the kindergarten play area, through the kindergarten and main buildings, and off the property across the adjacent street into the adjacent residences and terminated approximately 250 feet west of the westerly boundary of the school site. Concrete slabs adjacent to the kindergarten and main buildings had separation cracks, primarily located at the cold joints. The separations typically ranged from ¼ to ½ inch in width. Within the southern portion of the play area, a zone of arcuate cracks were observed, which trend in a general east-west direction in the asphalt paving. Separations within the cracks were typically ¼ and ½ inch to locally 1-inch in width and showed both compressional and extensional features.

An additional reconnaissance was performed by a team of structural engineers to assess the structural conditions of the existing school buildings. Observations inside the buildings indicate that many of the cracks that occurred in the floor slabs and walls of the buildings were old cracks from 1971 that had reopened.

**Trenching**

The trenching was performed in areas where surface cracking had been observed to determine if the cracks were related to primary fault rupture and if these features extended through the alluvial materials from the surface. Two exploratory trenches, totaling 90 linear feet of trench, were excavated. The entire surface of the trench walls was closely examined for...
any indications of faults or fault-related features. These indications include offset units, contacts or laminations, tectonically disturbed or deformed layers, soil- or clay-filled fractures or fissures.

**Exploratory Boring**

The subsurface conditions at the school site were also explored by drilling and sampling seven borings adjacent to the CPT lines (described later) to depths of 48 to 124 feet beneath the existing ground surface. The purpose of the borings were for general stratigraphic correlation and verification of CPT data to determine the depth of the older alluvium and the underlying bedrock. Standard Penetration Tests (SPTs) were performed in two of the borings to provide additional information regarding the potential for liquefaction.

**Cone Penetration Testing**

Four lines of closely spaced cone penetrometer tests (CPTs) were performed to provide detailed information on the characteristics and stratigraphy of the underlying alluvial soils. Stratigraphic correlations between the CPTs were performed to characterize the underlying alluvial soil and determine if active faults were present beneath the site, especially in areas of recent surface cracking and where deep faults were identified in the geophysical survey (described later). A total of 51 CPTs were performed in four lines to provide detailed stratigraphic correlations and aid in locating the contact between the older and younger alluvium and possibly the surface of the bedrock.

CPT Line 1 trended north-south in the western portion of the play area along the western boundary of the property. The CPTs within this line were typically spaced laterally at 30-foot intervals along the 800-foot-long line. The depths of penetration along this line ranged from 27 to 67 feet, depending on the depth to refusal in the subsurface materials that typically contained gravel and cobbles.

CPT Line 2 trended northwest-southeast in the central portion of the play area and splays off of the north-central portion of CPT Line 1. The CPTs along this line were spaced laterally at 20- and 30-foot intervals along the 210-foot-long line and ranges in penetration depth from 32 to 53 feet. This line was performed to provide additional information to better interpret the nature of the possible stratigraphic discontinuities observed in Line 1.

CPT Line 3 was located on the eastern portion of the school site and trended north-south along the western portion of the parking lot, adjacent to Seismic Reflection Line 3. The CPTs along this line were spaced laterally at 20-foot intervals along the 260-foot-long line with penetration depths ranging from 15 to 79 feet.

CPT Line 4 trended northwest-southeast in the central portion of the parking lot and splayed off of CPT Line 3. The CPTs along this line were spaced laterally at 20-foot intervals along the 100-foot-long line with penetration depths ranging from 51 to 68 feet. This additional line was used to provide additional information to better interpret the possible stratigraphic discontinuities on Line 3.

Four additional CPTs were performed at selected locations of either structural damage or asphalt cracking. Seismic shear wave velocity testing of the subsurface was performed in these additional CPTs at 3- and 5-foot depth intervals. The seismic velocity information obtained from these CPTs was evaluated to estimate the dynamic soils properties in order to estimate dynamic stress and strain levels experienced at the site.

Additionally, pore water dissipation tests were performed in CPTs 1 through 21 to identify the depth to groundwater at the site. The measured water surface elevation within the CPTs was determined to be at a relatively constant elevation across the western portion of the site.

**Geophysical Survey**

The geophysical survey was performed using a combination of refraction and high-resolution seismic reflection methods to identify faults and the subsurface geologic structure at depths greater than 50 feet. Geophysical data was collected along four survey lines, totaling 1,940 lineal feet. Geophones were generally spaced at 10-foot intervals.

Seismic Reflection Line 1 trended north-south and was located along the western portion of the site adjacent to the main building and the adjacent street; the line extended approximately 720 feet. The southern two-thirds of this line was located adjacent to CPT Line 1. The northern portion of this line was located adjacent to the main building to determine if faults or other geologic features underlie the building; however, the data produced from this portion of the survey was ambiguous in a few areas because of interference by existing utilities. To provide better quality in this area, an additional survey line was added trending south from the intersection of Van Gogh Street and Titian Avenue for approximately 420 feet.

Seismic Reflection Line 2 trended east-west across the central portion of the site, south of the existing buildings, through the southern end of the parking lot, and was approximately 530 feet long.

Seismic Reflection Line 3 was located in the western portion of the parking lot, trending north-south between some existing relocatable buildings and the adjacent Van Gogh Street. The survey line was located adjacent to CPT Line 3 and was approximately 270 feet long.
FINDINGS

Exploratory Trenching

The geologic units observed within the two trenches included artificial fill, residual soil, and younger alluvial deposits. The contacts between the units were typically distinct; however, in some places, these contacts were laterally and vertically gradational.

No evidence of faulting was observed in the two exploratory trenches. The surface cracking in the play area was not observed to extend downward into the fill or upper alluvial soils. A small void was observed in the Trench 1. This feature was not, however, observed in the opposite wall, nor was this feature traceable through the uppermost alluvial unit. It is likely that this feature is a tension fracture formed during the 1971 earthquake. Desiccation cracks were locally observed in the fill soils, extending down from the ground surface into the fill soils to a maximum depth of 6 inches.

Cone Penetrometer Tests and Borings

The interpretation of the CPT and boring data indicate that there are no faults present in the younger alluvium. Additionally, the contact between the older and younger alluvium does not appear to be faulted. Correlations between the closely spaced CPTs and the borings were used to determine the contact between the younger and older alluvium and variations on soils characteristics, as shown on Fig. 2. The alluvial contact was identified in the CPTs as a significant increase on cone bearing measurements. The increase in cone bearing measurements in the CPTs was also directly correlated to a sharp increase in relative density of the soil samples obtained in the borings.

As identified in the CPTs and borings, the alluvial sediments beneath the site generally tend to be interfingered thin layers of soil zones. Many individual individual soil layers based solely on composition are laterally discontinuous and tend to gradually change composition, or pinch in and out, as is typical for the type of depositional environment at the site.

Initially only CPT Lines 1 and 3 were performed; however, the interpretation of the geophysical data indicated three distinct fault splays at depth which traverse CPT Line 1. Therefore, CPT Lines 2 and 4 were added to provide additional stratigraphic information regarding lateral continuity in the alluvial sediments and to better determine if any suspected faults observed in the geophysical data project up into the younger sediment.

The CPTs performed depict the interfingered thin layers of alluvial sediments which are laterally continuous over long distances. A distinctive zone with low cone bearing and sleeve friction measurements is present beneath the site, ranging from 4 to 24 feet thick, and is interfingered with thin layers of high cone bearing and sleeve friction, as depicted on Fig. 2. The contact between the older and younger alluvial sediments was observed in the majority of the CPTs performed at the site ranging from 30 to 53 feet beneath the existing ground surface. The contact was observed to be relatively level to slightly undulatory. Some distinct layering could be observed within the older alluvial sediment. Both the contact and the identifiable layering in the older and younger alluvial deposits do not appear to be offset by faulting.

Geophysical Data

The seismic reflection data was acquired to identify potential fault features, geologic structure, and gross stratigraphy at depth within the bedrock and the lowermost alluvial deposits. Good quality seismic reflection data can help to delineate faults and other geologic structures, where seismic reflectivity of the different layers is disrupted.

Interpretation of the geophysical survey data identified several suspected faults and other geologic features traversing the site. These features were observed to occur at depth within the bedrock materials. Four potential faults were identified from the four seismic survey lines. The buried Mission Hills Syncline was observed in Seismic Reflection Line 1, as was an erosional surface between the older alluvium and the Saugus Formation. Seismic Reflection Lines 2 and 4 showed the contact between the older alluvium and the Saugus Formation shallowing toward the east and north, respectively. The bedrock contact and three suspected faults interpreted along seismic reflection Line 2 are illustrated on Fig. 3.

Analysis

The exploratory data that was obtained along with strong-motion accelerograph records from locations in the vicinity of the school site were used to analyze the upper soils of the site for susceptibility to liquefaction and seismic settlement. The in-situ testing program and the laboratory testing program were established to provide the parameters needed for the liquefaction and seismic settlement analyses. The Cone Penetration Testing (CPT) provided classifications of soil types, estimated relative densities of materials, estimated equivalent Standard Penetration Test (SPT) blow counts, and shear wave velocities. Additionally, the shear wave velocities were measured at four of the CPT test locations using a seismic cone. Standard Penetration Tests were performed in some of the borings to estimate the in-situ relative density. From the boring samples recovered at the site, laboratory testing was performed to provide the grain size distribution of some of the soils, plasticity index, dry unit weights, and moisture contents.

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Ground shaking experienced at the site was estimated using records from nearby strong motion accelerographs that were triggered by the Northridge event (U. S. Geologic Survey, 1994, and California Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies, 1994). The Jensen Filtration Plant, located approximately ¼ mile from the Van Gogh Elementary School site, has a recording instrument owned by the Metropolitan Water District of Southern California, with the results distributed by the United States Geologic Survey. At the ground level of the Jensen Filtration Plant Generator Building, uncorrected peak ground accelerations recorded were 0.56g and 0.98g for the orthogonal horizontal components, and 0.52g for the vertical component. It is estimated that horizontal peak ground accelerations experienced at the Van Gogh Elementary School site were in the range of 0.6g to 0.9g. The digitized Arleta record of the Northridge earthquake was scaled to 0.9g and used as a surface acceleration record.

The cyclic shear strains and cyclic shear stresses in the upper soils were estimated using the computer program SHAKE91, a one-dimensional, equivalent-linear, closed-form solution dynamic analysis program (Idriss and Sun, 1992). For input, the previously described scaled Arleta record was used as a ground surface acceleration time-history. The shear wave velocities were obtained from the seismic cone CPT tests; the strain-dependent shear modulus reduction and damping curves presented in the SHAKE91 manual were used for the clays and sands of the soil profile; and the unit weights used in the analysis were determined from the laboratory testing program.

Using the cyclic shear strains and shear stresses estimated from SHAKE91, the liquefaction and seismic settlement potential of the site during the Northridge earthquake were estimated. The liquefaction potential was estimated using the liquefaction susceptibility plots of Seed and Idriss (1982). The procedures outlined by Tokimatsu and Seed (1987) were used to estimate the seismic settlement potential.

Although the water table was shallow (at a depth of approximately 16 feet to 20 feet across the site), the upper soils consist predominantly of fine-grained materials including silts and clays. For the most part, the sands also have a significant fines content. Based upon the in-situ testing performed on the site, the density of the sandy materials is relatively high, with values of relative density predominantly above 80%, and in combination with the fines content of the sands, would preclude the occurrence of significant liquefaction for any level of ground shaking that might be expected. Therefore, it is considered that liquefaction of the site is not a significant contributing factor to the cracking that occurred on the site during the Northridge earthquake. This conclusion is supported by the lack of any features that might be attributed to liquefaction, except for the surface cracking of the site.

Given the stiffness of the site as estimated from the shear wave velocities, moderate shear strains occurred in the sandy materials of the site during the Northridge event. However, given the high relative densities of the sandy materials and the small-layer thickness, negligibly small volumetric strains occurred on the site. Therefore, seismic settlement of the site is not considered a significant contributing factor to the cracking as a result of the Northridge event.

CONCLUSIONS

The use of multiple data sources has provided a means to evaluate the potential for various adverse geologic and soil conditions. All of the data sources used simultaneously provided detailed information about both the shallow and deep subsurface conditions at the school site. Furthermore, the subsurface information, in conjunction with ground motion data and laboratory test results, provide the necessary data for soils analysis to determine the liquefaction and seismic settlement susceptibility of the upper soils at the school site.

The interpretation of the geophysical data identified several suspected faults and other geologic features at depth within the bedrock materials. However, the correlation of the closely spaced CPTs and borings showed a thorough detail of the subsurface stratigraphy, which did not identify these suspected faults within the Holocene age alluvial deposits, nor did the contact between the Holocene and Pleistocene alluvial deposits appear to be faulted. The ground cracks observed during the mapping were not observed to extend downward into the alluvial soil.

Based on the results of the investigation, the cause of the surface cracking and damage at the school site was determined to be the result of a combination of the effects of tectonic uplift and deformation (regional folding) and secondary ground displacement at or near the ground surface due to earthquake shaking.

The evidence from the global positioning satellites in the area indicates that up to 40 centimeters of uplift occurred in the vicinity of the site. Previous geologic mapping and the results of the investigation indicate significant faulting and faulting at depth and lesser amounts of deformation of the surficial sediments.

Detailed analyses performed using the results from the in-situ and laboratory testing have determined that the upper soils beneath the site were not subject to liquefaction or seismic settlement due to volumetric change of the soils. Liquefaction or seismic settlement was not determined to be a significant contributing cause to the damage at the school site.

The faults identified in the geophysical data, by definition, would be potentially active only because the Pleistocene age older alluvial materials are apparently displaced. Based on this
information, the potential for primary surface fault rupture at
the site is judged to be low and primary surface fault rupture is
not considered to be a contributing cause to the damage at the
Van Gogh Elementary School.

The preexisting cracks and deep faults beneath the site could
act as planes of weakness. During very strong shaking, the
materials on either side of the zones would tend to move
independently, resulting in differential movements and
displacements. Prior investigations at the site have also
identified renewed movement along preexisting surface
creacks. Secondary movement of preexisting zones of
weakness may also contributed significantly to the ground
movement observed at the school site.

Potential for Future Surface Cracking

It is evident that similar surface cracking occurred at the site
as a result of the 1971 San Fernando earthquake and,
according to Fugro (1971), evidence of ground cracking prior
to the 1971 earthquake was observed. Therefore, there is a
significant potential for continued and similar ground cracking
to occur in the future. The average period between these
occurrences could be on the order of 20 to 30 years, to several
hundred years.

Based on the available data and certain assumptions made
during this investigation, some inferences can be made
regarding the magnitude of displacement of future ground
ruptures. Historically, large-magnitude ground ruptures
(displacements of several inches to more than 10 feet) have
been the result of primary surface fault rupture, liquefaction,
and to a lesser degree seismic settlement; however, the
damage at the Van Gogh Elementary School is not related to
these geologic hazards, which provides some evidence that
large displacements are unlikely. Most of the ground cracks
that have been documented are generally very minor (less than
¾ to ½ inch of actual displacement) with only a few cracks in
the area with displacement of 1 to 2 inches. No large
displacements were observed as a result of either the 1994 or
1971 earthquakes.

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Fig. 1  Site plan explorations and ground cracks with respect to building location.
Fig. 2  Portion of CPT Correlation Line 1. Stratigraphy is based on both boring and Cone Penetration Test data.

Fig. 3  Seismic Reflection Line 2 showing bedrock/alluvium contact and suspected faults.