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Water-Level, Velocity, and Dye Measurements in the Chicago Tunnels

by

K. A. Oberg and A. R. Schmidt[1]

Abstract

On April 13, 1992, a section of a 100-year-old underground freight tunnel in downtown Chicago, Illinois, was breached where the tunnel crosses under the Chicago River, about 15 meters below land surface. The breach allowed water from the Chicago River to flow into the freight tunnels and into buildings connected to the tunnels. As a result, utility services to more than 100 buildings in downtown Chicago were lost, several hundred thousand workers were sent home, and the entire subway system and a major expressway in the Loop were shut down. The breach in the tunnel was sealed and the tunnel dewatered by the U.S. Army Corps of Engineers (Corps) and its contractors. The U.S. Geological Survey (USGS) assisted the Corps in their efforts to plug and dewater the freight tunnels and connected buildings. This assistance included the installation and operation of telemetered gages for monitoring water levels in the tunnel system and velocity measurements made in the vicinity of the tunnel breach. A fluorescent dye tracer was used to check for leaks in the plugs, which isolated the damaged portion of the Chicago freight tunnel from the remainder of the tunnel system.

Introduction

A network of tunnels more than 80 kilometers (km) long were constructed beneath the part of downtown Chicago known as the Loop from 1899 to 1909. The purpose of the tunnel system was to haul freight between buildings in the Loop in order to reduce traffic on the streets above (Moffat, 1982). Miniature electric locomotives running on narrow-gauge rail were used to transport goods to and from Loop buildings. Rail cars could be brought to the surface by means of elevators for the purpose of loading or unloading. Several additions to the tunnel system were constructed from 1909 to 1915 and portions of the tunnel were removed during construction of the Loop subway from 1940 to 1959. The total length of the tunnel system varied from 95.1 km in 1916 to 75.9 km in 1959.

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[1]Hydrologists, U.S. Geological Survey, 102 E. Main Street, 4th Floor Urbana, IL 61801

The system was an outstanding engineering accomplishment in its day, costing approximately $30 million to construct (Chicago Tunnel Terminal Corporation, 1928). The tunnel was hand-excavated and lined by dry-packing unreinforced concrete, 0.3 meter (m) thick, behind wooden forms (Moffat, 1982). The tunnel invert varies from 12 to 15 m below land surface. The invert is deepest where the tunnel crosses under the Chicago River. Most tunnels were approximately 1.8 m wide and 2.3 m high; however, in some locations, the tunnel was wider and higher in order to accommodate a second or third set of rails.

Initially the tunnel system was used for the transport of coal, freight, cinders, and mail throughout the Loop. In later years most of the material transported was waste, especially coal cinders. The rail system was abandoned in 1959 because of a lack of funds to repair equipment and declining demand for service. Since that time the tunnel system has been used to carry power and fiber-optic cables beneath the Loop. Over the years, bulkheads were installed at various locations. However, most of these were not designed to be water-tight.

A breach in the freight tunnels beneath the Chicago River in April 1992 allowed river water to enter the tunnel system and connected buildings. This report describes water level, velocity, and dye measurements made in the tunnels and how the measurements were used in the efforts to plug the breach and dewater the tunnel system.

The Great Chicago Flood of 1992

On April 13, 1992, a section of the freight tunnel crossing under the Chicago River was breached. The breach was first reported at 5:57 a.m. after a Merchandise Mart employee noticed water rushing into the third (lowest) basement of the building. Within an hour two basements of the Merchandise Mart were filled with water. Water rose in the basements at a rate of 0.6 m per hour, despite efforts to pump it out. At about 8:00 a.m., a large whirlpool was reported near pilings in the Chicago River on the southeast side of the Kinzie Street bridge (Fig. 1). Initial attempts to plug the breach by dumping debris and quick-setting concrete into the whirlpool were unsuccessful. Sonar readings in the vicinity of the breach indicated that a car-sized hole was located near recently installed pilings at the Kinzie Street bridge.

The breach allowed approximately 950,000 cubic meters of water from the Chicago River to flow into the freight tunnels and into buildings in the Loop having access to the tunnels. By noon on the April 13, utility services were lost for many buildings in the Loop causing several hundred thousand workers to be sent home. In the end, utility services for more than 100 buildings were lost, the entire subway system in the Loop was shut down, and a major expressway in the Loop was closed because of the flooding. Recent estimates of the damages resulting from the flood exceed $1 billion.

The Corps and its contractors sealed the breach in the tunnel by constructing plugs in the tunnel on either side of the Chicago River near the breach. The construction of the plugs was complicated because the tunnel on the west side of the river splits into two branches, one running under Canal Street and the other under West Kinzie Street (Fig. 1). Access shafts ranging in diameter from 1.52 to 2.13 m were drilled from street level down into the tunnel. Initially, two access shafts were drilled at each branch of the tunnel on both sides of the Kinzie Street bridge. For each

branch, sandbags and stone were lowered into one of the two access shafts to slow the flow of water through the tunnel. Then concrete plugs were placed in the second access shaft, with a single pour, to at least 5 feet above the crown of the tunnel. In addition, the area between the two shafts and the bottom of each concrete plug was grouted using a combination of microfine cement, sodium silica grout, and cement grout (Inouye and Jacobazzi, 1992). As an added safety measure, the Corps installed additional plugs on each branch of the tunnel near the breach in order to allow greater head differential during dewatering of the tunnels.

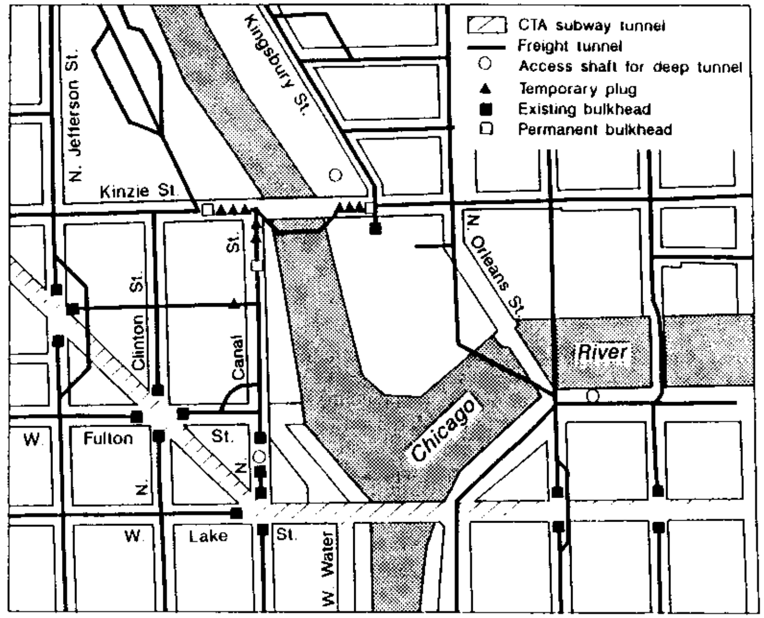

Figure 1.-- Chicago freight tunnels, plugs, and access shafts in the vicinity of the Kinzie Street breach. [Modified from Ferenczy, 1992, p. 9]

In order to dewater the tunnel system, the Corps initially established pumping stations at three locations in the Loop. The rate of drawdown in the tunnels was carefully controlled at about 5 to 8 centimeters per hour in order to minimize the risk of collapsing another part of the tunnel system. Seven other pumping stations in the Loop were eventually established in order to dewater the entire tunnel system. The dewatering was completed on May 22, 1992. After this, permanent bulkheads were constructed in the tunnels near Kinzie Street.

Water-level Measurements

Gages for monitoring water levels in the tunnels were installed by the USGS at seven locations throughout the Loop. The purpose of the gages was two-fold. The gages were used by the Corps to monitor the dewatering of the tunnel system and serve as an early warning system should another breach occur during the dewatering operation. Gages were installed at locations relatively near where the tunnel crossed under the Chicago River. Additional monitoring sites were desired, but were not feasible because of limitations in drilling access shafts and the possibility of destroying fiber-optic cables running through portions of the tunnel.

The first four gages were installed and operating within 24 hours of the initial request for assistance from the Corps. Each gage was equipped with an electronic datalogger, a stage sensor, and telephone telemetry. The electronic dataloggers were programmed to record water-level readings obtained from the stage sensor at 5 minute intervals. The stage sensor used was a potentiometer geared to a float and pulley system. The pulley turned in response to changes in water levels, causing the output voltage of the potentiometer to change. In addition, an auto-dial, auto-answer modem was installed with the datalogger. This allowed the Corps to interrogate each gage every 15 minutes, or at any desired time, via computer. All gages were removed by May 22, 1992, after all of the tunnel system, except the river crossings, had been dewatered.

Velocity Measurements

In order to evaluate the effectiveness of the temporary plugs installed on either side of the Kinzie Street bridge, the Corps requested that the USGS measure velocities in the tunnel on the landward side of the first temporary plugs. Velocities were measured in shafts drilled down into the tunnel from the top of Kinzie Street. The USGS proposed using a low-velocity, Price AA current meter and a Neil Brown Acoustic Velocity Meter[1] (hereafter referred to as Neil Brown). The advantage of the Neil Brown was the ability to measure low velocities and to determine flow direction. The latter was critical, because flow direction using Price AA current meters could only be estimated by noting the direction of flow at the surface. Water levels in these shafts were well above the tunnel, approximately equal to the water-surface elevation of the Chicago River. The shafts acted as stilling wells, making it difficult to determine the direction of flow by observing the orientation of the Price AA meter at the water surface. The Price AA meter was nevertheless used in some of the shafts so that any sudden changes in velocities could be observed.

There were several drawbacks to relying only on velocity meters to monitor leakage through the temporary plugs. These included (1) the resolution of the velocity meters, and (2) the possibility that velocities measured by the meters could be caused by pumping rather than a leak in the temporary plugs. The minimum resolution of the meters ranged from 0.9 centimeters per second (cm/s) for the Neil Brown meter to 3.0 cm/s for the Price AA meter. A measured velocity of 0.9 cm/s might therefore be interpreted as meaning there was negligible flow through the plug. However, a velocity of 0.9 cm/s would be equivalent to a leak of 25 liters per second (L/s) through the temporary plugs, assuming a cross-sectional area of 3.72 square meters.

[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey

Velocity measurements were made using both meters in shafts on the west side of the Kinzie Street bridge (West Kinzie) every 15 minutes, 24-hours a day from April 18-20 and at periodic intervals thereafter until the second set of temporary plugs were installed. Velocity measurements using a Price AA meter also were made in a shaft on the east side of the Kinzie Street bridge (East Kinzie) 24-hours a day from April 18 to May 9. Unusual changes in water levels or velocities were immediately reported to the Corps. Velocities measured using the two meters were always at or below the resolution of the meters, except for a few short periods when velocities measured in a shaft on West Kinzie Street ranged from 1.5 to 3.0 cm/s. Even though little or no flow could be measured using the meters, the data were useful to the Corps in evaluating the effectiveness of the plugs and providing a safety measure, should one of the plugs being to leak.

Dye Injection and Sampling

For the reasons mentioned above, a fluorescent dye tracer was used to more precisely determine whether the plugs isolating the breached section of the Chicago freight tunnel from the remainder of the tunnel system were leaking. In order to accomplish this, dye would have to be injected on the riverward side of the plugs and then water samples would have to be taken from the landward side of the plugs and analyzed for the presence and concentration of dye. The dye injection was planned to allow detection of leaks as small as 0.06 L/s. The dye injection and sampling was planned initially to indicate only whether water was leaking through the plugs and not to determine leakage rates.

The dye injection was planned based on results from computer models of dispersion and advection in the tunnels. These models were developed to assure that the quantity of dye injected would be sufficient to detect any leaks in the plugs. Although the dye injection was not planned to determine accurate leakage rates, the two models did allow gross estimates of the leakage rate to be computed by comparing model results with measured dye concentrations. One model was written to simulate the mixing of the dye in the isolated portion of the tunnel. This model was necessary because the concentration of dye immediately adjacent to the plugs changed with time as the dye mixed throughout the isolated part of the tunnel. This model estimated the time until dye reached the plug, simulated the change in concentration over time at the plugs, and simulated the effect of injecting dye at three different locations in the isolated part of the tunnel.

A second model simulated the advection and dispersion of dye that had leaked through the plugs. This model was necessary because the sampling points were not immediately adjacent to the plugs and because the dye concentration changed over time because of mixing, transport away from the plugs, changes in the concentration of dye leaking through the plugs, and changes in the leakage rate.

Based on the initial model runs, 10 liters (L) of rhodamine WT dye were injected into the isolated part of the tunnel system; 5 L into a shaft approximately 24 m riverward from the plug on East Kinzie Street, and 2.5 L into each of two shafts approximately 6 m riverward from plugs in West Kinzie Street and Canal Street, respectively (Fig.1). All three dye-injection shafts were cased holes, 10 centimeters (cm) in diameter, drilled into the tunnel. The water levels in these shafts were approximately 6 m above the top of the tunnel. The dye was injected through 0.9 cm diameter tubing that was lowered to the approximate center of the tunnel. This was to assure that the dye was mixing in the tunnel rather than remaining above the tunnel in the injection shaft.

Samples were collected from the tunnel from shafts drilled landward from the plugs and analyzed for dye concentrations. Samples were analyzed in a laboratory van using a fluorometer calibrated to standard solutions with concentrations of 0.0, 1.0, 10, 50, 100, and 200 parts per billion. The background fluorescence of the water in the tunnels was determined from water samples collected prior to dye injection from the sampling shafts and from the Chicago River at the Kinzie Street bridge. Samples were collected from the dye injection shafts until May 2, 1992, to determine the mixing of dye in the isolated part of the tunnel.

Concentrations of dye detected in samples collected from a shaft on East Kinzie Street indicated that water was leaking through the plug in the tunnel beneath East Kinzie Street. Preliminary estimates of the leakage rate, based on comparing these concentrations with those from model simulations used to plan the dye injection, were that the rate of leakage was between 0.3 and 0.9 L/s. The models were revised later to better simulate some of the unique aspects of this system, including the initial mixing of dye in the tunnel and the effect of grouting on the leakage rate during the time being simulated. Results from the revised models indicated that the actual leakage rate through the plug beneath East Kinzie Street was between 0.1 and 0.2 L/s.

Summary

Water-level, velocity, and dye measurements were made in the Chicago freight tunnels from April 18 to May 22, 1992 by the USGS. Information from these measurements assisted the Corps in plugging and dewatering the tunnel system following the tunnel breach at Kinzie Street on April 13, 1992. Data from seven gages installed throughout the Loop were used by the Corps to monitor the dewatering effort. Velocity and dye measurements were made in the freight tunnels near Kinzie Street in order to evaluate the effectiveness of the tunnel plugs. Velocity meter measurements were useful in providing an early warning in the event major leaks in the tunnel plugs occurred. Dye injection and sampling allowed for a more accurate assessment of the integrity of the tunnel plugs than could be made using velocity meters alone.

References

Chicago Tunnel Terminal Corporation. (1928). City of Chicago Tunnel System. Chicago Tunnel Terminal Corporation, Chicago, Illinois, 34 pages.

Ferenczy, M. (1992). "Corps of Engineers Uses Computer Mapping to Drain the Chicago Freight Tunnels," Illinois GIS and Mapnotes. Center for Governmental Studies, Northern Illinois University, DeKalb, Illinois, 11(1), p. 7-9.

Inouye, R. R. and Jacobazzi, J. E. (1992). "The Great Chicago Flood of 1992." Civil Engineering. 62(11), p. 52-55.

Moffat, B. 1982. Forty Feet Below--The Story of Chicago's Freight Tunnels. Interurban Press, Glendale, California, 84 pages.