Hydrogeologic controls on water intrusion into subway tunnels constructed in fractured rock, Washington, DC and Maryland, USA

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Abstract: Excessive water intrusion has been observed along stretches of underground subway tunnels constructed in gneissic and igneous rock near Washington, DC, USA. The leakage is correlated with tunnel construction in the igneous intrusions, where fractures are more numerous and have a greater degree of interconnectivity than in the gneissic rock. Hydraulic properties of the rock indicate that nominal pumping rates can lower the hydraulic head in the rock adjacent to the subway tunnel and reduce water inflow.

Key words: fractured rock, ground water, tunnels

INTRODUCTION

Excessive water intrusion has been observed along stretches of underground subway tunnels constructed in fractured rock in the Washington Metropolitan Area Transit Authority (WMATA) Red Line rail system (Figure 1), which serves Washington, DC and the neighboring state of Maryland, USA. The tunnels with the greatest amount of leakage were constructed in the late 1970's and early 1980's, when there was no water-sealing technology available to prevent water intrusion effectively. Excessive water leakage through the tunnel walls and the presence of water inside the underground facilities has damaged mechanical and electrical components in the tunnel, and has escalated the deterioration rate of the rail system and the associated infrastructure. WMATA is currently investigating technologies for reducing or eliminating water inflow into stretches of the subway tunnels, including the design of pumping wells to capture ground water before it enters the tunnels. To evaluate the costs of design, installation, and operation and maintenance of pumping and other alternatives, the hydrogeologic and geochemical controls on ground-water flow in the fractured rock are being investigated.

GEOLOGIC SETTING

The subway tunnels that are experiencing the greatest leakage WMATA rail system were constructed through gneissic rock and igneous intrusions[1,2], with the tunnels approximately

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45 meters below land surface and approximately 25 meters below the water table. The competent rock at depth is overlain by approximately 15 meters of saprolite, a clay-rich, unconsolidated material derived from the *in situ* weathering of the rock. The porosity of the saprolite is significantly greater than that of the competent rock.

Fractures in the gneissic rock have a general north-south orientation and are poorly connected, whereas fractures in the igneous intrusions have a general east-west orientation and are more numerous and have greater interconnectivity than fractures in the gneissic rock. Major structural features, such as faults and folding also have been mapped in the area[1]; their orientations generally conform to the mapped orientation of fractures in the lithologic units in which they are located. In general, there appears to be greater leakage in sections of the tunnel constructed in the igneous rock than in the gneissic rock.

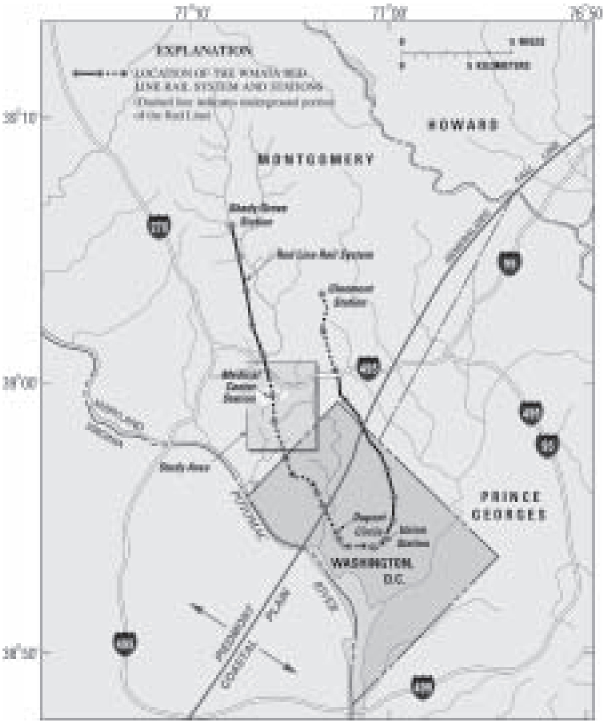

Figure 1. Location of the Washington Metropolitan Area Transit Authority (WMATA) Red Line Rail System and the study area near the Medical Center Station

HYDROGEOLOGY

Four boreholes were drilled in the igneous rock adjacent to the subway tunnel to facilitate this investigation, and a piezometer was installed in the saprolite. From single-hole hydraulic tests in discrete intervals in the bedrock boreholes, the transmissivity of fractures intersecting the boreholes varied over 5 orders of magnitude, from a maximum of approximately 10^{-4} square meters per second (m^2/s) to the detection limit of the *in situ* testing apparatus, which is approximately 10^{-10} m^2/s.

An aquifer test conducted by pumping one borehole and monitoring the drawdown in observation boreholes over 3 days showed approximately 20 meters (m) of drawdown in the competent rock 20 m from the pumped well when pumping at approximately 6.6×10^{-5} cubic meters per second (m^3/s); a drawdown of only 0.03 m was recorded in the saprolite piezometer. The transmissivity of the competent rock, as inferred from the aquifer test, is approximately 10^{-5} m^2/s, which indicates that the most transmissive fractures in the competent rock are not connected over significant distances. Also, there appears to be poor hydraulic communication between the competent rock and the overlying saprolite, which implies that water entering the tunnel is likely to be derived from the competent rock, rather than the unconsolidated saprolite.

LEAKAGE INTO THE TUNNEL

Leakage into the subway tunnel was measured at the pumping station that drains the section of the tunnel in the study area (Figure 2). The length of the tunnel draining to the pumping station is approximately 3500 m. The influence of precipitation events is seen in the pumping records from the tunnel, indicating that surface leakage around shafts and other structures is responsible for some of the tunnel inflows. Hydraulic head in the competent rock, however, also correlates with the pumping from the tunnel. There is greater pumping from the tunnel when there is higher hydraulic head in the competent rock; a higher hydraulic head in the competent rock implies a larger hydraulic gradient driving ground-water flow to the tunnel.

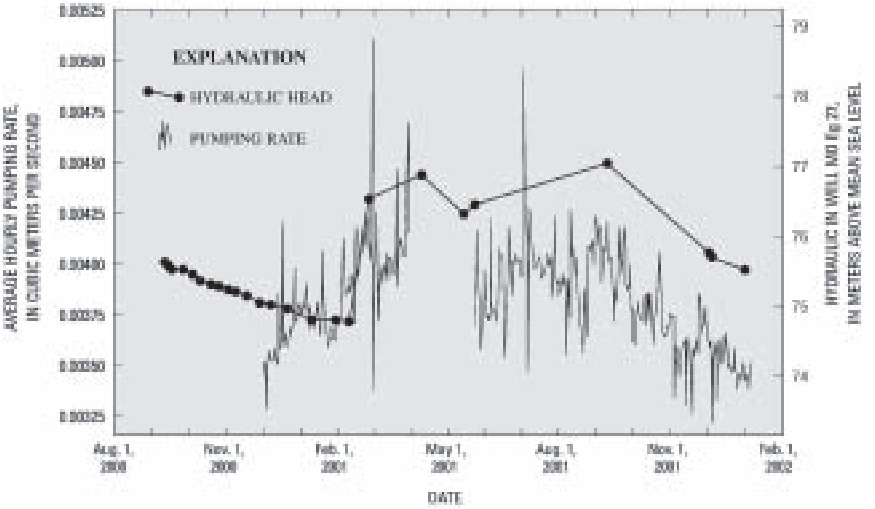

Figure 2. Comparison of hydraulic head in bedrock well MO Eg 27 near the Medical Center Station and the hourly pumping rate from the pumping station north of the Medical Center Station

CONCLUSIONS

Water leakage into WMATA subway tunnels constructed in fractured rock has damaged mechanical and electrical infrastructure. The worst leakage appears to correlate with the tunnel construction through igneous rock, which has numerous fractures with greater interconnectivity than the fractures in the gneissic rock. Aquifer tests conducted by pumping from the fractures in the competent rock showed poor hydraulic communication between the competent rock and the overlying unconsolidated saprolite, indicating that water inflow to the tunnel is likely to be derived from fractures in the competent rock. Leakage into the tunnel in the study area correlates with the hydraulic head in the competent rock; as the hydraulic head in the bedrock rises, the amount of leakage into the tunnel also increases. Based on this correlation and the estimated hydraulic properties of the rock, it is hypothesized that lowering the hydraulic head in the adjacent bedrock will decrease water inflows to the subway tunnels, and furthermore, only nominal pumping rates would be needed for this purpose. Leakage into the subways tunnels can also be reduced by effectively sealing around shafts and other structures that extend from land surface to the tunnel. The correlation between precipitation events and pumping from the tunnel indicates that disturbed geologic conditions around these structures permits some rapid infiltration to the tunnel.

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