Applied Geology and Geophysics Used in the Widening of New Hampshire's Interstate 93

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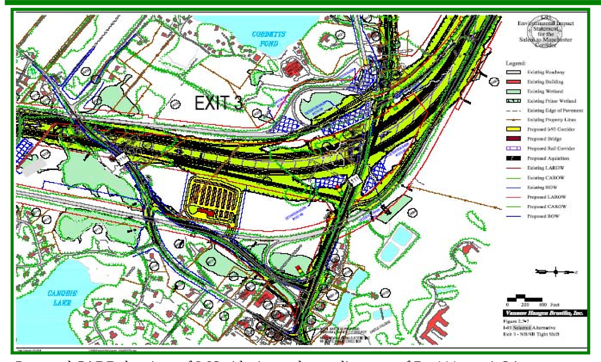
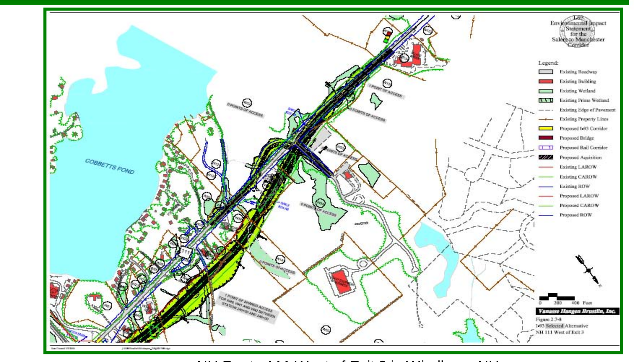


Proposed CADD drawings of I-93widening and new alignment of Rt. 111 at exit 3 in Windham, NH.



NH Route 111 West of Exit 3 in Windham, NH.

Abstract

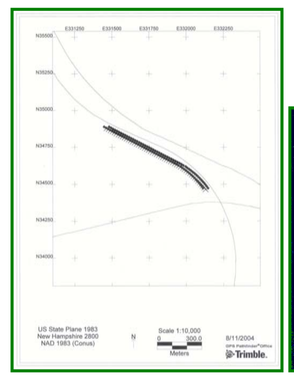
Interstate I-93 is an important northeast corridor, connecting the states of Vermont, New Hampshire and Massachusetts. Interstate 93 extends 210 miles from St. Johnsbury, VT in the north, through 142 miles in New Hampshire (including the cities of Concord and Manchester) and ends in Dedham, Ma. The original interstate was built in the 1960's and can hold a maximum volume of 60 to 70 thousand vehicles per day. The Department of Transportation (DOT) in NH found that in 1997 there was an average of 105,000 vehicles traveling per day on the section of I-93 in Salem and 60,000 to 80,000 vehicles traveling per day through segments north of Exit 1 in Salem. DOT traffic projections revealed that by 2020, 140,000 vehicles per day would travel or pass through the already very congested and dangerous stretch of I-93 in Salem.

The state of NH put forth plans to build two more lanes both north and south bound on I-93 from the border of New Hampshire and Massachusetts in Salem, NH to the I-93/I-293 intersection in Manchester, NH. The project will expand 18 miles of interstate and take ten years to complete at an estimated cost of 420 million dollars. The project will be one of the largest construction jobs in New England while under construction. The Engineering/Geology section of the DOT will play a large role in the planning of I-93. Before the expansion of I-93 can take place a great deal of preliminary geological data must be collected. To build a road properly engineers and construction companies need to gather critical geologic data including the soil type and depth to bedrock.

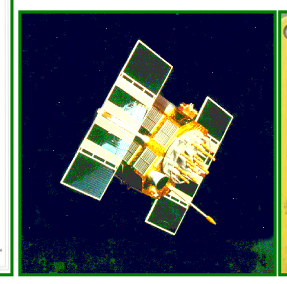
This poster reviews several important data collecting steps needed for making informed decisions on the amount and type of material to be removed during the roads construction. All of the data and information was collected along Rt. 111 near Exit 3, I-93 and along the southbound off ramp of Exit 3 in Windham, NH.

1. CADD & GPS

Most of the data that is collected by geologists for the development of a roadway system is taken after civil engineers design a preliminary draft of the proposed roadway. In most cases the preliminary plans are made using Computer Aided Design and Drafting (CADD). From this draft a survey crew or the geologists themselves stake out the alignment of the road using the Global Positioning System (GPS).



Plot of the I-93 south bound off ramp, exit 3. The black "x"s are waypoints showing the center of the new off ramp to be built. These waypoints will be transferred to the GPS data logger.

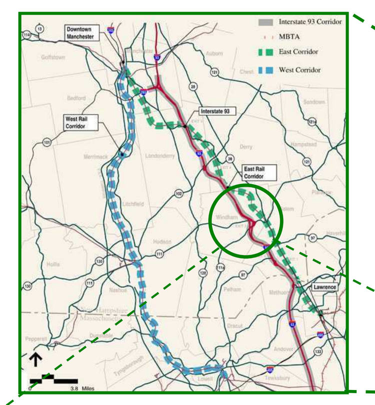


GPS satellite. Satellites orbiting the earth send radio signals to the GPS unit. There are 24 non-geostationary satellites at an altitude of about 26,000 km and circle the earth approximately every 12 hours. Up to 12 satellites are visible to the user at any point on the earth at all times (canopy and obstructions will hamper the amount the receiver can pick up).

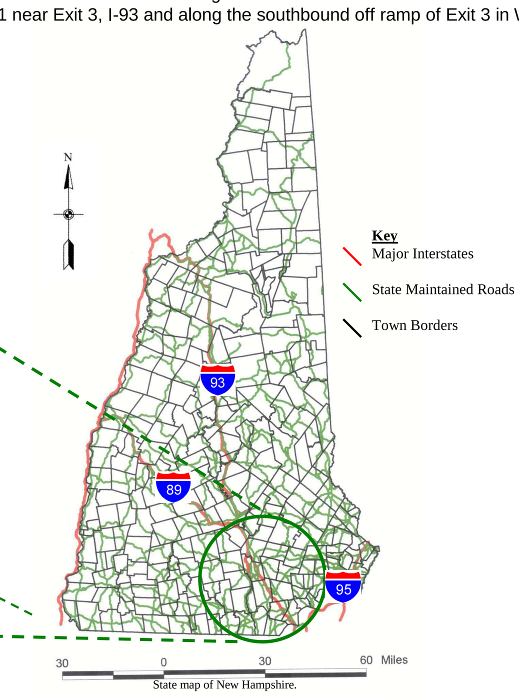
GPS data logger. Geologists take the waypoints that have been transferred onto the GPS unit, and stake them out. The proposed road is now actually being physically outlined in the field. The waypoints staked out by the DOT's geologists are based strictly on the GPS unit and therefore are an estimate of the proposed road. For greater accuracy, the construction company will survey the waypoints again during the roads production.

Full GPS unit. This unit consists of a data logger which runs a "Windows" operating system, much like a small handheld computer. The data logger is attached to a receiver (antenna) shown being carried on the back.

Waypoint stake found on route 111 in Windham. The LT. means left 27 meters of waypoint 2790 + 20 or left 20 meters of the center of the proposed road. 2790 +20 is essentially 20 meters passed the waypoint 2790 or 2790.20.

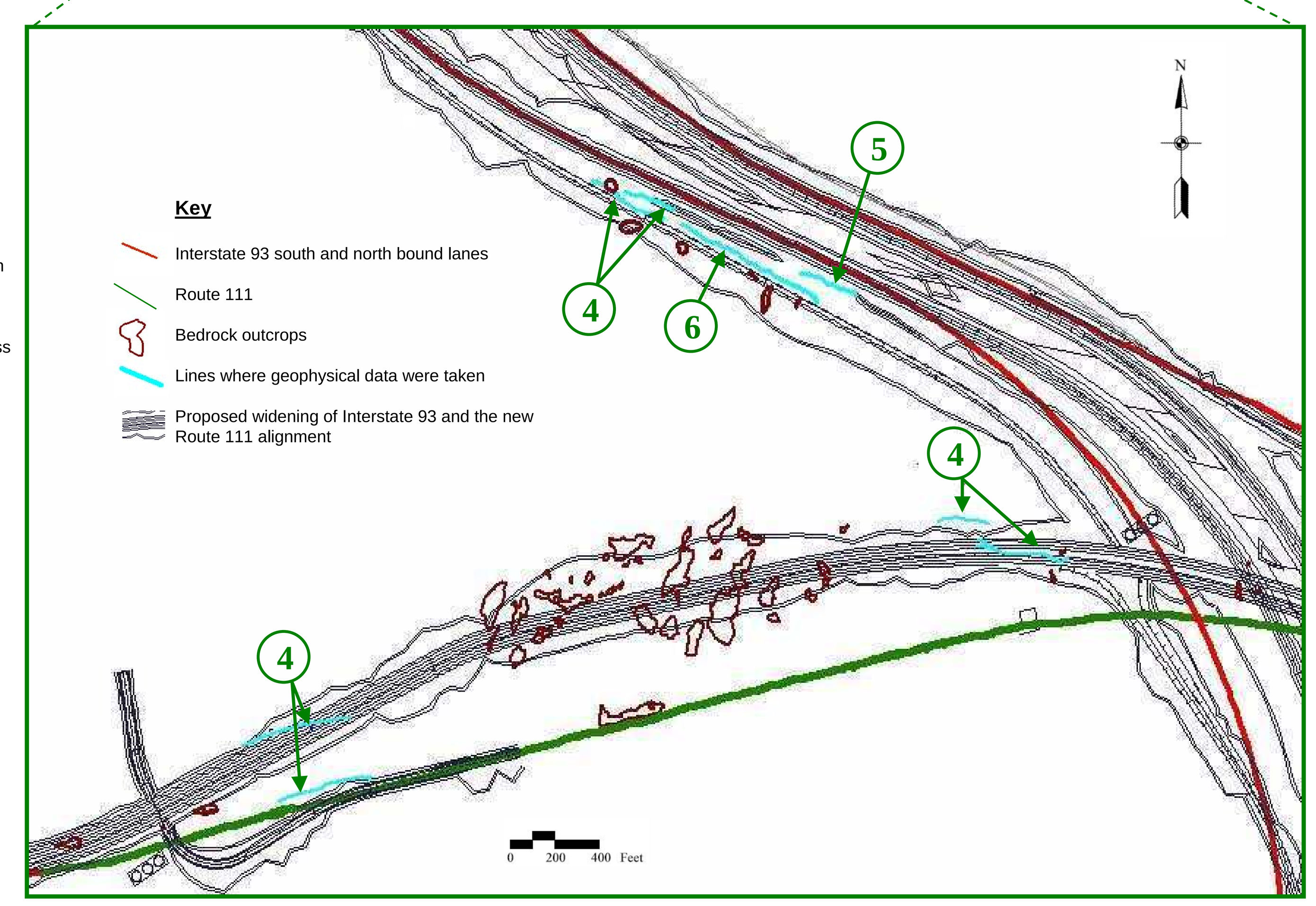


Map of proposed I-93 widening and construction of two railway tracks.



State map of New Hampshire.

CADD Drawing of Proposed I-93 Widening and Route 111 New Alignment Windham NH

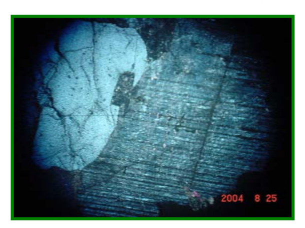


2. Strike & Dip of Bedrock Joints and Foliation

To build a road, engineers and construction crews need to know what lies beneath the ground. The amount of material that needs to be removed is very important for the state in determining how much right-of-way needs to be purchased. In NH, there is normally soil and underlying glacial sediments (sand & gravel, till, marine clay) above bedrock. The first step in determining this information is finding and mapping all visible bedrock outcrops. The principal rock unit is determined and then noted on the GPS data collector for each mapped outcrop. If needed, a sample is taken back to the lab where a thin section can be made of the rock. During and or after the outcrops are mapped, a description of lithology and selection of structural data (e.g., strike & dip of layering, foliation, and joints) are collected.

By using the GPS, geologists no longer have to pace and compass bedrock, but can simple walk around the edge of an outcrop and the GPS will record each step. The x & y error for the GPS is +/- one meter. In the lab one can download these images and place them right on the CADD drawing. Geologists can also plot a line showing where geophysical information was taken, such as the line shown in the picture above.

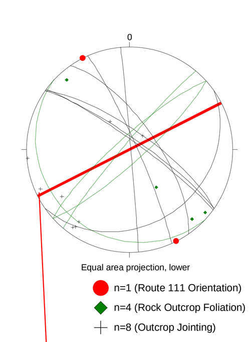
Brunton Compass. Using the Brunton Compass one can measure the strike and dip of joints and foliation on outcrops.



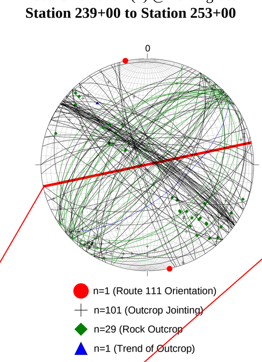
Thin section of an intrusive igneous rock found to the north of Rt. 111 in Windham, NH. The igneous rock is intruding schist throughout the area.

The strike and dip data is summarized on a stereonet using a computer program. For this project we used StereoNett version 2.1 by Johannes Duyster. The stereonet is helpful in plotting the foliation (green) and joints (black) of the exposed bedrock. The proposed roadway is also plotted on the stereonet (red). The stereonet data is then analyzed to determine the angle of cutback and the amount of rock to be removed from a rocks surface with its face parallel to the roadway. If the proposed roadway changes direction within the same rock unit the cutback angle can change as joints and foliation become more or less parallel with the road. Geologists will recommend to the engineers what angle the bedrock should be cut (blasted) based on the interpretation of these stereonets. The amount of material that needs to be removed is very important for the state in determining how much right of way needs to be purchased and to provide cost estimates.

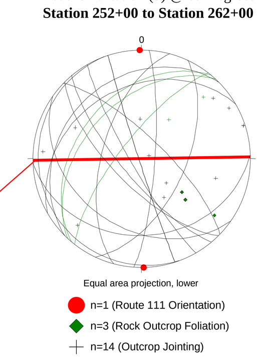
Stereogram of Bedrock Foliation and Jointing Along Route 111
Road Orientation (1) @ 63 Degrees
Station 230+00 to Station 233+50

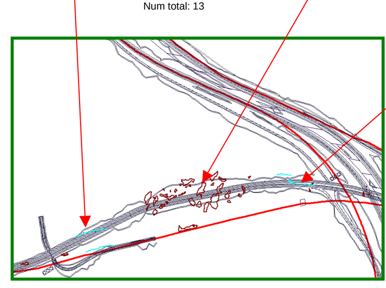


Stereogram of Bedrock Foliation and Jointing Along Route 111
Road Orientation (2) @ 78 Degrees
Station 239+00 to Station 253+00



Stereogram of Bedrock Foliation and Jointing Along Route 111
Road Orientation (3) @ 89 Degrees
Station 252+00 to Station 262+00





Different road angles along the proposed Rt. 111, Windham, NH at exit 3 off of I-93. Rock outcrops have been mapped in brown.

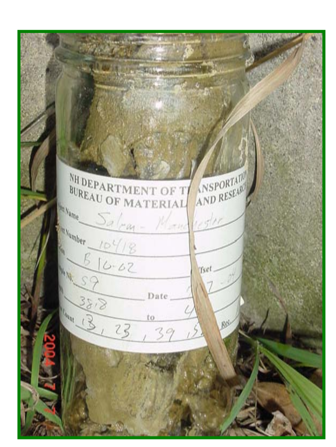
3. Test Borings

Test borings are a very helpful to geologists and engineers by exposing material otherwise inaccessible. Test borings allow geologists to see the subsurface and can reveal the depth to which soil layers or bedrock are expected. Geophysical methods can help determine where test borings need to be conducted or test borings can be used to determine where additional data are needed through geophysical methods.

Drill rig in Salem, NH conducting a test boring. A test boring will provide geologists a small but exact window of what is below the ground. When combined with the geophysics data, a detailed cross-section can be developed of the areas subsurface conditions.

A split-spoon being pounded into the ground. The split-spoon is a hollowed metal tube (pictured to the right). When driven into the ground by the drill rig, it will collect a sample of the soil below. The number of blow counts determines the density of the soil. The blow count is the number of "blows" it takes for a free falling 140 pound weight falling 30 inches to move the split-spoon 12 inches into the ground. The higher the blow count is the denser the material.

An open split-spoon revealing the collected soil. Geologists record the color, particle size and recovery (length of the collected sample). The split-spoon is pounded two feet into the ground, the recovery is then the amount (length) of soil collected from that two feet.



A sample is taken from somewhere within the split-spoon. The sample is labeled and placed in order of depth.

Rock core. Depending upon the depth of the drill hole, bedrock will eventually be reached. A core sample is taken to determine the rock unit and its physical characteristics.

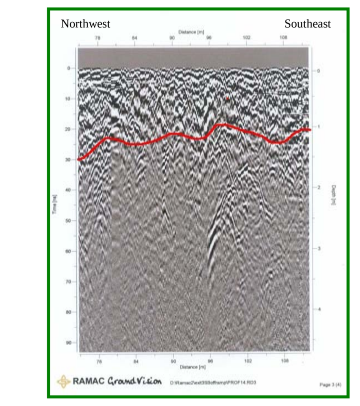
4. Ground Penetrating Radar

Ground Penetrating Radar is a geophysical tool used when bedrock is expected to be shallow and the overburden has little to no clay or silt. The GPR unit works by sending electromagnetic waves into the ground from a transmitting antenna. The waves penetrate the ground and travel approximately 3-30 times slower than the speed of light, depending upon the electrical permittivity of the material. The electromagnetic waves are reflected back to a receiving antenna and are amplified within the control unit and displayed on the computer screen.

500 MHz GPR unit. This unit and most GPR units, consists of a control unit, a computer for collecting data, and transmitting and receiving antennas.

A GPR unit being pulled through the woods which creates a subsurface profile that can be viewed during the traverse.

Results of GPR data displayed on a laptop computer.



Final results of the GPR traverse in Windham, NH. The x-axis is distance in meters, the y-axis is depth in meters. The red line represents the interpreted start of bedrock as found from analyzing the data. The line shows that the bedrock is very shallow only about 1 to 2 meters below the surface.

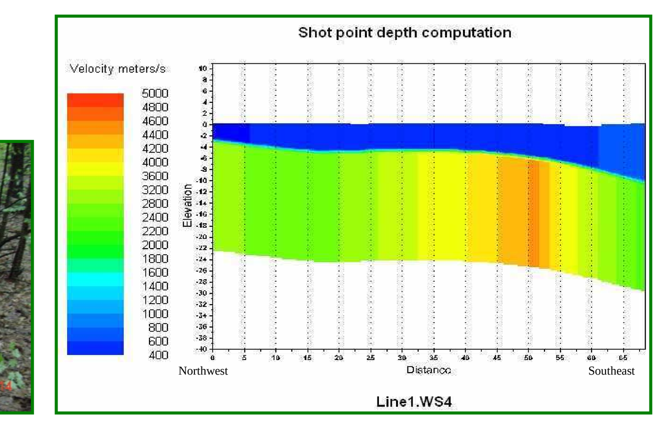
5. Seismic Refraction

Seismic refraction is a geophysical process based on the travel times and distance of compressional waves through an unknown material. Compressional waves are created by an energy source (NHDOT uses a Betsy Gun). These waves are then measured by geophones placed at known distances from the blast. The seismic energy propagates through the ground and is refracted as it travels through different layers of material. The 24 geophones pick up the refracted compression waves and the amount of time it takes the waves to reach each geophone. Compression waves travel at different speeds depending on the medium that they are traveling through, thus a dense material such as bedrock will show compressional waves that travel much faster as compared to those of a loose layer of sand.

Geophone hooked to a seismic line. This line used 12 geophones and was combined with an additional line of 12 geophones. The number of shots are dependent upon the ground conditions and spacing of the geophones but a minimum of three equally spaced shots are normally required for interpretable data. This line required seven shots; two offset shots past the ends of the line, two end shots, and three shots equally spaced along the line.

The Betsy Gun is inserted into the ground approximately two feet. The Betsy gun consists of a long metal rod with a shotgun shell attached to an open end. A hammer with a metal tip is then used to strike a metal piece on the top of the gun. Both metal pieces are fitted with a wire that when connected creates a signal that is directly sent to the recorder. The signal starts the acquisition of data collected from the geophones.

The signal is sent to a computer, printer, or other data collecting source. Where it can be stored or analyzed.



This graph is displaying two different layers of material below the earth's surface. The dark blue layer reveals a material with a much slower compression velocity of 400 to 600 meters per second. The green to red colors have a much higher average velocity of approximately 1800-4200 m/s. The higher the propagation velocity within a material, the denser the material will be. This graph can be interpreted as having a layer of soil (blue) covering very shallow bedrock (green) dipping slightly to the southeast.

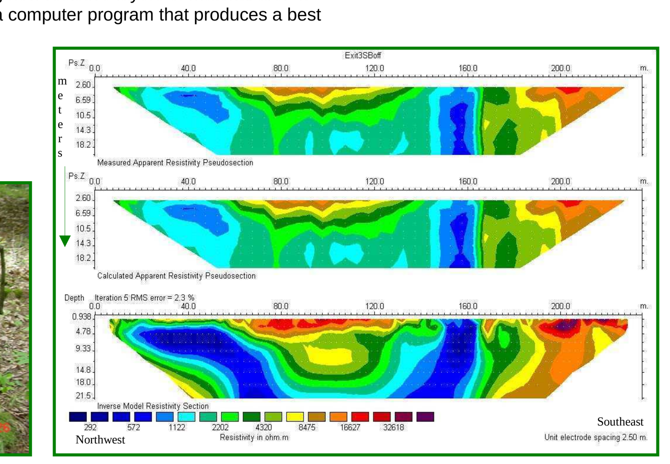
6. Resistivity Methods

Resistivity methods are found by passing a direct current into the ground between two electrodes, C1 and C2. Two more electrodes (P1 and P2) that do not carry a current, measure the difference of voltage caused by the current. Resistivity methods work well in materials that are more conductive than resistive. In the field the computer is measuring how resistive layers of material are. It should be noted, this is the apparent resistivity not the true resistivity which is found by a computer program that produces a best least square fit between the apparent and the calculated resistivity.

Resistivity line. This resistivity line was composed of two lines connected in the middle by a control box. Each line contained 24 electrodes for a total of 48 electrodes. Different arrays can be set up to locate C1, C2, P1, and P2. Only four electrodes operate at a time and large numbers of readings are taken along the line.

Close up of one of the electrodes. Each electrode is sequentially tested to measure its ground resistance in Kohm. For optimal results 1-3 Kohm are wanted, 4-20 Kohm are readable, but 21 and higher are unusable. If the test run produces numbers higher than 21 Kohm, saltwater is poured on the electrode to help lower the number by increasing the conductivity of the soil.

Running the resistivity unit.



The final product is produced by an inversion program back in the lab. The top cross-section is the apparent resistivity, calculated resistivity (middle), and inversion or true resistivity (bottom). Red has a much higher Ohm.m reading making it a more resistive material. The blue shows low Ohm.m and is the most conductive material. In general conductive materials are that of clay (1-100 ohm.m), sand (4-800 ohm.m), etc. While resistive materials, such as rock are granite (3x10^2 – 10^6 ohm.m), shale (6x10^2 – 4x10^7 ohm.m), etc. All materials will be more conductive when wet.

7. Conclusion

The geophysical data are analyzed and combined with the information from test boring samples and data obtained from surface exposures, to create a series of cross-sections showing an interpreted bedrock line. The cross-sections will be perpendicular to the proposed roadway and at a set distance interval. The developed cross-sections are then given to design engineers who will use the information to make decisions concerning the amount of material and the type of material that needs to be removed and thus the amount of right-of-way that will need to be purchased.

There are positives and negatives about whether the material that needs to be removed is bedrock or soil. If the material is determined to be soil, the cutback angle will be at a shallow two to one ratio. The work can be done by the general contractor with a bulldozer and excavator and therefore be less time consuming and cheaper. Unfortunately, more "right of way" will need to be purchased by the state or taken by "eminent domain". Purchasing more land could mean problems with taking land from taxpayers, problems with wetlands, etc. If rock, the cutback angle can be equal to or less than 83 degrees dipping towards the road. One of the positive aspects for finding bedrock is that less right-of-way needs to be purchased by the state. One of the negative aspects is that bedrock has to be blasted by a licensed company, which will increase removal costs. Blasted bedrock is harder to remove than soil, but it often can be used for fill in other areas of the project.

Public safety is always a concern when designing and building a public road even after it is built. Knowing what angle to cut a rocks surface back is critical to the public's safety for a number of reasons. Gravity is constantly working to release stored energy in rocks that may be 50 to 100 feet above a roadway. If not taken into account, bedrock with jointing systems, foliation, and other planes of fractures can become easily dislodged through the process of erosion. These planes of weakness are a very real hazard to the public. For these reasons, geologists must continually monitor rock cuts, even after the rock has been cutback to the most optimal angle and distance from the road.

The vast majority of the earth's continental bedrock is covered by overburden. Overburden can produce a false and unclear image of bedrock depth and shape of surface. With the application of geophysics geologist are able to provide a subsurface picture of the earth's bedrock in areas of interest to civil engineers. This saves time, money and helps to maintain public safety.

Route 111 in Windham - Salem (this construction site is east of exit 3 and is not at the site of our collected data but is still apart of the Rt. 111 new alignment). Drill rig is drilling production blast holes for the construction of the rock cut.

Route 111 in Windham – Salem. The picture was taken on August 18th 2004 a few thousand yards from the picture to the left. Stakes marking the boundaries of the new road can be seen along with removed bedrock at the center of the picture. The excavated rock was used as a large fill underneath the soil in the forefront of the photograph.

Resources

*All of the above data was collected and analyzed by Michael O'Brien and Marc Fish during the summer of 2004, utilizing NHDOT equipment.

NH Department of Transportation. http://webster.state.nh.us/dot/10418c.default.htm

CFLHD and Blackhawk GeoServices. "Applications of Geophysical Methods to Highway Related Problems". Technical Manual 2002-2003. September 2003.