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DAMAGE FROM COLLAPSED BACKFILL ROCK AND SOILS BEHIND RETAINING WALLS CAUSED BY EARTHQUAKE SHAKING

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ABSTRACT

The 17 January 1994 Northridge Earthquake caused extensive damage to thousands of buildings and condominiums throughout the San Fernando Valley. Not only to the buildings' structure, but also to the foundations and subdrain systems. This author investigated and documented hundreds of cases where condominium units experienced similar symptoms of damage resulting from collapsed backfill rock and soils from the earthquake forces.

A typical condominium building investigated was of three story construction with an 8 to 10 foot high retaining wall on three sides of the 4 to 10 unit building to contain the garages and utility rooms. Some building slabs and other ancillary features, ie. patios, wing walls,decks, steps, walks were constructed directly over the backfill rock and soil. The earthquake shaking especially the vertical acceleration caused the backfill behind the retaining walls to collapse as much as eight inches resulting in failure not only to the retaining walls and surface features, but also to the underlying subdrain pipes behind the building's retaining wall.

Detailed subsurface investigations found in almost every case collapsed backfill rock and cracked, crushed or deformed perforated and solid PVC drain pipes. Other investigations suggested that the crushed pipes were caused by improper installation during original construction. This author conduced lab testing and full scale field testing to demonstrate that the resulting failures were caused by the earthquake shaking and not installation. These failures resulted in millions of dollars in insurance claims and reconstruction of retaining wall backfills and reinstallation of subdrains.

INTRODUCTION

The majority of the over 400 condominiums investigated were constructed as a three story 4 to 10 unit building with an eight to ten foot high retaining wall on three sides of each building to contain the first level garages and utility rooms. The upper two levels of the main frame of the buildings were built on top of the retaining wall. Slabs on grade at some units were constructed at the second level on fill soils and crushed rock backfill behind the retaining wall. The slabs on grade were attached to the tops of the retaining wall with steel reinforced concrete.

The findings and observations will conclude that the retaining wall backfill gravel and fill soils collapsed due to the violent earthquake shaking by as much as six to eight inches. This is evidenced by:

1. Visual inspection of voids in the retaining wall backfill under stoops, chimney footings, garden walls and especially the building's wing walls which were attached to the CMU retaining wall.
2. Cracking of slab on grade footings and tilting of slabs above the retaining wall backfill.
3. Laboratory testing of backfill rock samples.

The result of the gravel backfill collapse is a loss of foundation bearing support for the wing walls, chimney foundations, garden walls, stoops, patios or stucco at the connection between the appendage and the main frame of the building of those buildings investigated which suffered moderate to major damage.

The slabs on grade were only for conversation pits and extended living rooms. However it was noted during our visual inspection that many of the slabs on grade above the gravel backfill did have cracked footings at the point of attachment to the top of retaining wall and it was noted that the floor surfaces were tilting. It was observed in may cases that following the earthquake, water started leaking through the retaining walls near the bottom where subdrain pipes for the retaining wall were placed.

FIELD INVESTIGATION, LAB TESTING AND OBSERVATIONS

Dozens of test pits were dug for observation of subsurface conditions. Most of these test pits were dug behind the garage rėtaining wall through the gravel and soil backfill down to a depth encountering the perforated PVC drain pipe. The upper 1½ to 2½ feet was a silty clayey soil which was moist and loose to medium stiff. Underlying the soil layer was a gravel backfill to the full depth of the test pit which was the top of the retaining wall footing for a gravel depth of 5 to 7 feet. The gravel was a ½ to 1½ inch crushed rock, relatively clean and extending back from the retaining wall 2 to 5 feet.

At the bottom of the trench perforated drain pipe was encountered and exposed for horizontal distances of four to six feet. The drain pipe encountered in most cases was Hancor 4 inch perforated pipe with an ASTM designation D3350. At most test pit locations the PVC pipe was split and/or crushed. It was also observed that the installed pipe was directly on the retaining wall footing concrete or one or two inches above it and next to the retaining wall or one to three inches from it.

During the test pit inspections, large bag samples of the gravel backfill were retrieved and sent to the laboratory for testing. The test performed was a gravel consolidation test using vibratory equipment to simulate the earthquake. A description to the equipment used and the procedure follows.

- Vibrating equipment used in this procedure is similar to the unit in the sieve analysis ASTM D422 test. The unit must be allowed sufficient motion to simulate an earthquake. This particular procedure is estimated to simulate a 5.5 to 6.0 g earthquake. The unit was suspended from a ceiling beam and attached to very heavy duty elastic bands held in place with "C" clamps attached to a heavy table.

- The 5.5 inch diameter by 12 inch tall, metal cylinder was filled with sample gravel material. The filled cylinder was placed on a level plate and weights were placed on top of the gravel and held in place with heavy elastic straps. The equipment was allowed to vibrate for 30 seconds. The amount of settlement was measured in six areas around the cylinder. Numerous tests were performed using this method to obtain an average. The gravel material used in the test was remixed with the remaining material from the bag sample after each test and the cylinder refilled.

In general the testing showed an average consolidation of 1.108 inches for a test column height of 9.75 inches or 11.4% settlement, which translated to about eight inches of settlement for a six foot depth of gravel, which was the average depth encountered in the test pits.

FULL SCALE FIELD TESTING

It was concluded by other investigators that the damaged PVC drain pipe was crushed "due to improper installation" and "occurred during the backfilling process." Based on our observation of the collapsed stoops, walks, fences, patios, etc., the laboratory consolidation of the rock under simulated earthquake conditions, and the fact that at all locations inspected the PVC pipe was split or crushed, we set out to determine if the pipe could be improperly installed and crushed during backfill. A test trench was dug to a depth of six feet and

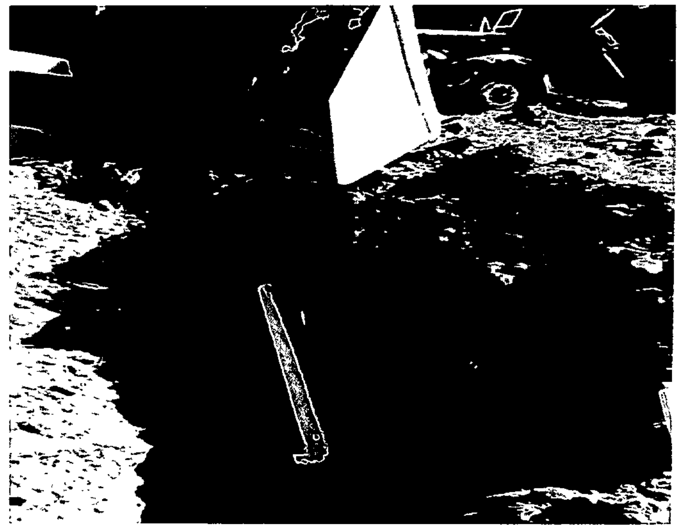

Fig. 1– Test Trench with PVC Pipe & CMU Wall Portion

a footing and bottom portion of the CMU retaining wall installed (Fig. 1). The concrete for the top of footing was left in a rough finish condition. The footing was stepped so that the installed PVC pipe would rest directly on the rough concrete, and on 1½ inches of crushed rock, and on 4 inches of crushed rock. The installed PVC pipe was also angled so that the end of

Fig. 2 – Crushed Rock Dumped into Test Trench

the pipe that was on bare concrete was next to the retaining wall and the end on 4 inches of crushed rock was 4 inches from the retaining wall.

Crushed rock was than dumped directly on the pipe from a height of up to ten feet with a half yard bucket and brought to a level of three to four foot above the pipe. A 10 ton tractor was then used to compact the gravel at the three to four foot level and to bring the gravel up to the six to seven foot level (Fig. 2).

The gravel backfill was left for over one week, and saturated with water. The gravel was then removed with the 10 ton tractor down to the two to three foot level above the PVC pipe and down to the one to two foot level above the PVC pipe with a 3 ton tractor. (Fig. 3). At all time the right set of wheels of the two tractors were running directly over the drain pipe and the buckets were fully loaded with gravel. The PVC pipe was then carefully removed and examined for cracking or crushing. No visible damage could be found to either of the two drain pipes, in two separate tests.

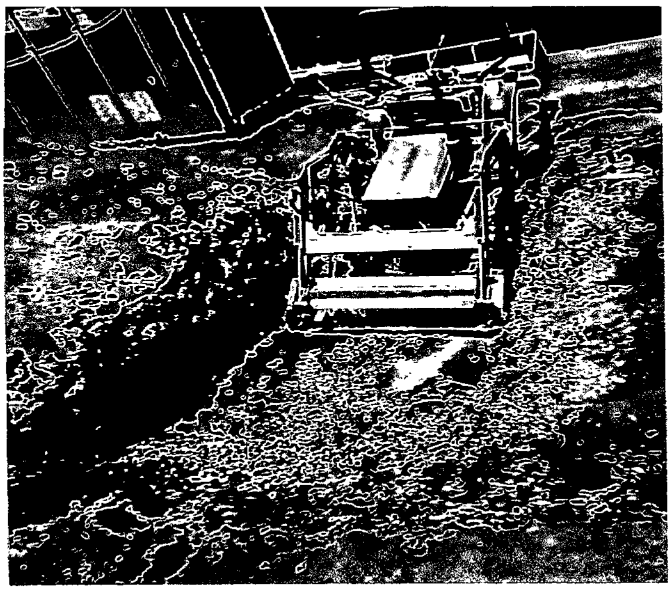

Fig. 3 – Removal of Gravel by 3 Ton Tractor

A section of PVC pipe was then placed directly on asphalt and run over with the 3 ton tractor (Fig. 4). The pipe pushed out of round, but was not crushed or split. The pipes were then cut in half and further examined for internal cracking, but none could be found.

FINDINGS AND CONCLUSIONS

Based upon our visual observations it is obvious that the Northridge Earthquake of 17 January 1994, caused extensive damage to the property improvements overlying the retaining wall backfill. Major damage has occurred at nearly every unit to either stoops, walks, fences, garden walls, slabs on grade, patios, wing walls, chimney foundations or building stucco. Since the majority of this distress and damage that was observed was not existing before the earthquake, it is easily concluded that the earthquake caused the damage.

The question then arises, what did the earthquake do to cause the damage? The violent shaking of the earthquake caused the

Fig. 4 – PVC Pipe Being Run Over by Tractor

retaining wall backfill to collapse. This is clearly demonstrated by the observed voids between the bottom of foundations for the appended wing wall, chimney foundation, garden wall, etc. and the laboratory testing of gravel samples. What remains unresolved is how did the retaining wall PVC drain pipe rupture in most cases explored? It is this engineer's professional opinion that the PVC drain pipes split, flattened and crushed under the dynamically increased weight of the overlying crushed rock, fill soils and concrete as a result of the vertical acceleration of the earthquake. It has been further demonstrated by this author that improper construction installation could not rupture the pipe. Since no other known subsurface conditions changed between completion of installation and the 17 January 1994 earthquake, it remains that the cause of pipe failure was the earthquake.