Introduction

Rail transportation in the United States has historically been thought of as rural in nature. The image of a locomotive with trailing freight or passenger cars rolling through the pastoral countryside is an easily recognized image. However, the landscape in 21st America is changing with urban encroaching on rural more and more frequently. A set of railroad tracks with the cows looking over the fence as the train goes by is a scene giving way to those same tracks threading their way among tall buildings, shopping malls and highway structures. The impact of urban development on rail infrastructure is becoming increasingly critical. Deep excavations adjacent to rail facilities, tunneling under track embankments and construction over or beside rail tunnels are becoming more commonplace and their impact on rail facilities can be detrimental. This can be especially true for those rail corridors handling high-speed rail passenger service.

This paper addresses the current state of the art for instrumentation systems in the monitoring of track and tunnel behavior associated with the impact of urban development. A discussion of instruments, methodology, system design and implementation is followed by three case studies.

Background Information

Rail Service in Washington

In a general perspective Washington is served by main line rail from two principal directions. From the north, via the B&O Railroad (now part of CSX) and from the south on tracks of the Southern Railroad (now part of Norfolk-Southern). In addition, Richmond, Fredericksburg and Potomac tracks (now part of CSX) once terminated at their enormous facility, Potomac Yard in Alexandria just across the river from Washington.
High-speed Rail Passenger Service

In 1976 the nation celebrated its bicentennial and Washington opened the first portion of what would later evolve into over 100 miles of high-speed rail passenger track. The Washington Metropolitan Area Transit Authority is charged with the implementation, management and maintenance of this system of tunnels, embankments and aerial structures comprising the various routes serving the Washington area.

The rail transit system serving the city is laid out much like the spokes of a bicycle wheel. Tracks radiate from the center of the city reaching out into the suburbs with various transfer points where train routes merge allowing travel to other suburban points without entering the city. The tracks are primarily in tunnel structures close to and inside the city with earth embankment or above ground tracks in the far outlying suburbs. At river crossings and locations such as Reagan National Airport the tracks are carried by aerial structures.

The service is a dual track system. Tunnels were either constructed by “cut and cover” methods or mined in areas of either rock or soft ground with boring machines. Mined tunnels are typically circular with either steel or concrete liner plates in soft ground or concrete lined in rock tunnels. The “cut and cover” tunnels are square in cross section with many locations having both tracks in the same box section.

Urban development in and around Washington

In the past twenty-five years the Washington area has seen steady and continued growth. The landscape is constantly changing with vacant land developed at a brisk pace and older parcels, either commercial or residential, demolished and newer projects put in their place. The pressure on the infrastructure especially close to the city is accelerating and does include pressure on the rail transit system as well as tracks of the major freight carriers, primarily CSX.

Currently the rail right of ways, whether passenger or freight, are increasingly encroached upon by utility crossings or adjacent construction at the right of way line. For example an excavation for a large building will require the use of a support system, which in most cases will use the “tieback” to hold soldier piles. These support strands may be drilled and anchored in the soil under tracks. The rail industry must become increasingly aware of the need to manage these activities in, under and around their facilities. The costs of repair and replacement due to the effects of such activity cannot be taken lightly.
The Need For Instrumentation

It goes without saying, the management of rail service includes both what is carried on the tracks as well as the integrity of the tracks themselves. Not just track integrity due to age, use and installation but track integrity caused by outside influences unrelated to the norm. An excavation support system on the rail right of way line could create movement of the soil base under rock ballast and even a lateral shift of rail alignment. Digging under the rail embankment for a fiber optic cable duct bank could create a localized area of track settlement. The list of possible activities is large. The information as to what distress if any of these activities may be causing is extremely important and vital to good track management. The unknowns of construction with a large project can be numerous and information both timely and reliable is critical to decision making. The bottom line is to avoid and stop a situation before it becomes a problem, which in turn could cause lost revenue or worse, property damage and loss of life.

Instrumentation Program Elements

The information considered vital to any evaluation program can include; movement of rail geometry, movement of ballast and embankment material, strain is the structural material of tunnels and bridges, change in ground water pressure, movement and rotation of aerial structures and the effect of shock waves due to blasting.

The instruments and methods for measuring the behavior of rail elements are varied. Methods as simple as utilizing optical surveying instruments can be helpful in some instances. However the speed with which some activities can be undertaken requires a more instantaneous flow of information. The “manual” nature of survey data is time consuming to recovery and compile. Electronic instruments either hard wired or radio controlled are common place in industry and are cost effective for the use in measuring performance behavior of rail facilities.

The design of a simple instrumentation system can be summarized. A sensor to measure, for example strain in a bridge beam, is placed in the field. A readout unit is placed in the field at some convenient location and connected to the sensor either by wire or radio. With an onboard battery, the readout unit can trigger the sensor to take a reading and be transmitted back and stored. A computer, whether in the field or back in the office via telephone can connect with the readout unit to retrieve the data, process the information and generate a summary of activity. All of this within a matter of seconds. If the issue is critical an alarm system can be installed and triggered by the computer as it analyzes incoming data.

These systems are both cost effective and provide greater degrees of precision and reliability. The most important factor is the speed with which information is
gathered. With any planned undertaking influencing rail facilities a contingency plan must be in effect. If adverse movement begins to occur a plan must be in place to deal with it. If the rails begin to move what will be done to stop it before it becomes a problem? Will trains have to stop or reduce their speeds?

This paper examines three case studies involving projects adjacent to or under existing rail facilities in the vicinity of Washington, D.C. Instrumentation systems were installed to monitor the behavior of rail facilities to detect possible adverse effects from the associated construction.

**Case Study One - Storm Drain Outfall Construction**

A large commercial development was undertaken in Alexandria, Virginia just across the Potomac River from Washington. The development consisted of retail and office with some high density residential as well. The existing infrastructure of sewer, storm drain, water supply, etc. was vastly inadequate.

The natural topography of the area is such that drainage flows directly to the Potomac River. The site is situated with the river to the east with a set of WMATA embankment tracks, a two-lane highway and parkland in between. Storm water collected on site, after going through retention and other water quality measures, was to be discharged through a 96 inch line running to the river. Thus, the proposed storm drain would align, in a somewhat perpendicular manner, under the WMATA tracks as it proceeds to the river outfall.

The proposed 96-inch outfall was to be built with a tunnel-boring machine with a total run of just over 120 feet from approach pit to receiving pit. The WMATA right of way in between the two was 60 feet wide. As a condition of WMATA approval for the project the boring must be continuous, it must be completed between 7:00 PM on a Friday and be completed by 5:00 AM Monday. This requirement was placed to allow the activity to proceed during the weekend when there are fewer trains running. However, train speeds would be kept normal. In addition, a monitoring program and a contingency plan must be in effect at all times.

The proposed construction activity is summarized as follows. The storm drain outfall was to be tunneled by boring machine. An approach pit was excavated as well as a receiving pit for insertion and extraction of the boring machine. Prior to tunneling, a pre-condition grouting program was undertaken. Grout was injected into the soil mass of the rail embankment to create a stiff “shelf” between the tracks and proposed tunnel. Grout tubes were drilled in place for injection of grout. These tubes were left in place for compensation grouting as the machine progressed forward. An instrumentation program was installed in the track bed to detect any heave from the grouting or settlement due to tunneling. Precast concrete pipe sections were inserted behind the tunneling machine and grouting was done to fill voids on the outside face of pipe.
The instrumentation program was designed to detect any heave or settlement of the track embankment during both the grouting program and tunneling. WMATA required there be no disruption to train movement and the instruments installed should allow the retrieval of data during continuous passenger service. The instruments used were electrolytic tilt sensors mounted on brackets anchored into the rock ballast. Movement of the ballast, the structural element support the ties and rails, was of critical concern. These sensors were hard wired through conduit in the ballast to a data logger placed outside the rail right of way. A computer was placed on site to download data, compile and analyze. Sensor placement was correlated to grout tube installation. Thus if any sensor detected heave, grouting pressure could be reduced or if the case of settlement due to tunneling, grouting could be initiated to prevent settlement.

During both grouting and tunneling operations data was retrieved from each sensor every 60 seconds. During those periods of down time data was gathered
Grout Tube Installation

Pre-Condition Grouting

Tunneling and Compensation Grouting

Continuation of Track Monitoring
less frequently. The grouting technician and instrumentation technician were in contact with each other via radio during the entire operation. Once grout tubes were in place the pre-condition grouting program was undertaken. Grout was injected and just as its correlating sensor began to show movement the pressure was released. During tunneling settlement began to occur but grout was immediately injected to counter the downward trend. Please see the attached figures.

Tunneling was completed ahead of schedule on Sunday afternoon about 1:00PM. Sensors were able to show that any settlement trends were averted by grout injection. A post construction rail geometry survey, by traditional optical surveying methods, also showed that change in rail position were within acceptable tolerance. The automated sensor system proved itself to be both cost effective and reliable and allowed the project to be completed safely and without disruption to passenger service.

Case Study Two - Sanitary Sewer Crossing

In the southern part of Alexandria, Virginia dual tracks of the rail passenger system run side by side with three tracks of the CSX system. A proposed commercial development required the construction of a 36 inch sanitary sewer under these five tracks to link up with a sanitary main leading to the City of Alexandria treatment facility. The sewer was to be installed by micro tunneling techniques. Both railroads (CSX and WMATA) required tunneling to be undertaken during a weekend and to be continuous. In addition an automated instrumentation program was implemented to detect any adverse movement to the tracks of both systems.

Similar to the storm drain installation, approach and receiving pits were excavated. Due to the depth of the proposed sewer a grouting program was not undertaken other than to fill voids outside the pipe lining itself. Additionally, the WMATA tracks were in a slight cut section and concrete retaining walls were on either side of the dual tracks. WMATA also required a system to monitor both settlement and rotation of the walls.

The instrumentation program utilized electrolytic tilt sensors placed in the track bed of each CSX track, the track bed of the WMATA tracks as well as the base of each retaining wall. In addition vertical tilt sensors were placed on the face of each retaining wall at three locations to monitor potential rotation. All sensors, a total of 36 were hard wired to a data logger placed in the staging area of the approach pit. A computer was placed on site and used to analyze data. As tunneling proceeded each sensor was read every 60 seconds. In the event of adverse settlement the grouting program was in place to be initiated as necessary.

The total length of the bore was over 200 feet. The sewer was completed on schedule with no movement trends occurring and again, the instruments proved
themselves appropriate and reliable. The instrumentation program helped provide for a safe project. Please see the attached graphics for views of the sewer crossing and instrumentation layout plan.

**Case Study Three – Raw Water Intake Tunnel**

A third case study examines the impact of a proposed intake/outfall tunnel constructed under an existing rail tunnel in Arlington County, Virginia. A heating and refrigeration plant was constructing a 96-inch intake/outfall tunnel leading to and from the Potomac River. The intake portion of the tunnel aligned under a portion of the rail tunnels of the WMATA transit system. The subway tunnels had been constructed by “cut and cover” methods and the intake tunnel was to pass below and built by a continuous boring machine. The rail tunnels were constructed within older fill material of a reclaimed land area while the intake conduit would be in the original alluvial material underneath.

The instrumentation program for the rail tunnels was in two parts. The first was a series of electrolytic tilt sensors placed inside the running tunnels to detect any heave or settlement of the tracks. The second was an array of horizontal inclinometers placed in the soil mass between the rail tunnels and the proposed intake tunnel. All devices would be hard wired to a data logger placed at the surface near the receiving pit. Sensor cables were run out through a ventilation shaft.

The data logger was placed in an instrumentation trailer with an on site computer. As tunneling progressed for the intake conduit, data from both types of sensors was gathered every 60 seconds. Prior to tunneling a precondition grouting program was undertaken. Grout was injected into the soil mass above the proposed intake conduit and below the horizontal inclinometers. The grout tubes were in the same configuration as the horizontal inclinometers in a pattern radiating from the receiving shaft. Once movement was detected in the horizontal inclinometers grouting pressure was relieved. Again, as in previous case studies a rigid shelf was created under the rail tunnel.

WMATA required that all tunneling activity for the intake be continuous until completion and as in previous projects all work was to take place on a weekend when trains were not running as often. This requirement would take effect when the boring machine reached a point 75 feet in front of the WMATA right of way. However, the instrumentation program to monitor behavior of the rail tunnel was to run continuously during all construction of the intake tunnel. Thus, if any adverse effect occurred as the TBM passed under the rail system it could be clearly defined.

Tunneling for the conduit began on a Wednesday and progressed steadily and reached the WMATA right of way Friday evening with the machine breaking through into the receiving pit in the early hours of Monday morning. During the
entire operation there was no discernable movement of the WMATA rail tunnel. The horizontal inclinometers showed movement but well within acceptable tolerance. As with all projects, WMATA requires a post construction rail geometry survey. Once the conduit was complete, the TBM completely removed and compensation grouting completed the optical survey was performed. The survey of rail position showed no movement in the alignment of the rails for either the inbound or outbound tracks.

The instrumentation program was again found to be both reliable and cost effective. At those moments when information about the behavior of the rail tunnels was crucial the system proved invaluable and allowed construction to proceed and without delays.
Summary

The need for reliable and timely information about the behavior of rail systems is vital. The potential for damage and the lost time to make any repairs greatly outweighs any costs associated with the instrumentation necessary to obtain the information. Railroad networks will be increasingly affected by adjacent construction activity. The ability to make a decision about the integrity of the rail system as it happens allows for actions to avoid such damage. Current state of the art instrumentation systems, properly implemented will give the information the railroad industry needs and be both reliable and cost effective.