RESEARCH PAYS OFF

New Blasting Technique in Washington State Saves Money and Time

Washington State Department of Transportation

On May 18, 1980, a catastrophic earthquake induced a landslide, debris avalanche, and the associated volcanic eruption of Mount St. Helens. These events resulted in 57 deaths, devastated 570 km^2 (220 mi^2) of timberland, and destroyed 9 bridges and 48 km (30 mi) of Washington State Route 504. Most of the avalanche was deflected westward down the North Fork Toutle River valley by the east-west trending Johnston Ridge. A portion of the debris flowed over this ridge and westward through the South Coldwater Creek drainage, depositing as much as 50 m (164 ft) of debris on the valley floor.

In August 1982 the U.S. Congress established Mount St. Helens National Volcanic Monument. SR 504 was intended to provide the primary access to the monument. The project prospectus for the reconstruction of SR 504 issued in spring 1985 included 40 km (24.9 mi) of new alignment on the mountainous north side of the North Fork Toutle River valley. In 1989 an additional 10.6 km (6.6 mi) was approved to extend the project eastward, the alignment of which is shown in Figure 1.

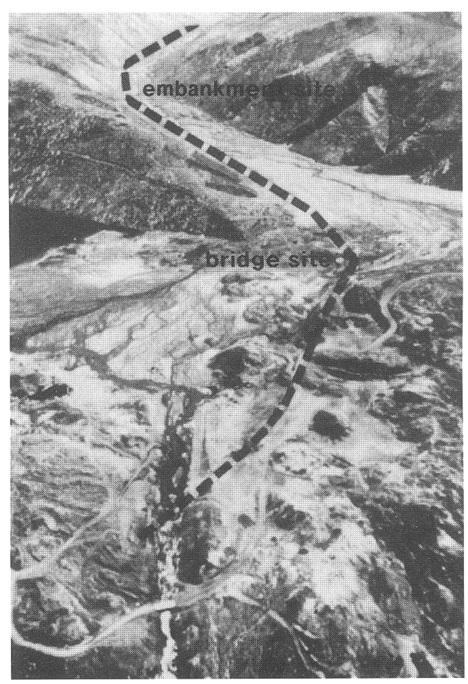
Problem

Since 1986 the Washington State Department of Transportation (WSDOT) has been coordinating the design and construction of the new highway. In 1990 design began on the last phase of the project, where the highway alignment runs over debris avalanche deposits 50 m thick. This portion of the alignment is located within the active Mount St. Helens Seismic Zone, which is estimated to be capable of producing earthquakes of 6.2 to 6.8 magnitude on the Richter scale and associated high ground accelerations (ground acceleraton is the rate of change of the ground velocity as an earthquake wave passes by). These anticipated ground accelerations posed a difficult design problem for the South Coldwater Creek Bridge sited in the loose, saturated debris avalanche deposits. The concern was the potential for liquefaction or dynamic settlement of the foundation soils. Liquefaction is an extreme loss of soil strength because of the rapid buildup of water pressures in the soil pores. The loose, saturated, noncohesive soils at the site are highly susceptible to liquefaction. With depth the liquefaction potential diminishes, but dynamic settlement still could occur. The effects of both these phenomena could include loss of foundation support, lateral spreading, and ground settlement.

Solution

WSDOT considered several options to mitigate the potential for seismically induced liquefaction and dynamic settlement at the bridge site. One of these options was to construct shallow spread footings for the bridge. These footings would be founded on ground modified to depths of 10 to 15 m (33 to 49 ft), which would increase the soil's bearing capacity and reduce the potential for liquefaction and dynamic settlement near the surface. However, the condition of the lower 15 to 30 m (49 to 98 ft) of the avalanche deposit still raised concerns about deep liquefaction and dynamic settlement.

Several techniques were considered to improve the density and strength of the



WSDOT

FIGURE 1 Alignment of SR 504 showing location of bridge and pavement section where blast densification was used.

deposit and still allow for use of cost-effective shallow spread footings: blast densification, vibrocompaction, vibroreplacement (stone columns), deep soil mixing, jet or compaction grouting, and deep dynamic compaction. Deep dynamic compaction was eliminated because of its limited effectiveness in saturated soils and because soil improvement typically occurs to a maximum depth of less than 15 m. Blast densification was selected because the presence of boulders and large wood debris in the deposit posed high risks of damaging the equipment used for the other techniques. The cost of blast densification was also approximately half that of the other options.

Blast densification uses explosives detonated in boreholes to densify loose, saturated soils. The blast energy induces high pore water pressures that liquefy the soil mass. During and after dissipation of these pressures, soil particles are rearranged into a denser configuration. Significant ground settlement and surface discharge of groundwater typically occur immediately after blasting (Figure 2). Ground settlement and densification of the soil mass continue over a period of several weeks in a little-understood phenomenon referred to as "aging."

Because blast densification had not previously been used on a highway project in the United States, the Federal Highway Administration directly funded it as an experimental project. The contract did not specify densification or acceptance criteria, but it was acknowledged that certain benchmarks needed to be achieved to ensure the mitigation of potential settlement and liquefaction. Two benchmark parameters were set: in situ density of soil, measured with the Standard Penetration Test, and ground settlement on the order of 1.5 to 3 m (4.9 to 9.8 ft) in the treated areas.

Instruments were installed to measure surface and subsurface ground displacements, changes in pore water pressures, and ground accelerations induced by the blasting. A test section was treated first. The contract allowed one week for evaluating the results of blasting and sixteen weeks for evaluating aging effects.

Comparison of pre- and post-blasting data clearly indicated that the required degree of densification had occurred to the needed depth. Blast densification also allowed the use of a relatively inexpensive spread-footing foundation for the bridge. This ground improvement technique proved to be highly cost-effective and expedient for ground improvement.

Applications

During the early construction phase of the approved 10.6-km extension of SR 504, partially loaded scrapers hauling over an area near the bridge site initiated unusual ground failure. General observation and drilling indicated that the soil mass had liquefied to a depth of 10 to 12 m (30 to 40 ft) and the soil was also much less dense than before. Further investigation revealed that similar density losses had occurred for a length of 550 m (1,804 ft) along the alignment. Embankments to 15 m in height were planned for this area. The only two feasible actions to improve the foundation condition for the embankment were vibroreplacement or blast densification. The urgency of remediating the soil condition, the potential for construction cost savings, and the experience gained at the bridge site with similar soils led the project team to combine blast densification with realignment to minimize the embankment footprint. An area of approximately 9800 m^2 (11,720 yd^2) with an average depth of 12 m was treated within 30 days.

Benefits

Using blast densification at the bridge site instead of vibroreplacement, the next least expensive method, yielded a cost savings of approximately $300,000, or 50 percent. Experience gained at the bridge site was successfully applied to a section of roadway on the same project. The problems of foundation soil liquefaction and settlement were mitigated at both sites. At the roadway site an estimated cost savings of $881,000 was realized over the use of vibroreplacement. The potential delay costs were estimated to be in the millions of dollars if blast densification had not been used. The construction cost ranged from $2.50 per m^3 (1.3 yd^3) of treated soil at the bridge site to $3.20 per m^3 for the roadway site.

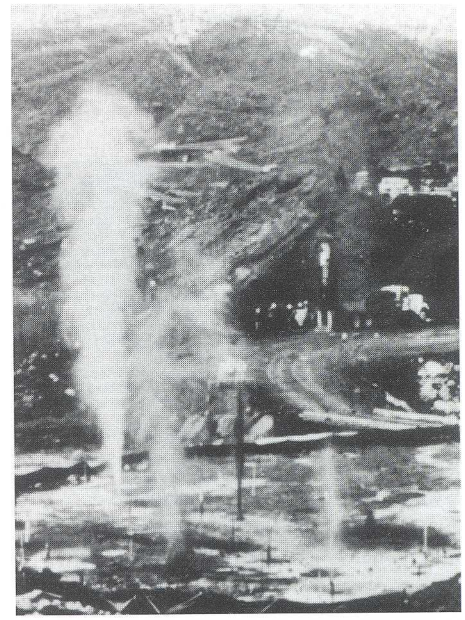


FIGURE 2 Dewatering of saturated cohesionless soils by eruption of silty water after blasting.

The SR 504 project established the feasibility and cost-effectiveness of blast densification of appropriate materials in nonurban areas away from structures that are sensitive to ground motions. Blast densification is now considered a viable ground improvement option for other highway projects in Washington State.

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Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-2952).