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Design of Road Cut Adjacent to Existing Structure

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SYNOPSIS Interchange improvements within an urban environment required the deepening of a hillside cut. Design restraints required as deep a cut as possible without disburbing a water tower located at the crest of the slope or interfering with a shopping center at the toe. The water tower, constructed in 1933 with a steel tank encased in a concrete and brick structure, was founded on shallow spread footings. Foundation soils were silts and silty sands with seams of silty clay. The design investigation involved hydrogeologic studies, SPT borings, undisturbed sampling, laboratory testing, and stability analyses. Laboratory studies involved routine and unusual testing procedures to evaluate deformation potential upon drying. Results of the investigation allowed the deepening of the cut some 20 feet using conventional construction techniques. This paper details the geotechnical investigation, laboratory testing, analysis procedure, construction monitoring, and project results.

INITIAL CONDITIONS

In 1976 the Wisconsin Department of Transportation initiated an improvement project for the interchange between S.T.H. 23 and Taylor Boulevard within the City of Sheboygan, Wisconsin. The existing at-grade crossing was becoming one of the cities busiest with Taylor Boulevard providing the only access to a large shopping center complex. Proposed plans called for both a lowering of Taylor Boulevard and a raising of S.T.H. 23 grades to provide a grade separation. Alignment of both roads was to be essentially unchanged, with access to S.T.H. 23 provided by new interchange ramps. To achieve adequate clearances required that Taylor Boulevard be lowered some 20 to 25 feet. The deepest part of the cut was to be adjacent to an existing elevated water storage reservoir.

The reservoir, known locally as the Taylor Park Water Reservoir, was constructed in 1933, and is shown in Figure 1. The water tower stands some 60 feet above ground level, and is located at the highest point in Sheboygan County. Thus, it provides pressure control for the entire city water system. The 185 foot diameter reservoir consists of a 4 million gallon steel tank within a reinforced concrete and brick structure. Foundation for the structure consisted of 80 individual spread footings at depths ranging from 4 to 8 feet below ground surface for perimeter and interior footings respectively.

A shopping center, located across Taylor Boulevard directly west of the water tower provided an additional design restraint. A considerable cut had been made adjacent to Taylor Boulevard to permit construction of this complex. A reinforced concrete retaining wall had also been constructed to allow an auto service store within the complex to be located closer to Taylor Boulevard. The existing cut and retaining wall are shown in Figure 2.

Fig. 1. Taylor Park Water Reservoir

Fig. 2. Existing Taylor Boulevard Cut

INVESTIGATION

A geotechnical investigation was conducted to evaluate the effects of the proposed cut on the existing water tower. This investigation included a review of hydrologic and geologic literature, a field investigation and sampling program, and laboratory testing.

Preliminary Investigation

The geotechnical investigation began with an on-site reconnaissance and an office review of available U.S. Geologic Survey Reports, geologic maps, and well drilling logs in the area. Results of this initial investigation indicated that soils in the area were likely to be stratified silts, clays, and fine sands. Geologically the soils were classified as being lacustrine sediments accumulated from glacial melt water and deposited into a glacial lake basin on the ice. Final glacial melting resulted in a subsequent deposition creating the high domed land surface that now exists. The site reconnaissance revealed some cracking in the reinforced concrete support pedestals of the water tower and obvious signs of distress in the shopping center retaining wall. The retaining wall face was cracked and tilted outward, while soils behind the wall appeared to be sloughing, as seen in Figure 2. The retaining wall had weep holes, which did drain water in the Spring of the year. Ground water seepage was also observed in a side hill cut for a city street approximately 800 feet south of the reservoir.

Field Investigation

Results of the preliminary subsurface investigation indicated that a rather extensive subsurface investigation was warranted. Nine exploratory borings were made over the site, as shown in Figure 3. Continuous Standard Penetration Tests, ASTM D 1986, were made to delineate soil layers, obtain representative soil samples, and provide indications of relative density and soil strength parameters. Large diameter split-spoon and 3 inch diameter Shelby Tube samples were also taken to provide relatively undisturbed samples for laboratory testing.

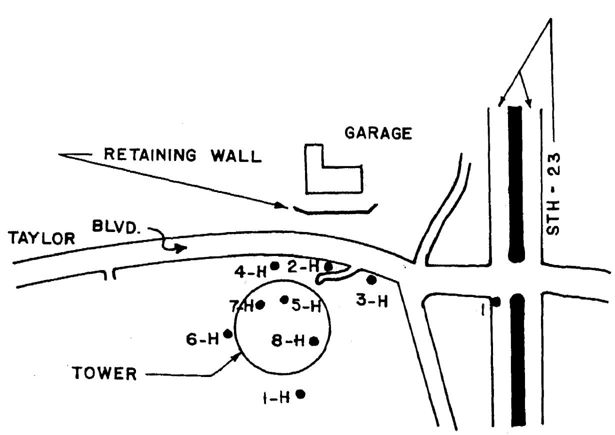

Fig. 3. Boring Location Plan

Soils encountered were predominately silts, with varying amounts of fine sand. Seams of silty sand, sandy silt, and silty clay were also logged in every boring. Standard Penetration Tests (SPT) results were quite variable, with N-values ranging from 4 to as high as 90 blows per foot recorded. The majority of the SPT N-values, however, fell within a range of 5 to 25, with an average value of 15.

Upon completion of the borings, with the exception of boring 7H, perforated downspout was placed in the bore holes to provide cased water observation wells. Water readings made over several weeks showed the water table under the water tower to be at a depth of approximately 25 feet, or elevation 710. The ground water surface then dropped towards the shopping center cut. While no observation wells were installed on the shopping center side of Taylor Boulevard, the water table was assumed to continue dropping to at least the retaining wall weep hole elevation of 695$\pm$.

Laboratory Investigation

In addition to the field investigation, a supplemental laboratory investigation was conducted to determine soil shear strengths and ascertain shrinkage potential of the foundation soils. Natural moisture contents were determined on virtually every SPT sample taken. In addition, classification tests consisting of gradation, liquid limit, and free swell were performed on representative samples. Shear strength testing was limited to direct shear tests, while shrinkage tests included shrinkage limit, linear shrinkage, and shrinkage under load.

Classification Tests

Natural moisture contents were quite variable, as was expected with the stratified soils. Moisture contents above the observed ground water level were somewhat dryer with an average moisture content of 12.5%, while below the average was found to be 19.2%. Mechanical analysis results indicated that the majority of the soils contained high percentages of silt and fine sand, with very low percentages of clay. These soils also had very low free swell results, generally less than 25%, and were classified as being SM and ML by the Unified Classification System. Exceptions to this were the seams and layers identified on the field boring logs as being silty clay. Test results of these soils showed from 20% to 30% passing the 2 micron size with a Liquid Limit of approximately 20 and a Plastic Index of 5. These soils were classified as CL and free swell results ranging from 35 to 50%.

Direct Shear Tests

To assess soil strength properties, direct shear tests were run on two undisturbed Shelby Tube samples. Test results are shown in Table I.

Table I

Soil Type	ϕ	c (psf)
SM	37^{o}	0
ML	$37\frac{1}{2}^{o}$	190

Shrinkage Limit Tests

Shrinkage Limit determinations were made on several representative samples. Test results showed a minimal volume change during the test, with volumetric shrinkage ranging from 0.5% to 4.2%. Typical results are shown in Figure 4. Reliability of the results from this test were questioned, though, due to the difficulty in accurately measuring the volume change of the largely sandy material. Also, the procedure for this test calls for taking remolded soil wetter than actual field conditions and oven drying them to moisture contents far below that which would be expected in the field. Thus it was felt that these results represented the most conservative approach.

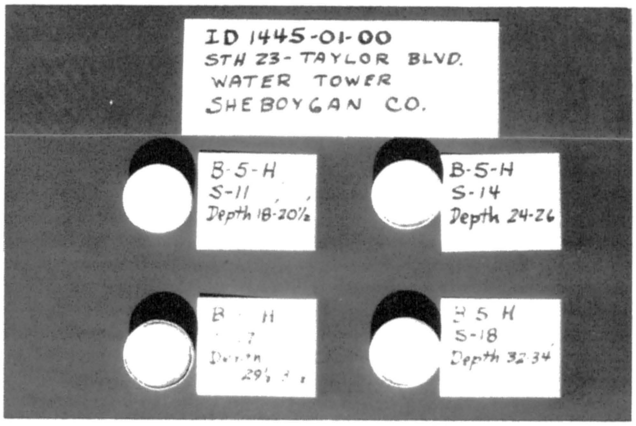

Fig. 4. Shrinkage Limit Test Specimens

Linear Shrinkage

Recognizing that volume change measurements are affected by molding moisture and density conditions, Linear Shrinkage tests were run to more nearly duplicate field conditions. Soil samples obtained from the large diameter split spoon and Shelby Tubes were carved to exactly fit in bar molds. Thus the samples were near their insitu moisture content and density at the start of the test. The bar molds used were Autoclave Expansion Molds for measuring length change of hardened cement paste. These molds had an overall length of 6.25 inches with a width and height of 1 inch. Mold sides were lubricated with petroleum jelly, and the soils oven dried. Results of this test showed negligible shrinkage, with the highest measured lineal shrinkage being 1.6% for the silty clay. Test specimens are shown in Figure 5. As with the Shrinkage Limit Test, this test was also felt to yield conservative results as the soil samples were dried to moisture contents well below actual field conditions.

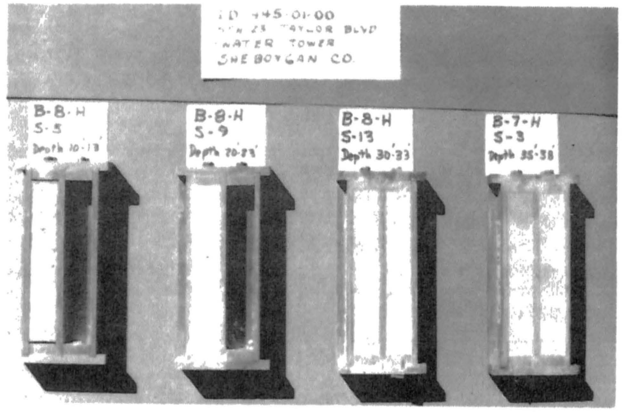

Fig. 5. Linear Shrinkage Test Specimens

Shrinkage Under Load

To assess the settlement potential of the foundation soils under actual field loadings, samples were placed in conventional consolidation testing equipment. One-dimensional shrinkage was measured by placing a constant load, equal to the estimated overburden stress, and drying the specimen. Drying was accomplished by surrounding the consolidation ring with calcium chloride pellets. Figure 6 shows the test equipment. Conventional consolidation tests were also run on companion samples to determine the amount of settlement that would occur at this same location.

Fig. 6. Consolidation Under Load

These test results again showed very minimal shrinkage amounts, with percent of vertical shrinkage ranging from 0.56% to 2.81%. The largest measured percent of shrinkage again was noted in the silty clay soils. These results were also felt to be conservative, as the soils were dried to moisture contents similar to those achieved by oven drying, and equipment deformations and "seating load" settlements were also added into the total percent shrinkage calculations. When settlements measured with the conventional test are subtracted from the drying test measurements, almost negligible amounts of shrinkage are obtained.

ANALYSIS

During preliminary hearings for the project the city expressed extreme concern over potential damage to the elevated water reservoir. Early engineering assessments by their geotechnical representatives indicated that the only feasible alternatives were limited to slurry trench type retaining wall construction, underpinning of existing footings, or relocation of the entire facility. It was the latter option that the city and their consultants felt the most comfortable with, and preferred. This geotechnical analysis was undertaken to evaluate other possible alternatives which would be economically feasible while minimizing risk to the structure. Based upon results of the field and laboratory investigations, it was felt that either a conventional earth cut slope or earth retaining structure could be utilized. The design analysis focused upon the problems of normal cut slope stability and soil subsidence from desiccation and increased effective stress caused by a lowering of the water table due to water bleeding from the cut slope.

Slope Stability

The stability of various cut slopes and crest locations were analyzed using a computerized slope stability program. The program assumes a circular failure surface and utilizes Bishop's Symplified Method. Soil shear strength properties were selected as $\phi = 30^{\circ}$ and c = 0, based upon direct shear test results and SPT values. Loadings from the water tower foundations were treated as a uniform surcharge loading of 350 psf.

Existing grade line of Taylor Boulevard adjacent to the water tower was at elevation 720. Interchange design plans required a maximum new elevation of 700, with a preferred elevation of 695. With the severity of potential problems, it was recommended to lower the grade only as much as was absolutely necessary. Horizontal alignment was also critical, with the water tower and shopping center garage directly across from one another. Slopes flatter than a $1\frac{1}{2}$:1 required either an earth retaining structure or placing the crest of the cut slope dangerously close to the water tower footings. Consideration of bearing capacity dictated that the slope crest be placed no closer than 10 feet to the tower's nearest perimeter footing. Numerous combinations of side slopes and retaining wall heights were evaluated, along the variations in shear strength parameters. Stability analysis results indicated safety factors of 1.06 for a $1\frac{1}{2}$:1 slope and 1.25 for a 2:1 slope. Based upon this analysis, it was recommended that cut slopes for the project be no steeper than a 2 horizontal to 1 vertical. The calculated 1.25 factor of safety for the 2:1 cut slope was somewhat lower than usually desired. It was felt, however, that this was an acceptable value based upon the relatively conservative analysis, confidence level of the soil strength parameters, and that careful construction monitoring would be utilized.

Use of the relatively steep 2:1 cut slope still required the use of a retaining wall. Roadway designers preferred a wall location on the water tower side of Taylor Boulevard. Stability analysis results indicated that a temporary earth retention system would be required to construct the wall in this location. With the high cost of such a system, and the potential for ground loss during construction, it was recommended that the wall be placed on the shopping center side of the roadway.

Soil Subsidence

Ground water measurements from the observation wells indicated that the water table dropped from approximately elevation 710 under the water tower to elevation 695 at the weep holes of the existing retaining wall. With the proposed 2:1 cut slope and grade line elevation of 710, it was concluded that the ground water level near the water reservoir would not be significantly changed. Figure 7 shows a plot of the assumed water table in relation to the proposed cut.

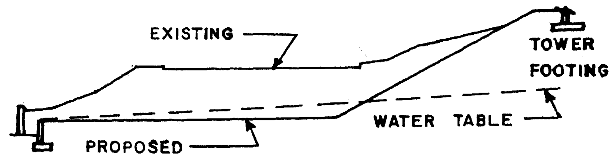

Fig. 7. Estimated Water Table Location

Laboratory test results indicated that soil shrinkage was not likely to occur even should a lowering of the water table occur. Though the shrinkage tests conducted were of a qualitative nature, the test results conclusively demonstrated that the foundation soils were stable and unlikely to undergo detrimental volume changes due to reduction in moisture content.

DESIGN AND CONSTRUCTION

Final design plans utilized the recommended 2:1 cut slope with a new retaining wall near the auto service building as shown in Figure 8. A perforated pipe underdrain was also to be placed along the roadway curbline adjacent to the cut slope approximately 2 feet below grade, to assist in removing water from the Taylor Boulevard subgrade. To ensure that the water reservoir was not damaged an instrumentation and measurement program was recommended.

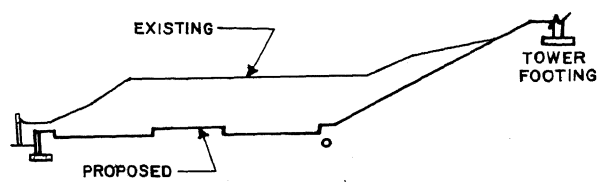

Fig. 8. Final Design Plans

Construction Monitoring

As a documentation measure, a preconstruction crack survey of the elevated reservoir structure was conducted jointly with WisDOT personnel and the city. Horizontal and vertical ground movements were measured during and after construction to determine if objectionable movements were beginning to occur so that remedial measures could be initiated. Horizontal ground movements were monitored with a slope inclinometer located between the slope crest and the closest exterior tower footing. In addition to these measurements, offset measurements from a fixed reference line were also made to detect any horizontal movement along the slope crest. Structure settlements were monitored by optical survey techniques using reference markers established on several of the towers support columns. Settlement of the ground surface was measured by elevation readings on stakes driven into the ground. Observation wells set under the tower during the field investigation also remained in place during construction. Montoring of the inclinometer, settlement points, and water wells was done frequently during construction operations by WisDOT personnel. Monitoring of structure settlements was also done by the city's engineering consultant using an independently established reference system.

Construction Operations

Project construction began in the spring of 1979, and was completed in the fall of the same year. During construction, problems developed with the excavation procedures. Ground water in the cut area was much higher than expected from the field investigation and analysis. Earth moving equipment continually became mired down in the wet silts and silty sands, as is demonstrated in Figure 9. Much of the cut was finally excavated with a dragline and bucket operation. After reaching final grade and installing the edgeline underdrain the roadway subgrade dried to the point that the roadway construction could proceed. Areas of the cut slope, however, continued to seep water causing surface sloughing. Additional pipe underdrain was placed laterally into these areas and allowed to drain into the edgeline underdrain. This stabilized the slope to the point where topsoil could be placed.

Fig. 9. Construction Excavation Problems

PERFORMANCE

Horizontal ground movements, structure settlements, and ground water levels were measured during construction and for a two year period after project completion. Results of these measurements showed that no measureable structure settlement or horizontal ground movement had occurred. This was also substantiated with studies made by the city's consultant. A cursory inspection of the reservoir structure also indicated that the structural cracking observed in the preconstruction survey had not worsened. Water level readings made over this same period showed that the water table in the area of the water tower had dropped approximately 5 feet, with no adverse effects on the structure from desiccation. The pipe underdrains placed along the curbline and into the cut slope stabilized the subgrade and slope so that both the pavement and backslope have performed satisfactorily. While instrumentation monitoring was terminated at the end of 1981, some 2 years after project completion, the instrumentation has remained in place for additional readings if needed. The cut has been continued to be observed, however, with no visual signs of problems, as shown in Figure 10.

Fig. 10. Completed Excavation

The undertaking of this geotechnical investigation, using some non-conventional techniques, resulted in construction alternatives which provided a considerable cost savings, a workable construction procedure, and a safe functional end product.