Chapter Four
INVESTIGATION

4-1.0 GENERAL

The investigation of subsurface conditions along a new or, in the case of maintenance projects, existing highway alignments is called a survey. The survey may be preliminary, such as a corridor study or pavement selection, or it may be more elaborate, such as the more common geotechnical and pavement surveys described in Sections 4-2.0 and 4-3.0, respectively. Surveys are performed for all projects, with the exception of minor maintenance. The level of detail required in a survey depends on the complexity of the project.

4-1.01 PURPOSE OF SURVEYS

The purpose of a survey/investigation is to define the in-situ soil, rock, ground water, and existing pavement/subgrade conditions to the extent necessary for the design and construction of a safe, economical, smooth riding, and durable pavement structure.

It is important to stress that the samples taken be representative of the subsurface and/or pavement conditions. If they are not representative, the test results will be meaningless no matter how carefully the sampling and testing techniques were performed. The reliability of any pavement design is directly related to the accuracy of the obtained inputs.

4-1.02 TYPES OF SURVEYS

4-1.02.01 PRELIMINARY

Preliminary surveys are performed either in preparation for the Environmental Impact Statement (EIS) in a corridor study or to provide information for the selection of a pavement surface type during cost studies following selection of the route. The District Soils Engineer is responsible for scheduling these surveys.

1. Corridor Study. Some borings at critical locations along a corridor may be desirable when selecting a route, but they are not required as a matter of routine. Additional information on physical features such as rock outcrops, swamps, and other obstructions that might affect the roadway alignment should be included. Generally, high altitude photos of one to 24,000 USGS Quad sheets are of adequate detail for reference. There is not much need for this type of survey at the present time.

2. Pavement Selection. Borings1.5 to 3 meters (5 to 10 feet) deep on 150 to 300 meters (500 to 1,000 foot) centers are performed as part of the pavement selection process. The drilling frequency depends upon the variability of the subgrade as well as the encountered terrain. The shorter, 500-foot spacing is recommended when the existing conditions are highly variable or erratic. Even shorter spacing may be required for particularly erratic areas. Such problem areas could include swamp crossings, deep cuts or fills, or areas of observed seepage. Reference maps and the accuracy of boring locations will vary with this type of survey, from one to 24,000 USGS. Aggregate sources should be identified as a part of the pavement selection survey.

4-1.02.02 FOUNDATION

Data for the design of bridges, large culverts (more than 7.4 square meters (80 square feet)), retaining walls, and buildings are obtained from a Foundation Survey. The Foundations Unit (Office of Materials) is responsible for scheduling these surveys and will provide all drilling and sampling, laboratory testing, and foundation recommendations. In addition, the Foundations Unit will provide piezometer and/or slope inclinometer installations where detailed stability analyses
need to be performed. The District Soils Engineer may also be involved in reading the piezometers and slope inclinometers and performing other data gathering to assist the Foundations Unit.

4-1.02.03 GEOTECHNICAL AND PAVEMENT

Soil, rock, and ground water information is included in geotechnical and pavement surveys along with construction recommendations. Borings are usually spaced at intervals of 30 meters (100 feet) along the proposed grade of the highway depending on expected and encountered conditions. These borings should extend at least 1.5 meters (five feet) below the proposed or existing grade in cuts and fills. A minimum of one boring per fill section should extend to a depth equivalent to the proposed fill height. The maps used for these surveys should be adequate to locate the borings accurately to 1.5± meters (5± feet) horizontally and 0.15± meters (0.5± feet) vertically. Borings should never be terminated in unusually soft or unsuitable soils, or at a level above the ultimate frost penetration depth unless specifically directed. The Foundations Unit (Office of Materials) should be notified if such unsuitable soils are encountered so that they may schedule additional borings, sampling, and testing as required.

Questions regarding bedrock (auger refusals, rock type, backslope design, excavation characteristics, etc.) and groundwater can be directed to the Geology Unit (Office of Materials). The survey information can be obtained using both destructive and non-destructive testing (NDT) means.

1. Destructive Methods. Destructive methods include borings, pavement cores, and test pits.

   a. Borings. Machine-advanced flight auger borings are used to obtain soil information on every bridge and culvert project, among others. It is best to use the drill rigs wherever possible because they normally provide more consistent results; however, hand augers may be used in locations inaccessible to the rigs.

      Materials encountered during these surveys are visually described (Section 3-2.01.01) and sampled in the field. These samples are taken either from the cuttings as the hole is advanced or, preferably, from the auger as it is withdrawn from the hole (Section 4-2.04.02). Following completion of the boring, the hole should be backfilled in accordance with current Minnesota Department of Health Regulations. These regulations are summarized in Section 4-2.08.

   b. Pavement Cores. Cores cut through existing pavements are used to provide material samples for laboratory analysis and measure the pavement layer thicknesses. In addition, the relative amount of stripping can be observed for bituminous pavements.

      The laboratory analysis of pavement cores produces much useful information. The gradation and moisture properties of non-stabilized granular bases can be determined if the base is not overly contaminated with coring water. A visual examination of a core taken at a PCC joint or crack will provide information about the condition of the joint. Many other properties of the surfacing material (Portland cement concrete or asphalt) can be determined from laboratory tests performed on the extracted cores. The core holes are typically backfilled with either a hand-tamped cold mix patch or hand-batched concrete.

   c. Test Pits. Backhoe-dug test pits may be used for shallow soil exploration in areas inaccessible to the drill rig. Test pits may also be used in pavement areas, in lieu of cores, to obtain a larger sample of the base and subbase aggregates.
This is often done to test the reusability of the pavement materials. Excavated test pits should be backfilled with thin lifts of the cuttings or other suitable fill material and properly patched, if necessary.

d. Dynamic Cone Penetrometer (DCP)  The DCP is a rapid hand-held testing device that can be used to quickly test dozens of locations along the alignment. The information obtained with the device can be used to supplement, verify, and/or correlate test results with subsurface conditions determined from soil borings and pavement cores.

2. Nondestructive (NDT) Methods.  NDT methods may be a good option for the exploration of new or operational pavements and subgrades. These include ground-penetrating radar (GPR), static and dynamic deflection measuring devices such as the Falling Weight Deflectometer (FWD), skid testing equipment, and geophysical methods including seismic, resistivity. In addition, a number of more specialized devices have been used in pavement applications. These include the Transient Dynamic Response (TDR) device (which has been used for detecting subsurface voids), the half-cell potential survey (which has been used to detect corrosion in reinforced pavements), spectral analysis of surface waves (SASW) (which has been used to characterize the strength and thickness of surface layers), and wave propagation (which has also been used to identify layer properties).

a. Radar Equipment.  Several companies market radar instrumentation capable of identifying subsurface properties. These devices send short radar pulses that pass through pavement materials but are reflected back to the surface by layer interfaces. This equipment is able to survey pavements at speeds of up to 65 km/hr (40 mph) when mounted on vehicles. The data is then analyzed for layer thicknesses, the presence of voids, and the presence of subsurface moisture. It has also been used to locate buried objects, such as utilities.

b. Deflection Equipment.  Deflection measuring equipment has been in use for many years. Originally, static deflection devices, such as the Benkelman beam, were used to measure the response of a pavement to a known applied load. Dynamic deflection devices have received more widespread use in recent years as they have been found to more accurately and rapidly simulate the moving loads applied to a pavement. The responses from deflection measuring equipment have been used to estimate layer strengths and subgrade moduli for both asphalt concrete and Portland cement concrete (PCC) pavements. In addition the responses have been used to identify the location of voids at joints and assess the degree of load transfer across joints in PCC pavements. More discussion on this topic is found in Section 4-3.0.

c. Geophysics.  Resistivity and seismic surveys are the geophysical methods most commonly used by the Geology Unit to explore subgrade materials. The resistivity method utilizes electrical currents to determine subsurface material characteristics, while seismic refraction/reflection utilizes seismic waves to measure vertical and lateral changes in soil and rock materials. Geophysical methods are non-destructive tests that are particularly useful when a drill rig cannot be utilized, e.g., in areas of rough terrain, crop lands (or other non-accessible areas), or where auger drilling meets "refusal" and it is uncertain whether the refusal is on a boulder layer or on bedrock.

d. Skid Testing Equipment.  A locked-wheel trailer is used to evaluate the frictional properties/characteristics of the pavement surface.
4-1.03 ACCESS AUTHORIZATION

Before driving onto the site, it must be verified that the property owner has granted authorization to enter and drill borings. Any lessees and/or regular users of the property must have knowledge of the authorization, as well. This authorization should be obtained in writing prior to any mobilization, excepting locations on State-owned right-of-way.

4-1.04 UTILITIES

Utilities (including gas, electric, water, sewer, and telephone) must be located prior to drilling. In lieu of contacting each utility company directly, a centralized utility location service called the "Gopher State One Call" may be used. This service requires that the exact project location and limits be phoned in (St. Paul/Minneapolis area, 651-454-0002; other areas, 1-800-252-1166) at least 48 hours in advance. Whenever possible, and certainly in locations where numerous or critical utilities are located, it is still recommended that the Drilling Foreman meet utility representatives at the site for an orientation.

4-1.05 SAFETY

Each and every job undertaken by Mn/DOT will be more successful within a safe environment, regardless of size or deadlines. Drilling operations immediately come to mind when considering safety, and that is the main thrust of this section. However, other office and field activities, travel between work and home, and our many personal activities must also be included. Safety is not just the responsibility of one person, but is everyone's job.

Most accidents can be prevented. The use of common sense, application of learned safety practices, and proper training will help achieve a safe drilling environment. Your health and safety, and that of your coworkers, depends on how well you practice safety. Each employee is responsible for his or her own personal safety, the safety of their fellow workers, and for using available safety devices prescribed for accident prevention. Refer to Mn/DOT's Safety and Health Guidelines for more complete coverage of safety issues.

4-1.05.01 TRAINING

All workers must be trained so that they are aware of their job duties, requirements, and safe working practices. This is particularly important with new employees. A new worker cannot be expected to be immediately familiar with all of the dangers or hazards associated with a job.
It is the Drilling Foreman's responsibility to take charge in knowing, observing, and enforcing safe working practices. New workers learn from this leadership both informally, through the observation of the proper use and maintenance of equipment and protection devices, and formally, through participation in on-the-job safety meetings. Part of this training involves applying the following steps:

- Tell the new worker what must be done.
- Warn of any known dangers or hazards.
- Show how to do the job in a safe manner.
- Watch closely as the work is done, to see if safety precautions are applied.
- Don't allow new employees to work alone until there is certainty of their ability to do so safely.

Whenever possible, the Drilling Foreman and coworkers should work in pairs or groups, continuously observing and improving each other's safety practices. This approach is also important in the event that an accident resulting in personal injury or incapacitation of one of the workers occurs.

4-1.05.02 PERSONAL GEAR

Each employee is responsible for obtaining, using, and maintaining their own personal protective gear. In general, the requirements for this equipment are that it be comfortable and not unduly restrict the worker's ability to perform their job while, at the same time, providing significant protection from a danger or hazard. The following gear is included.

1. Clothing and Footwear. Obviously the type of work being performed and prevailing conditions dictate the proper clothing. However, some generalizations can be made. Clothing should be seasonal to provide protection from the elements. Shirts and full-length pants must be worn, even in the summer months, because of the protection they provide from sun, weeds, and insects. Clothing and accessories, including jewelry, should not be loose or baggy as these have a tendency to get caught in rotating or moving parts of drilling equipment and other machinery. Heavy cloth or leather gloves should be worn to protect the hands from cuts and abrasions from burrs and sharp edges during the handling of drilling tools, equipment, and supplies. Steel-toed shoes or boots are required at all times for field crews engaged in drilling or support activities to protect the feet from falling objects.

2. Reflectorized Safety Vests. Whenever an employee is working on the right-of-way in a construction or a maintenance work area, or on the roadway where vehicles are moving, the employee is required to wear a reflectorized safety vest. These are of great value in increasing visibility to other vehicle operators. Reflectorized safety vests are available through the District stock rooms. They should be available on the drill rig and used by each and every member of the crew.

3. Safety Helmets or Hard Hats. Hard hats should be worn whenever drilling operations are underway or when any other overhead hazards exist. This includes all times on the work site: loading and unloading, setting up, tearing down, and drilling. Headband and crown straps should be adjusted for a comfortable fit to encourage full-time use of the hard hat. Hard hats can also be fitted with a cotton liner to provide additional protection to the head and ears during cold weather. Hard hats and liners are available for each employee in the District stock room.

4. Safety Glasses or Goggles. A common rule to remember is that safety glasses should be worn at all times a hardhat is worn. They are required at all times on the work site: loading and unloading, setting up, tearing down, and drilling. They should also be worn...
to protect the eyes at any other time when there is a danger of flying dust or debris, such as when cleaning equipment or chipping ice. Prescription safety glasses or plain-glass goggles are available for each employee in the District stock room.

4-1.05.03 VEHICLES AND TOOLS

Vehicles and tools can be used safely provided they are used with common sense, that learned safety precautions are applied, and that they are periodically inspected and maintained in a safe working condition. All of the generally learned precautions apply with regard to vehicular safety. For example, care should be taken to avoid getting in the way when drilling or support equipment is being moved, particularly when vehicles are backing up and the driver's vision is obstructed. When traveling in vehicles, safety seat and shoulder belts must be worn at all times.

As a part of the Department's approach to safety, each driver is responsible for vehicle maintenance including proper operation, care, and appearance. As a minimum, the following care of the vehicles is required:

- Correct lubrication;
- Checking and maintaining oil levels;
- Proper care of tires;
- Checking and keeping the cooling system, fan belts, battery, and air cleaner in good working order;
- Checking for and tightening loose bolts and parts; and
- Cleanliness and appearance.

Equipment is to be serviced whenever practical and as consistently as possible, at the District Maintenance Shop.

4-1.05.04 SITE HOUSEKEEPING

The general cleanliness of a site greatly contributes to safe operation. The site and equipment should be kept neat and orderly, with all tools and supplies assigned to a safe and accessible storage spot. Work areas should be free of excess mud, ice, spilled lubricants, and other debris that could cause workers to slip, trip, or otherwise injure themselves.

4-1.05.05 NATURAL OR MAN-MADE HAZARDS

There are many dangers or hazards that can affect the safe operation of drilling equipment. Some of these are discussed below.

1. Utility Lines. Both overhead and underground utilities can be hazards to a safe drilling operation. Telephone and telegraph lines, video (cable), and electrical transmission lines may be located overhead. The minimum safe distance between the drill's mast and telephone and telegraph lines is 15 feet. The minimum safe distance between the drill's mast and electric transmission lines or video (cable) is dependent on the power being carried in the line; however, in the absence of other specific information, a distance of at least 35 feet should be maintained. Extra care must be taken when drilling around overhead utilities so that the workers do not become complacent relative to the presence of the utilities. It is surprisingly easy to forget, after a long day of drilling, that the utility lines are still there.

Underground utility lines include water, sewer, telephone and telegraph, video (cable), gas, and electric; these can be particularly dangerous to the safety of the crew and equipment because they can't be seen. See Section 4-1.04 for instructions on using the "Gopher State One" program to locate these hazards. All probing beneath the earth's
surface should be done a minimum of 10 feet from the identified location of these utilities.

2. Electrical Storms. To prevent injury from lightning strikes, drilling operations should not proceed when there is the threat of an electrical storm. In these situations, the mast should be lowered until the storm passes whenever possible. The drill crew should move away from the drill equipment and into a safe area.

3. Inclement Weather. In situations where it is too unbearable or impractical to drill, such as rain, snow, severe heat, or severe cold, other activities should be conducted. The possibility of heat stress or heat stroke exists in extremely hot weather. Frostbite and hypothermia are dangers in extremely cold weather.

A salamander or L.P. gas heater may be used during cold weather to augment the standard cold-weather equipment. With either type of heater, special care must be taken in transport, setup, and fueling.

4. Over Water or Ice. When working over water, such as a swamp crossing or on ice, each member of the crew should wear a life vest or preserver.

Before moving any equipment over ice be sure that the ice thickness and condition are adequate for support. The Department's experience indicates that a minimum of 16 inches of good ice is required to support the average loaded truck. If the ice is soft, a minimum of 24 inches is required. If the ice is honeycombed or has undercurrents, no attempt should be made to traverse the ice with equipment. The Drilling Foreman is responsible for the safety of such movements over ice.

5. Toxic or Hazardous Substances. If an area is suspected of being contaminated with toxic or hazardous substances, the District Soils Engineer should not attempt drilling. Instead, a request for such drilling should be directed to the Environmental Services Section (Office of Technical Support). They will then schedule the drilling, which will be done by the Foundations Unit (Office of Materials) or a consultant, depending on the current workload and/or anticipated hazard level.

If a previously unidentified toxic or hazardous substance is encountered during what was thought to be a routine exploration, the drilling should be immediately stopped and the Environmental Services Unit contacted for instructions.

4-1.06 TRAFFIC CONTROL

Extra care must be taken when working or standing on the shoulder of or in an existing roadway. It is the Drilling Foreman's responsibility to implement the use of flagmen, barricades, warning lights, arrow boards, message boards, and other safety precautions, as well as coordinating their use with state, county, or city authorities.

Work which affects vehicular or pedestrian traffic should be provided with traffic control that is in accordance with the current edition of Appendix B, "Traffic Control for Short Term Street or Highway Work Zones." The Appendix is a supplement to Part VI of the Minnesota Manual on Uniform Traffic Control Devices (MMUTCD). This Appendix is intended to show applications of the basic principles to be observed when performing short-term work on any street or highway.
4-2.0  GEOTECHNICAL SURVEY

4-2.01  PURPOSE

The purpose of a geotechnical survey is to determine the nature and physical properties of foundation soils, identify construction concerns, and locate sources of construction materials.

4-2.02  OFFICE STUDIES

The first steps in completing a geotechnical survey are performed in the office, prior to going into the field. First, the project is classified as either a thin overlay, resurface, recondition, reconstruction, major reconstruction, or new construction project. This will provide an indication towards the extent and complexity of the required survey, analysis, and design recommendations. Next, a review of existing information should be made. This review includes anticipated geologic conditions of the project area, collections of personal experience, and a review of the area’s construction history. Lastly, planning of the field operations can begin after reviewing the above documents and information.

4-2.02.01  PRELIMINARY PLANS

The proposed route and grade are part of the preliminary plans. Many of the conditions that could potentially cause problems can be identified and planned for by studying these plans. Included are swamp crossings, major cut and fill sections, and the presence of existing buildings or features. District Soils Engineers should be informed of the early project scoping and preliminary location/layout work so that potential obstacles and problems such as slides, unstable ground, groundwater, and rock can be avoided or planned for.

4-2.02.02  MAPS

Maps will be useful in determining the extent to which the physical site conditions will influence construction. Particularly useful are topographic and geologic maps, which can be used as guides in planning the investigation and defining areas of concern for the site reconnaissance. Agricultural maps are likely to be of limited value, because they usually deal only with the surficial deposits and do not provide much insight to the engineering properties of encountered materials.

4-2.02.03  PREVIOUS WORK

Studies and construction plans completed for the existing or nearby projects can be useful in identifying problem areas. In particular, previous investigations (Design Recommendations Reports) and existing construction records (including the Construction Log) that give a history of the roadway should be useful in planning the investigation.

4-2.02.04  MAINTENANCE INPUT

A valuable, but often overlooked source of information is the past maintenance records. An interview with the Maintenance Supervisor and review of maintenance documents can provide site information/concerns including past performance, history, and frequency and type of repairs.

4-2.02.05  ENVIRONMENTAL CONCERNS

Any environmental-related information, relative to what might be encountered during the geotechnical survey and its impact on design, should be reviewed. Included are the possible presences of old underground storage tanks, hazardous or toxic spills, etc.
4-2.02.06 AGGREGATE SOURCES

There are several aids available to identify potential new and existing aggregate deposits and their characteristics. Gravel pit condition surveys are regularly performed at the District level and filed with the Aggregate Unit (Office of Materials). This unit maintains a statewide master file of aggregate source information consisting of aggregate source maps ("pit sheets") and a computer file known as the Aggregate Source Information System (ASIS). It is described in detail, along with information on leasing procedures, in the following paragraphs.

The District Soils Engineer, in cooperation with the Aggregate Unit, should identify potential and existing aggregate sources to determine their characteristics and extent. New sources are routinely located and tested, and existing sources occasionally have their boundaries extended by the Aggregate Unit. The Aggregate Unit's Geologist routinely conducts prospecting statewide, using aerial photo interpretation and geologic field reconnaissance. This activity often results in the initial contact with the property owner. The "Gravel Exploration and Leasing" information sheet is then given to each property owner who is contacted for preliminary testing. This form (which is shown in Appendix A1) is available to the District and may be used in a similar manner by the District Soils Engineer.

Bedrock quarries are always privately owned and rarely leased by the State as sources of aggregate material. Information on quarries and rock quality can most easily be obtained from the Geology Unit (Office of Materials).

New aggregate prospects, as well as existing aggregate sources which require additional or updated information, are drilled and sampled by the Aggregate Unit using a 250-mm (10-inch) diameter auger rig. The District often performs preliminary testing and sampling. To improve the gradation results, it is recommended that at least a 150-mm (6-inch) diameter auger be used instead of the standard 115-mm (4-1/2-inch). The Aggregate Unit should be equipped for both preliminary and final testing of aggregate sources. Requests for such assistance should be addressed to the Aggregate Engineer.

If gradation and quality results from the preliminary testing are acceptable, either the District Soils Engineer or the Aggregate Engineer should submit an aggregate source leasing request to the District Right-of-Way Office for possible leasing. Before this lease is signed the State Historical Preservation Office (SHPO) must clear the property. If a District is initiating a lease, they should contact the Aggregate Unit. The Aggregate Unit will facilitate the SHPO clearance through Mn/DOT Cultural Resource Unit. Most leases negotiated with property owners are written on Mn/DOT Form 25681, entitled "Non-exclusive Material Pit Lease." This form is included in Appendix A2. This non-exclusive lease does not require a lump sum payment by Mn/DOT, nor does it prevent the owner from selling aggregate to others while the Department's lease is in effect. This type of lease is usually more acceptable to the property owner than an exclusive lease, which reserves the materials for the exclusive use of the leaseholder, e.g., Mn/DOT. Almost all private road contractors obtain exclusive leases from property owners to ensure a known supply of aggregate for their use.

More thorough sampling using the Aggregate Unit's 250-mm (10-inch) diameter auger is scheduled following the acquisition of the lease. Some coarse deposits may require trenching or other exploration methods. Generally, the spacing of the borings should be on a 30.3-m (100-foot) grid, with closer spacing in erratic deposits and possibly greater spacing in uniform deposits. A representative sample should be taken from each boring every 3 m (10 ft) or at each substantial change in the appearance of the material. When the material extends below the water table separate samples should be taken above and below the water table and the water level recorded. Samples may be tested at either the District or Office of Materials Laboratory.

All new aggregate source surveys are done by electronic methods, and the resultant pit sheets are placed on a USG contour map. Electronic and hardcopies of new and revised pit sheets are sent to District offices on a routine basis. Following the completion of a pit sheet, an analysis of the deposit as well as quality and quantity computations are made by the Aggregate Unit and entered into ASIS, a computerized data base available to all Department offices through the Aggregate
The ASIS database is updated daily, however there is a lag time between when the web site is updated. For the most current version of ASIS, contact the Aggregate Unit.

ASIS consists of a master file of some 7,300 Mn/DOT-owned, Mn/DOT-leased, commercial aggregate sources (gravel pits), and rock quarries (separate from gravel pits, which are never referred to as quarries). A unique identifier, called a "source number" (replacing the old "gravel pit number") is assigned by the Right-of-Way Property Management Unit (Office of Right-of-Way and Surveys) to each source. Each record contains data on location, status, owner/operator, date of lease expiration, date of last revision, date of last condition survey, and quality and quantity information. The majority of sources identified in the ASIS database represent privately owned aggregate deposits which have, at one time or another, been leased by the Department but which are not currently in use.

When the District requests that ASIS be updated, they must notify the Aggregate Unit.

Gravel pits that are recommended as "possible aggregate sources" either by the District Soils Engineer or the Aggregate Unit and are listed in the project plans should be field checked by District personnel or the Aggregate unit approximately one year prior to the project letting date. If conditions have changed, the pit should be resurveyed and the new information should be promptly forwarded to the Aggregate Unit.

Locations of aggregate sources contained in ASIS are shown by symbols on Mn/DOT county map sheets, which are maintained on the Aggregate unit web site. The "status" field in ASIS refers to one of five source symbols shown on the county maps. The status categories and map symbols are discussed below.

A = Active. Indicates an active file in the Aggregate Unit office, however, this does not definitely indicate whether or not the source is producing aggregate at the present time. In fact, such a source status (and symbol on the map) may indicate nothing more than an aggregate deposit that was at one time tested and leased by the Department but from which no material has ever been excavated.

I = Inactive. Indicates an inactive file in the Aggregate Unit office, where the aggregate source is either depleted or unavailable for further use by the Department. If future circumstances make an Inactive source available, the status may be changed to Active.

Q = Quarry. Indicates a bedrock quarry. Most of the quarries presently listed in ASIS and identified by this symbol on the county maps are found in southeastern Minnesota's limestone/dolostone deposits. Igneous and metamorphic bedrock quarries in other parts of the state may also be added when they are adequately identified and assigned source numbers.

C = Commercial Aggregate. Indicates a known commercial source of aggregate that has never been leased by the Department but which has been assigned a source number in ASIS to facilitate tracking of test results if and when the source is used by the Department or counties in the future. These sources are often used for concrete aggregate and are also identified in the Concrete Office's COPES - PIT database at the Office of Materials (Section V-A in the "ASIS Users Guide").

M = Mn/DOT owned aggregate pit. These aggregate sources are owned by the Department and number about 450 throughout the state. Department-owned sources that contain usable reserves of aggregate, especially where private sources are unavailable or in short supply, should be recommended and listed in project plans. Private road contractors can use them only if they are listed in the plans prior to the bid letting. Requests for use of Department-owned pits are occasionally made by private road contractors for projects they have been awarded, but where the pit was not previously listed in the project plans. In these cases, such "after the fact" use is not permitted, because it could be construed by others as providing unfair advantage to the successful bidder.
Mn/DOT prohibits the use of Class 5 and better materials for common and granular borrow to ensure the "best use" of Mn/DOT-owned materials. The above restriction continues to apply even if a Mn/DOT-owned source is shown in the plans because it is recommended as a possible source in the Design Recommendation Report (Section 1602 of Mn/DOT's Specifications).

It is important to keep in mind that a privately owned or leased aggregate source should only appear in project plans as a possible source if the term of the lease extends through the anticipated construction period. One way to ensure the availability of a gravel source, in lieu of an outright purchase by the Department, is the negotiation of an exclusive lease. These are most commonly negotiated for five to ten year periods with an initial lump sum payment to the owner.

Aggregate source information is supplied by the Aggregate Unit whenever a District Engineer requests a Surface Type Determination for a new project. This information is furnished on Mn/DOT Form TP-02471-02 (7-83) and is primarily for the purpose of preparing cost estimates by the Estimating Unit (Office of Technical Support). The sources listed on this form do not necessarily have current leases, and many are commercial sources that have never been leased by Mn/DOT. Therefore, these sources should not be listed as "possible sources" in the Design Recommendation Letter unless it is known that a current lease exists (or will be forthcoming from Right-of-Way).

"Natural Materials Sources" (Section 1602 of Mn/DOT's Specifications) contains additional information on aggregate source acquisition, use, and rehabilitation.

4-2.02.07 BORROW SOURCES

The District Soils Engineer reviews the proposed alignment and grade and works with the designer at the District level to determine the need for borrow material. Identification of past borrow operations, as well as a general knowledge of geologic conditions along the project alignment, can aid in identifying potential borrow sources.

4-2.02.08 EXISTING TOPOGRAPHY, VEGETATION, AND DRAINAGE

A study of an area’s topography, vegetation, and drainage can provide a good deal of useful information, including the identification of potential problem areas. Examples are steep slopes (which could require stability studies), rock outcrops (which could indicate anticipated subsurface conditions), and thick underbrush or wet areas (which could require underdrains or other special treatment).

4-2.02.09 EXISTING STRUCTURES

The condition of existing privately owned structures, particularly adjacent to deep cuts or fills, should be assessed and carefully recorded. The condition of these structures should be documented by photographs at several points during construction. Similarly, there may be a need to replace or extend existing roadway structures, such as the extension of culverts for shoulder/slope widening projects.

4-2.03 BORING PLAN

Boring locations should be planned by the District Soils Engineer utilizing all of the information gathered in the office studies described in the previous section and in accordance with the following guidelines.

4-2.03.01 SOILS

Subsurface conditions and materials are assessed through the use of disturbed borings, undisturbed borings (for foundations), test pits, or hand augers. Borings should be deep enough to develop the engineering data required for analysis and should penetrate major soil horizons, frost depth, and frost-susceptible materials. Borings should be taken to a depth of at least 1.5 m (5 ft) below the proposed grade line in cut areas and at least 1.5 m (5 ft) below natural ground in fill sections. At
least one boring in each fill section should extend to a depth equal to the height of the proposed fill. Generally, borings are extended to depths of 1.5 to 3 m (5 to 10 ft) and are located at approximately 30 m (100 ft) intervals, but consideration needs to be given to the variability of the subsurface conditions encountered along the planned alignment and grade. The boring plan should be adjusted accordingly to reflect changing conditions. On divided highways, the borings on the two roadways may be staggered.

Where non-uniform subgrade soils or water conditions are encountered, boring intervals should be decreased. The importance of recognizing non-uniform conditions is that they are often to blame for poor pavement performance and need to be specifically addressed by the District Soils Engineer or District Design Engineer in their design recommendations.

In general, sufficient numbers of borings must be taken so as to develop typical and representative cross-sections and profiles to identify and delineate all geological conditions that have a significant effect on the project design and construction.

4-2.03.02 ROCK

Boring intervals should be decreased and additional borings should be taken as needed on cross sections when there is evidence of bedrock or if refusal occurs above the planned bottom of boring. The number of borings required depends on the anticipated rock variability and length of cut. When there is evidence of bedrock above the proposed grade line, rock coring will be required. Requests for geological work, geophysical work, and/or rock coring should be made through the Geology Unit, with copy to Foundations Unit (Office of Materials).

4-2.03.03 GROUND WATER

Ground water levels vary with season, precipitation, infiltration, and other factors. The level and rate of inflow of the ground water should be determined both during and after drilling (preferably 24 hours), so that the need for long-term observation methods can be evaluated and the effect of ground water on the roadway design can be considered. When water is encountered in a boring, it should be reported as a "water level" or "water encountered" unless the specific occurrence of the water is known, i.e., water table, perched, artesian.

Both short- and long-term methods can be used to observe the ground water level. Short-term methods are relatively quick and easy, and include observing drilling tools and cuttings during the drilling operations for water contact and measuring the depth from the ground surface to the water level after the boring is finished. These observations are more reliable in pervious soils, such as sands and gravels, than in clayey soils of low permeability. In clayey soils, the ground water may not have had time to stabilize and/or the sides of the borehole may have become smeared, either of which can give the impression that the ground water table is deeper than it actually is.

More reliable methods of determining ground water levels include referencing historical ground water levels in the area and performing long-term measurements, such as the installation of piezometers. The Foundations Unit (Office of Materials) should be contacted if long-term measurements become necessary.

(Note that the installation and abandonment of wells, peizometers and bore holes penetrating the groundwater table is regulated by state laws and regulations and shall be pursued only by qualified persons in compliance with all applicable rules).

4-2.03.04 SWAMP AREAS

Boring intervals should be decreased and additional borings should be taken as needed on cross-sections to better determine the extent and composition of swamp areas. A minimum of three borings is required for each section when relatively uniform swamp bottoms are encountered. These borings are usually taken at the centerline and on each side of the roadway halfway between the shoulder P.I. and the toe of the slope. At least one boring should extend 15 feet below the apparent swamp bottom to provide adequate evidence against a false bottom. Resistance
soundings, which consist of advancing the augers without sampling and recording the level where resistance is felt (assumed bottom of swamp), may be used to supplement boring information.

Scheduling of work in swampy areas is important. It may be easier to access the site during winter months when the swampy area is frozen. If it is determined that excavation of the swamp will result in injury to persons or damage to adjacent facilities, or if a floated embankment is desired, the Foundations Unit (Office of Materials) should be contacted to obtain undisturbed samples, install piezometers, and/or perform stability studies.

### 4-2.03.05 DEEP OR SIDEHILL CUTS

Care should be taken in determining the soil and water conditions present whenever deep or sidehill cuts of appreciable magnitude are proposed. In such areas, boring intervals should be reduced, and borings should be taken along the centerline as well as the edge of the roadway. Where general instability could create a problem, borings should be placed on sections perpendicular to the centerline on the uphill side of the cut. Where buildings or structures are located adjacent to the crest of slope, the Foundations Unit (Office of Materials) should be notified so that undisturbed sampling, piezometer installation, and/or stability studies can be performed.

### 4-2.03.06 SETTLEMENT/FROST HEAVE/SLIDE AREAS

Ground movements should be monitored through the use of field surveys, the installation of slope inclinometers, etc. Level surveys should be performed in both the winter and summer to determine differential transverse and longitudinal heaving. It may be advisable to set frost-free benchmarks for winter and summer reference.

Although the Foundations Unit (Office of Materials) has the responsibility to analyze the effects of ground movements, the District Soils Engineer plans the survey work, coordinates it with the Foundations Unit and other offices within the District, and may assist in obtaining field measurements.

### 4-2.03.07 AGGREGATE SOURCES

Proposed aggregate sources should be explored a number of borings sufficient to determine the quantity and quality of aggregate available. These borings are usually spaced on a 30.5 m (100 ft) grid pattern, although the grid should have tighter spacing in erratic deposits and may be looser in especially uniform areas. The Aggregate Unit (Office of Materials) may be contacted to perform the initial investigation or when more thorough sampling is required after a lease is obtained. Reference is made to Section 4-2.02 and the Appendix A6, which describes the Department's ASIS system.

### 4-2.03.08 BORROW SOURCES

Potential borrow sources should be explored by sufficient borings to determine the quantity and quality of borrow materials and the level of the ground water table. Borings should be extended 1 m (3 ft) past depth of planned excavation and spaced on a 30.5 m (100-ft) grid pattern, or closer in the case of non-uniform deposits. The Foundations Unit (Office of Materials) may be contacted to obtain undisturbed samples if accurate shrink/swell factors are desired.

### 4-2.03.09 STRUCTURE FOUNDATIONS

It is the responsibility of the District Soils Engineer or District Design Engineer to notify the Foundations Unit (Office of Materials) of the need to perform a Foundation Survey (Section 4-1.02.02).

Small culverts, defined as those less than 7.4 square m (80 square ft) in size, may be investigated by the District. A minimum of three borings should be planned on a section along the culvert alignment in these situations. The borings should be extended to provide subsurface and groundwater information to a depth below the proposed culvert footing equal to at least twice the width of the footing.
4-2.04 SAMPLING PLAN

4-2.04.01 PURPOSE AND TYPE OF SAMPLES

Disturbed and undisturbed samples of subsurface and pavement materials must be obtained for laboratory analyses (and/or tested in the field) to determine their engineering properties. The extent of the program depends both on the nature of the project and the site-specific subsurface conditions.

Undisturbed samples, defined as intact specimens of material that are minimally altered from their in-situ condition, are required to test for those properties that are controlled by the overall material mass, such as strength and permeability. Disturbed samples, defined as samples that are broken up and/or remolded, can be used for determining properties that are controlled by the individual components of the material such as the grain-size distribution and Atterberg limits. The following paragraphs discuss these samples and the procedure for obtaining them.

1. Disturbed Samples. Disturbed samples are taken by the District with augers in accordance with AASHTO T 203. The augers are rotated and advanced into the soil the desired distance. They are then withdrawn (pulled dead) from the hole and the soil is removed for examination and testing. Samples may also simply be obtained from the auger cuttings.

   For testing purposes, minimum sample quantities needed for the required tests are given in Table 4-2.1.

2. Undisturbed Samples. Undisturbed soil samples and rock cores required for foundation design are obtained by the Foundations Unit (Office of Materials).

---

Table 4-2.1. Required sample quantities.

<table>
<thead>
<tr>
<th>Test</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradation for granular material</td>
<td>9-14 kg (20-30 lb)</td>
</tr>
<tr>
<td>Gradation for cohesive material</td>
<td>4.5 kg (10 lb)</td>
</tr>
<tr>
<td>Gradation and moisture-density for cohesive material</td>
<td>11-14 kg (25-30 lb)</td>
</tr>
<tr>
<td>Fertility</td>
<td>4.5 kg (10 lb)</td>
</tr>
<tr>
<td>R value determination</td>
<td>27 kg (60 lb)</td>
</tr>
<tr>
<td>pH for surface water</td>
<td>0.5 liter (1 pint)</td>
</tr>
<tr>
<td>pH for soil</td>
<td>450 g (1 lb)</td>
</tr>
</tbody>
</table>

Pavement Cores are used for measurement of the pavement/base thickness and evaluation of the condition of the existing roadway. They are obtained by the District.
4-2.04.02  SAMPLING FREQUENCY AND DEPTH

1. Borings. When possible, it is advantageous to screw the augers into the ground slowly and then pull them out without rotation (pulled dead); this allows for a better visualization of the changes/transitions in the stratigraphy. Representative samples of each material type that is significant to the project design or construction should be saved for classification, \( M_r \) and R-value determination, and turf establishment testing. It is common to obtain one soil sample for subsequent classification testing at every 1.5 m (5 ft) penetrated as well as every significant change in material type. More frequent sampling may be dictated by unusual soil conditions.

Samples for classification, R-value, and/or \( M_r \) testing should be obtained of the material that will be placed in the upper 1.2 m (4 ft) of the subgrade. For investigations of potential aggregate sources, a representative sample of the material should be taken from each hole for each substantial change in the appearance of the material as well as at least one sample for each 3 m (10 ft) of penetration. Separate samples from above and below the water table should be taken where the material extends below the ground water table. Samples from auger-bored holes deeper than 12 m (40 ft) are not considered reliable because of the disturbance and displacement of materials as they rise on the auger.

Minimum sampling rates required for various tests are listed below.

a. R Value and resilient modulus. Table 5-3.1 establishes guidelines for the frequency of sampling for the determination of R-values as a function of the soil classification. These guidelines can be assumed for \( M_r \) testing until a new protocol is established.

b. Fertility. Where the topsoil is to be removed and replaced to provide planting soil, samples should be taken at the approximate rate of one per mile from the full depth of the topsoil to be removed. Additional samples are required if there is a major change in soil type.

If the topsoil is not being replaced, samples should be taken from all horizons that will be exposed and expected to support some type of turf. In this case, the sampling rate should be one per horizon per mile.

c. pH. pH values are obtained for turf establishment recommendations and culvert type determination. Water samples for pH determination should be obtained from all stream, river, or waterway crossings that might require a culvert installation. Soil pH samples should be obtained as needed.

2. Test Pits. Random representative samples of the materials encountered during test pit excavation should be retained for subsequent classification, R-value testing, and/or \( M_r \).

4-2.05  FORMAT FOR GEOTECHNICAL SURVEY FIELD NOTES

Visual observations, the sequence of materials encountered in the borings, and the results of field tests should be carefully and accurately recorded. Most organizations use a "boring log," "record of subsurface exploration," or some similarly titled form for this purpose. The Department does not have a mandated form, but strongly recommends that each District Soils Engineer keep such data in a uniform, organized, and retrievable manner.

The record of each boring in the field book should be capable of standing alone, complete with all of the following information, entered in the order given:

- Project identification and number
- Boring location, typically by roadway station and offset left or right of centerline
- Method of drilling and sampling (e.g., flight augers with grab samples)
- Date of start and completion
- Names of drill crew members
- Surface elevation
- Description (Section 3-2.04) and depth of materials encountered
- Sample locations
- Ground water information when encountered and at recorded times after drilling
- Other pertinent information and/or comments

The accuracy of the recorded information is important because it becomes the basis for subsequent design recommendations. For example, the level of silt seams may impact frost design, wet or saturated layers may impact dewatering or drainage requirements, and shear planes or other discontinuities may impact a slope stability problem.

4-2.06 TESTS

Classification testing is routinely performed at the District level. All testing of undisturbed samples to determine engineering properties (including R value and/or \( M_R \)) is performed by the Office of Materials. Turf establishment testing (fertility) is performed for the Office of Materials by the University of Minnesota.

The following sections outline many of the tests that may be performed by the District or the Office of Materials on soil samples obtained for input into the design process. These descriptions are provided to give the District Soils Engineer adequate instruction and references to perform classification testing or to provide an understanding of testing performed by the Office of Materials. General reference is made to Mn/DOT’s Grading and Base Manual and/or Lab Manual, for detailed descriptions of the following tests. In the case of differences, preference should be given to the above-referenced Mn/DOT manuals.

4-2.06.01 MECHANICAL ANALYSIS

A mechanical analysis consists of a sieve analysis of a sample’s coarser portion and a hydrometer analysis of its fine-grained portion.

1. **Sieve.** A sieve analysis is used to determine the grain-size distribution of the portion of a soil not passing the 0.075 mm (No. 200) sieve. The method of performing a sieve analysis is presented in full detail in Section 5-692.215 of Mn/DOT’s Grading and Base Manual and Section 1200 of Mn/DOT’s Laboratory Manual. This test is based on AASHTO T 27.

2. **Hydrometer.** A hydrometer analysis is used to determine the grain-size distribution of the portion of a soil passing the 0.075 mm (No. 200) sieve. A brief description of the test procedure follows; for complete instructions, refer to Section 1302 of Mn/DOT’s Laboratory Manual. This test is based on AASHTO T 88.

The hydrometer analysis requires approximately 100 grams of soil passing the 2.0 mm (No. 10) sieve (or 50 grams of air-dried soil passing the 0.425 mm (No. 40) sieve). 100 grams should be used for sandy soils; and 50 grams should be used for silty or clayey materials. The resulting sample is then treated with 125 milliliters of sodium hexametaphosphate, a dispersing agent, and left to mix for 12 hours. After the 12-hour time period has elapsed, the material is mechanically dispersed for 60 seconds using a mechanical stirring device and placed in a glass container. Distilled water is added until
a volume of 1,000 milliliters is attained, then the container is shaken vigorously for one minute before being placed gently on a level table. Readings are obtained by using a hydrometer at intervals of 2, 5, 15, 30, 60, 250, and 1440 minutes. If temperature changes are possible within the test environment, then the temperature of the mixture should be taken at each interval.

The data is then reduced and recorded on a grain-size distribution chart that relates the percent passing (or retained) and the grain size.

4-2.06.02 ATTERBERG LIMITS

The Liquid Limit (LL) is defined as the water content of the soil at which a standard groove cut in the remolded soil sample will close, following 25 blows of the LL cup falling 10 millimeters onto a hard rubber base. The test begins with a fairly dry soil sample. Assuming that the groove in this sample does not close following the 25 blows, water is added and the process is repeated until the groove closes. A moisture content test is performed on the sample following the close of the groove to determine the LL. For further information, see Section 1303 of Mn/DOT's Laboratory Manual. This test is based on AASHTO T 89.

The Plastic Limit (PL) is defined as the water content at which a thread of soil barely crumbles when it is carefully rolled out to a diameter of 3 mm (1/8 in). For further information see Section 1304 of Mn/DOT's Laboratory Manual. This test is based on AASHTO T 90.

The Plasticity Index (PI) is the range of water contents over which a soil is plastic. It is determined by Equation 4-2.1.

\[ \text{PI} = \text{LL} - \text{PL} \]  
\[ \text{Eq. 4-2.1} \]

The liquid and plastic limit tests are performed on the minus 0.425 mm (No. 40) sieve fraction of the initial soil sample.

4-2.06.03 ORGANIC CONTENT

The organic content of a soil sample should be computed using AASHTO T 267 if the total percentage of organics is desired. AASHTO T 194 should be used if the suitability of the soil material for supporting growth is desired. The total percentage of organics method is briefly described below.

10 to 40 grams of oven dried (230°F ± 9°F) soil that pass the 2.0 mm (No. 10) sieve are weighed and placed into tared crucibles or porcelain dishes. Then, the sample and container are placed in an oven/furnace for six hours at 833°F ± 18°F. The sample and container are reweighed after the container has cooled. The organic content can be calculated using Equation 4-2.2.

\[ \text{Percent Organic Matter} = \frac{A - B}{A - C} \times 100 \]  
\[ \text{Eq. 4-2.2} \]

where

\[ A = \text{weight of container and oven dried soil before ignition, gm} \]
\[ B = \text{weight of container and oven dried soil after ignition, gm} \]
\[ C = \text{weight of container, gm} \]

4-2.06.04 IN-PLACE MOISTURE AND DENSITY

1. Moisture. The moisture content of a soil sample is most commonly determined using either the oven or the calcium carbide gas pressure (speedy moisture) method. These methods are covered in full detail in Section 5-692.250 of Mn/DOT's Grading and Base Manual. They are based on AASHTO T 217 (speedy moisture) and T 265 (drying oven).
2. Density. Many methods are available for determining the density of a soil mass. Among them are the sand cone, drive cylinder, rubber balloon, block sample, and nuclear methods. Initially, the wet weight, the volume, the moisture content, and the dry weight of the soil sample must be determined for each of these methods. From this information, the wet and dry density can be determined.

Specific instruction on the method normally used by the Department - the sand cone test - can be found in Section 5-692.242 of Mn/DOT’s Grading and Base Manual. The bases for these tests are AASHTO T 191 (sand cone), AASHTO T 204 (drive cylinder), AASHTO T 205 (rubber balloon), AASHTO T 233 (block sample), and AASHTO T 238 (nuclear method).

4-2.06.05 STRENGTH

The following strength tests are performed at the Office of Materials.

1. R Value. To determine the R-value, four separate samples of the soil are prepared that bracket the optimum moisture content of the soil as determined by a Proctor test.

After allowing these samples to stand overnight, they are compacted into a 101.6 mm (4 in) diameter mold in four equal lifts to a height of 63.5 mm (2-1/2 in). Each lift is compacted by a mechanical ram, the first three of which receives 10 tamps at 345 kPa (50 psi) and the final 100 tamps at 2,410 kPa (350 psi), depending on the soil.

A phosphor-bronze disk and filter paper is then placed on the specimen and, using a compression testing machine, a load is applied at a rate of 8.9 kN/minute (2,000 pound feet/minute) until a specified indication of water in the sample has been exudated. The total load at that instant is converted to kPa (psi), with the target reading (exudation point) being 1650 kPa (240 psi). Therefore, it is essential that the four sample specimens "bracket" a reading of 1650 kPa (240 psi).

The specimens are then placed in the expansion-pressure device and water is added to the top of the sample. These specimens are allowed to soak for 16 to 20 hours in this manner. The amount of expansion is measured to the nearest 0.0025 mm (0.0001 in) and the expansion pressure is then calculated in kPa (psi).

Next, the resistance value is determined by applying a 34.5 kPa (5 psi) horizontal pressure to the specimen, while a vertical load is applied as to achieve a vertical displacement of 1.3 mm (0.05 in) per minute. The loading is stopped once an 8.9 kN (2,000 lb) reading is achieved; the horizontal pressure is recorded at this point. The vertical load is then reduced to 4.5 kN (1,000 lb) and the horizontal pressure adjusted to 34.5 kPa (5 psi). Next, the stabilometer pump handle is turned at a constant rate of two turns per second, and the number of turns required to raise the horizontal pressure from 34.5 to 690 kPa (5 to 100 psi) is recorded as the turns displacement. The resistance, or R-value, is determined from Equation 4-2.3.

\[
R = 100 - \left[ \frac{25}{D} \right] \times \left( \frac{160}{P_h} - 1 \right) + 1
\]

where

- \( R \) = resistance value
- \( D \) = displacement of stabilometer fluid necessary to increase horizontal pressure from 34.5 to 690 kPa (5 to 100 psi)
- \( P_h \) = stabilometer gauge reading for 1103 kPa (160 psi) vertical pressure
If the height of the specimen is not exactly 6.35 cm (2.5 in), it must be corrected using the available height-correction chart. Specific testing information can be found in AASHTO T 190.

Table 5-3.2 in Section 5-3.05.02, Bituminous Pavement Design, provides R-value estimates by soil classification. These values may be used for design purposes on smaller projects.

2. California Bearing Ratio (CBR). To determine the California Bearing Ratio (CBR), three separate samples should be compacted in three layers each by tamping with a 2.5 kg (5.5 lb) hammer. The compactive energy (number of blows) should be varied for each sample so that the samples' dry densities ranges between about 95 and 100 percent of the previously determined maximum dry density. A dial indicator and surcharge weights approximately equivalent to the design overburden weight (but not less than 4.5 kg (10 lb)) are set on the sample. It is then immersed in water and allowed to soak for four days. Following this period, a reading is taken from the dial indicator and the percent swell calculated using Equation 4-2.4.

\[
\text{Percent swell} = \frac{\Delta \text{length}}{4.584} \times 100
\]

where

\[x = \begin{array}{l}
\text{material resistance or the unit load on the piston (pressure) –} \\
\text{for 2.5 mm (0.1 in) or 5 mm (0.2 in) of penetration.}
\end{array}
\]

\[y = \begin{array}{l}
\text{standard unit load (pressure) for well-graded crushed stone} \\
= 6.9 \text{ MPa (1000 psi) for 2.5 mm (0.1 in) penetration} \\
= 10.3 \text{ MPa (1500 psi) for 5.0 mm (0.2 in) penetration}
\end{array}
\]

After taking the reading, the sample is removed from the water and allowed to drain for 15 minutes. Thereafter, the penetration piston is seated with a 4.5 kg (10 lb) load and surcharge weights equal to those used during the soaking are placed on the piston. A load is then applied to a piston 1935 mm$^2$ (3 in$^2$) in area at a rate of 1.3 mm (0.05 in) per minute. The total load readings are recorded at penetrations ranging from 0.64 mm (0.025 in) up to 7.62 mm (0.3 in). The data collected is then graphed as a stress (load/area) versus strain (penetration/length) curve. This data is corrected for shape and the CBR values calculated at 2.5 mm (0.1 in) and 5.0 mm (0.2 in) of penetration using Equation 4-2.5. If the CBR at 5.0 mm (0.2 in) of penetration yields the greatest CBR value the test should be re-conducted.

For detailed instructions on the procedure refer to AASHTO T 193. Also, refer to section 3-2.03.05 for additional information.

3. Resilient Modulus. To conduct the resilient modulus ($M_r$) test, numerous load cycles are applied to compacted samples confined in a triaxial cell. A pulsed, vertical load is applied to simulate a traffic loading and the resultant deformation of the sample is measured. The test can be run using varying confining pressures and moisture contents to determine their effect on the $M_r$.

The applied deviator stresses and cell pressures are different depending on whether a cohesive or granular material is being tested. Initially, a series of 1,000 or 1,200 loads are applied for cohesive or non-cohesive samples, respectively. Once these "conditioning loads" have been applied the data cycles begin.

For cohesive samples, 1,600 additional load cycles with various deviator stresses and cell pressures are conducted, with measurements of the recovered deformations after the 200th load for each combination. For non-cohesive samples, 5,400 additional load cycles are used.
The $M_r$ is defined as the ratio of the repeated axial deviator stress $\sigma_d$ to the recoverable axial strain $\varepsilon_r$.

$$M_r = \frac{\sigma_d}{\varepsilon_r} \quad \text{Eq. 4-2.6}$$

$M_r$ = resilient modulus;
$\sigma_d$ = repeated axial deviator stress ($\sigma_1 - \sigma_3$), psi
$\varepsilon_r$ = recoverable axial strain.

The material model for:

(a) Fine-Grain Soils

$$M_r = K_1 \sigma_d^{-K_2} \quad \text{Eq. 4-2.7(a)}$$

$\sigma_d$ = repeated deviator stress, psi
$K_1, K_2$ = material constants

(b) Coarse-Grain Soil

$$M_r = K_{1'} \sigma_d^{K_{2'}} \quad \text{Eq. 4-2.7(b)}$$

$K_{1'}, K_{2'}$ = material constants

The stress sensitivity of fine grain and coarse grain soils is described by Eqs. 4-2.7(a) and 4-2.7(b), respectively. For fine-grained cohesive soils, the resilient modulus decreases with increasing stress while granular soils will stiffen with increasing stress.

For detailed instructions on conducting the resilient modulus for soils refer to AASHTO T-274.

4. Cohesion and Angle of Internal Friction. A soil’s cohesion (c) and angle of internal friction ($\Theta$) may be determined using either unconfined compression, triaxial, or direct shear tests. Each of these methods is discussed in the following paragraphs.

a. Unconfined Compression. To run an unconfined compression test, as described in AASHTO T 208, the sample must be undisturbed and have a minimum diameter of 33 mm (1.3 in). The height-to-diameter ratio should be between two and three. The sample may be tested using either controlled strain or controlled stress procedures. For controlled strain tests, the sample is loaded with a strain rate between one-half and two percent per minute and load and deformation readings are taken every 30 seconds. Load readings are taken until 20 percent strain is reached or until the load readings begin to decrease. The strain rate should be estimated to provide for failure in less than 10 minutes.

For controlled stress tests, the failure load is estimated based on previous experience or by using some type of penetration device, such as a pocket penetrometer. Loads are then placed on the sample in increments of one-tenth to one-fifteenth of the failure load. Readings of strain are taken 30 seconds after each load is applied. This is continued until 20 percent strain is reached or failure occurs. The magnitude of the loadings should be adjusted if more than 15 or less than 10 load increments are required. After the test is complete, the moisture content of the sample should be determined and a stress versus strain
plot prepared. The stress and strain are determined by Equations 4-2.8, 4-2.9, and 4-2.10.

\[ \varepsilon = \frac{\Delta L}{L_o} \]  
Eq. 4-2.8

where

- \( \varepsilon \) = axial strain
- \( L \) = length of sample, mm (in.)
- \( L_o \) = initial length, mm (in.)

\[ A = \frac{A_o}{1 - \varepsilon} \]  
Eq. 4-2.9

where

- \( A \) = area of sample, mm\(^2\) (in\(^2\))
- \( A_o \) = initial area of sample, mm\(^2\) (in\(^2\))
- \( \varepsilon \) = axial strain

\[ \sigma_c = \frac{P}{A} \]  
Eq. 4-2.10

where

- \( \sigma_c \) = compression stress, kPa (psi)
- \( P \) = load, kg (lb)
- \( A \) = area of sample, mm\(^2\) (in\(^2\))

b. Triaxial. Four different types of triaxial compression tests can be performed depending upon the consolidation and drainage conditions allowed during the test. They are the unconsolidated undrained test (UU or Q), the consolidated undrained test without pore pressure measurement (CU or R), the consolidated undrained test with pore pressure measurement (CU- or R-BAR), and the consolidated drained test (CD or S). The test conditions should be determined by the anticipated field conditions, with the laboratory sample modeling the "real-world" situation. Tests run by the Office of Materials are most often consolidated undrained tests designed to determine the effective soil strengths.

For all triaxial tests, a minimum of three samples should be tested. One sample should be tested at the overburden pressure. The second should be tested at a lower pressure, and the third should be tested at a higher pressure. The samples should have a minimum diameter of 1.3 inches and a height to diameter ratio between two and three.

For a Q test, the sample is confined and no volume change due to consolidation is allowed in the sample. Load is then applied to the sample by means of controlled strain with a strain rate of 0.3 to 1.0 percent per minute: 0.5 percent per minute is suggested. Load and deformation readings are recorded until the load ceases to increase with strain or until 20 percent strain is reached. After the test is completed, the moisture content of the sample should be determined and a stress versus strain plot prepared for each test. The stress and strain are determined by Equations 4-2.8, 4-2.9, and 4-2.10.

For an R or R-BAR test, the sample is confined and volume change due to consolidation is allowed and recorded. Loading begins once the sample has consolidated under the applied confining pressure. The load should be applied at a rate that allows for the pore pressure to remain uniform throughout the
sample; no volume change should be allowed during loading. Load and deformation readings should be taken at intervals to accurately define the stress-strain curve. If an R-BAR test is being conducted, the pore pressure should be recorded along with the load and deformation. Readings should be taken until failure or 20 percent strain. After the test is completed, the moisture content of the sample should be determined and a stress versus strain plot prepared for each test. The strain values are determined by Equations 4-2.8 and 4-2.9. Equation 4-2.10 is used to determine the stress for an R test, while Equation 4-2.11 is used for an R-BAR test.

\[ \sigma_c = \frac{P}{A} - U \]  
\[ \text{Eq. 4-2.11} \]

where

- \( \sigma_c \) = compression stress, kPa (psi)
- \( P \) = load, kg (lb)
- \( A \) = area of sample, mm\(^2\) (in\(^2\))
- \( U \) = pore pressure, kPa (psi)

For an S test, the sample is confined and volume change due to consolidation is allowed and recorded. Loading begins once the sample has consolidated under the applied confining pressure. The load should be applied slowly enough that no pore pressure is developed. Volume change during loading is recorded along with the load and deformation. Load and deformation readings should be taken at intervals to accurately define the stress-strain curve and should be taken until failure or 20 percent strain. After the test is completed, the moisture content of the sample should be determined and a stress versus strain plot prepared for each test. The stress and strain values are determined by Equations 4-2.8, 4-2.9, and 4-2.10.

c. Direct Shear. Another method for determining a soil's cohesion and angle of internal friction is the direct shear test, as described in AASHTO T 236. A direct shear test is essentially a consolidated drained test in that no pore pressure is allowed to develop in the sample during shearing.

Similarly to the triaxial compression tests described above, a minimum of three samples should be tested. One sample should have a normal stress equal to the overburden pressure. The second should be tested at a lower pressure, and the third should be tested at a higher pressure. The samples should be at least 50 mm (2 in) in diameter (or width, if rectangular samples are used) and have a thickness of at least 12.5 mm (0.5 in) or six times the maximum grain diameter. The minimum diameter to thickness, or width to thickness, ratio should be two to one.

The normal load is applied after the samples are securely placed in the shear box. Consolidation readings are taken as in a one-dimensional consolidation test. When consolidation is complete, the time to 50 percent consolidation may be determined from the consolidation data. The time to failure is then determined by Equation 4-2.12.

\[ \text{time to failure} = 50t_{50} \]  
\[ \text{Eq. 4-2.12} \]

where

\( t_{50} \) = time to 50 percent consolidation
The rate of shearing should be estimated by dividing the estimated shear deformation at failure by the computed time to failure. Load and deformation readings should be taken at intervals to accurately define the stress-strain curve and should be taken until failure or 10 percent strain. After the test is completed, the moisture content of the sample should be determined and a stress versus strain plot prepared for each test.

5. Dynamic Cone Penetrometer (DCP). Refer to the Grading and Base Manual Section 5-692.255 for more information on this test.

4-2.06.06 PERMEABILITY

A clear understanding of the terms relating to the flow of water is necessary before discussing permeability. Figure 4-2.1 defines several of the terms discussed in this section.

Two methods for determining the permeability of soils are as follows:

1. Constant Head. A constant head permeability test, as described in AASHTO T 215, is used to determine the permeability of granular materials. A sample is selected and compacted into the permeability mold. (The density of compaction affects the permeability.) It is then saturated under a vacuum to assure that no air remains in the sample. Water is then allowed to flow through the sample from the constant head tank to a collector tank. Water is continually added to the constant head tank to maintain the water level.

Once a stable head condition is obtained, readings of time, head, quantity of flow, and water temperature are recorded. The head is then increased by five millimeters and the test is repeated. This is continued until the turbulent flow boundary is reached. This is determined as the head when the velocity (v) and hydraulic gradient (i) do not have a linear relation, where v is defined in Equation 4-2.13 and i is defined in Equation 4-2.14.
\[ v = \frac{Q}{At} \quad \text{Eq. 4-2.13} \]

where

\[ v = \text{velocity, mm(in)/sec.} \]
\[ Q = \text{volume of flow, mm}^3 \ (\text{in}^3) \]
\[ A = \text{area of sample, mm}^2 \ (\text{in}^2) \]
\[ t = \text{time, sec} \]

\[ i = \frac{h}{L} \quad \text{Eq. 4-2.14} \]

where

\[ i = \text{hydraulic gradient} \]
\[ h = \text{hydraulic head, mm (in)} \]
\[ L = \text{length of sample, mm (in)} \]

The coefficient of permeability is determined using Equation 4-2.15. The permeability is corrected for the water temperature by multiplying the calculated permeability by the ratio of the viscosity of water at test temperature to the viscosity of water at 20°C (68°F).

\[ k = \frac{QL}{At} \quad \text{Eq. 4-2.15} \]

where

\[ k = \text{coefficient of permeability, mm (in)/sec} \]
\[ Q = \text{volume of flow, mm}^3 \ (\text{in}^3) \]
\[ L = \text{length of sample, mm (in)} \]
\[ A = \text{area of sample, mm}^2 \ (\text{in}^2) \]
\[ t = \text{time, seconds} \]
\[ h = \text{hydraulic head, mm (in)} \]

2. Falling Head. A falling head permeability test can be used to determine the permeability of fine-grained soils. The sample should be compacted and saturated in the same manner as the constant head test. The constant head tank from the previous test should be replaced with a burette. The difference in water level from the burette to the collector tank is measured and recorded as \( h_1 \). Water is then allowed to flow out of the burette and into the collector tank. Once a predetermined change has occurred, the head is measured again and recorded as \( h_2 \). The time required for the change in head and the temperature of the test water should also be recorded. The coefficient of permeability is then determined using Equation 4-2.16. The permeability is corrected for the differences in water temperature as in the constant head test.

\[ k = 2.303 \frac{aL}{At} \log \frac{h_1}{h_2} \quad \text{Eq. 4-2.16} \]

where

\[ k = \text{coefficient of permeability, mm (in)/sec} \]
\[ a = \text{area of burette, mm}^2 \ (\text{in}^2) \]
\[ L = \text{length of sample, mm (in)} \]
4-2.07 COMPRESSIONNESS

One-dimensional consolidation tests, which are run on either undisturbed or recompacted samples of plastic soils, are performed to determine a material's compressibility. These tests are performed by the Foundations Unit in the Office of Materials.

The largest component of compressibility is primary consolidation, which is the volume reduction that occurs when water in a soil structure flows out under a loading and the voids that it occupied gradually close. The application of a load to a saturated soil causes the immediate reaction of the load being carried by the water in the soil. As the water flows from the soil mass, the load is increasingly carried by the soil matrix and the empty voids close. The rate at which primary consolidation occurs depends on the permeability of the soil. In general, primary consolidation is much faster for granular soils than plastic soils.

After the primary consolidation is complete, the soil undergoes a realignment and adjustment of the soil particles. This is called secondary consolidation, and is usually a smaller volume change than primary consolidation (marls, peats, and some organic soils being exceptions). A third (tertiary) type of consolidation may exist for peats and marls when water is squeezed out of the plant fibers or soil structure.

Samples to be tested should be trimmed and placed in the consolidation ring in such a manner as to avoid disturbance and moisture loss. The consolidation properties of the soil sample are determined under a series of loads, which are varied depending on the anticipated field conditions. The thickness of the sample should be recorded prior to the placement of a load and again at the following times after placing the load: 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 minutes, 1, 2, 4, 8, 12, 24, 48, etc. hours. Readings should be plotted as thickness versus log time. Loading states may be switched when the linear secondary portion of the curve is well defined.

After the load cycles are completed, the thickness versus log time graphs are used to determine the deformation for zero percent consolidation and 100 percent consolidation as well as the time to 50 percent consolidation for each load cycle. The procedure to find each of these items is known as the Casagrande construction. The coefficient of consolidation ($c_v$) should also be computed for each load interval by Equation 4-2.17. The initial void ratio, water content, density, and degree of saturation are calculated after the test is completed and the sample is dried. For complete procedures, see AASHTO T 216.

\[
c_v = \frac{0.05H^2}{t_{50}} \tag{Eq. 4-2.17}
\]

where

- $c_v$ = coefficient of consolidation mm (in)/s
- $H$ = length of longest drainage path, mm (in)
- $t_{50}$ = time to 50 percent consolidation, days or sec

4-2.07 SOILS PROFILE

To better visualize the physical relationship between the existing soil or pavement conditions and the new roadway, a soils profile should be prepared. This diagram is a drawn cross-section or visual presentation of the information obtained during the performed surveys. It should be drawn at a scale, such as one-inch equals five to 10 feet vertically and one inch equals 20 to 100 feet horizontally, depending on the detail and complexity of the project. Plan/profile presentations should be used whenever possible.

The following should be included on the soils profile:

- Project identification
- Existing and proposed grades, and/or existing ground lines
- Boring locations, including station and offset
- Existing pavement and subgrade conditions, including interpreted stratigraphy
- Ground water
- Pertinent test results

Figure 4-2.2 is an example of a properly prepared soils profile.

Figure 4-2.2. Example soils profile.
A soils profile should be routinely submitted as part of the Design Recommendations Report on projects where there is significant soils work. For projects that do not typically require extensive soils information, such as overlays, a soils profile would not be necessary.

4-2.08 SEALING OR BACKFILLING BORINGS

All borings meeting the legal definition of an “Environmental Borehole” will be drilled and sealed in accordance with Minnesota Department of Health regulations. Environmental Boreholes will be bored and sealed only by personnel licensed and equipped to do so legally. A boring is considered an Environmental Borehole when all three of the following criteria are met:

1) The boring encounters a water-bearing layer.
2) The boring is greater than 25 feet in depth or goes through a confining layer.
3) The boring is used for measuring or testing physical parameters e.g., field identification of soils, checking water levels, rock depths, etc.).

Contact the Mn/DOT Foundations Unit with any questions or assistance with Environmental Boreholes.

All borings not meeting the definition of an Environmental Borehole shall be backfilled with the drill cuttings, on-site soils, or imported material, with a texture and permeability similar to materials encountered in the boreholes. Imported backfill materials shall have a lower permeability than material encountered. The borehole shall be completely filled from the bottom or cave-in depth to the original ground surface. Tamping or compacting the backfill material shall be performed as necessary to minimize voids or backfill subsidence. Backfilling shall be performed in a timely manner after completion of the borehole.

Borings shall not be permitted in known or suspected contaminated areas regardless of boring depth or groundwater elevation. If contamination of any type is noted while drilling, work shall be stopped and the next level supervisor contacted immediately for further instructions.

4-2.09 SUMMARY

As discussed in this section, all information relative to the existing subgrade needs to be considered as background by the District Soils Engineer in preparing design recommendations for a new roadway. Results from previous office studies (Section 4-2.02), newly obtained borings and samples (Sections 4-2.03 and 4-2.04), and testing (Section 4-2.06) should all be used in the design stages.
4-3.0 PAVEMENT SURVEY

The primary purpose of a pavement survey is to obtain data, either on a project or network level, that can be used to monitor pavement performance over time and provide input to pavement management functions. Minnesota has had a Pavement Management System (PMS) since 1965, when a ride roughness and surface distress rating procedure was initiated to rank potential pavement candidates for resurfacing. The performance data obtained serves as the basis for several Department activities, such as programming and budgeting of candidate projects, as well as the design of the rehabilitation measures deemed necessary to keep the entire network of roadways above an acceptable level of serviceability.

The process currently followed by Mn/DOT in the survey of its pavements, as part of the PMS, is described below.

4-3.01 PURPOSE

Pavement condition surveys are performed to assess and document current pavement conditions. Although many different types of data can be collected in the field, it is generally recommended that efforts concentrate on the type, extent, and severity of distress, which can be used to determine the optimal timing for rehabilitation actions and the level of rehabilitation needed.

The ability to predict future conditions from an assessment of current conditions is critical for scheduling future rehabilitation needs. Maintaining a historical record of pavement conditions allows past pavement deterioration patterns to be evaluated and used to forecast future performance trends. Historical records also provide feedback on the effectiveness of past pavement design strategies. Such feedback should be used to improve future design and rehabilitation strategies.

The type and extent of pavement survey data collected depends primarily on the projected use of the data. If it is to be used as baseline data to determine overall network condition and/or needs, it is considered to be network-level data. Typically, at the network level, a statistically representative portion of the pavement network is surveyed to determine general condition levels.

A pavement survey may also be conducted to determine the rehabilitation needs of a specific section that is targeted for repair. In that case, a greater level of detail is required, which influences the type of equipment used in the survey procedure and the percentage of the pavement section inspected.

Data collection efforts must also take into account the traffic levels anticipated on each roadway segment. Pavement surveys that require slow speeds or stationary equipment along busy roadways create traffic control and safety problems for the inspection crew and the traveling public. Recent technology is advancing the state of the practice through the development of automated survey equipment that can operate at or near traffic speeds.

It is the intent of this section to provide information regarding the types of pavement data currently being collected by the Department as well as to discuss the procedures that should be followed to collect and evaluate this data.

4-3.02 OFFICE STUDIES

Although data collection efforts are typically focused on the collection and evaluation of field data, it should be recognized that a great deal of information can be obtained within the Department's offices. This information is important to the pavement survey process and serves as the basis for building an inventory of relevant pavement-related data. Stored information may include location, length, width, subgrade properties, base and subbase materials and properties, surface properties, as-built design, traffic, historical data on maintenance or rehabilitation actions, and any other information that has a bearing on the ability of the pavement section to perform its given function. Various types of data that may be collected from office studies, and where the data may be obtained, are discussed in the following sections.
Investigations that were prepared for previous design projects are often a good source of information regarding in-situ properties. These data can provide background information to assess the characteristics of the existing pavement layers and make knowledgeable decisions about appropriate rehabilitation design actions. Various Mn/DOT office memoranda, including Foundation Investigation and Recommendations Reports and Recommendations for Grading, Base, and Surfacing Reports, may contain this information.

Pavement thickness information is important in determining feasible rehabilitation strategies. Clearance heights for bridges, for example, must be considered before an overlay can be designed. If the maximum tolerance is reached, a portion of the existing surface must be removed prior to the application of an overlay. The thickness of the existing layers is an important factor in determining the feasibility of removing existing material and building overlays. The presence of fabrics, rubber and/or other additives in the pavement structure should be identified before removal takes place as they may have an adverse effect on the removal process and/or recycling efforts. Copies of the corrected final plans from District files or Plan Files in the Central Office are a good source for in-place pavement data. Previous geotechnical surveys or other investigative studies included the coring of pavements would probably include layer thicknesses as well. Existing pavement management database files, such as Roadway History, may also be a source of this type of information.

At the time of data collection and evaluation an effort should be made to investigate whether the particular roadway segment under consideration is undergoing any type of rehabilitation, resurfacing, reconstruction, or informal research. If there are research sections, the Physical Research Unit of the Office of Materials should be informed of the nature of the proposed work so that further recommendations, analysis, evaluation and conclusions can be made or drawn prior to initiating any detail design and/or construction operations.

Existing construction data files provide the engineer with information concerning the actual construction of bituminous pavement sections. Engineering design requirements, as well as quality control test results, are available to provide information such as mix types, aggregate sources, mixture properties, in-place densities, and roadway histories.

1. Mix Types. Information on the type of mix that was used in the construction of a pavement surface should be included. Where applicable, mix types used in underlying layers may also be provided. Any special mix properties or additives that may have been used during construction should be noted.

2. Aggregate Sources. Aggregate quality and gradation have a large impact on the durability and performance of a pavement surface. Typically, construction files list this type of information. Comparisons of pavement sections constructed with different aggregate sources would assist in developing mix properties that best ensure that the pavements perform as they are intended.

3. Mixture Properties. Mixture property tests contain information on asphalt content, asphalt type, and aggregate gradation. In addition, data are available on mixture air void contents on many projects built after 1986. Mixture air void control is critical in increasing pavement life.

4. In-place Density. In-place density data are available on projects with compaction control by the Specified density or Control strip (Nuclear) methods. Good compaction is necessary to assure predicted pavement life.
5. Roadway Histories. Information is available on pavement cross-sections including subgrade type, base type and thickness, and pavement thickness. Traffic data and maintenance information regarding the pavement section are available from Mn/DOT office’s.

4-3.02.04 CONCRETE CONSTRUCTION DATA

As described in the previous section, construction data files are an important source of information for the evaluation of concrete pavements. Important factors which influence the performance of concrete pavements include mix properties (cement type, water/cement ratio, cement void ratio, slump, entrained air, strength, etc.), aggregate types, aggregate gradations and top size, aggregate sources, thickness, joint spacing, joint sealant type and reservoir dimensions, dowel bar diameter, tie bars, and steel reinforcement. The construction methods and equipment are also important considerations.

4-3.02.05 AGGREGATE/STABILIZED BASE CONSTRUCTION DATA

Base material properties are as important as the surface properties. Aggregate type, sources, additives, and gradations will affect the performance of the pavement section and influence the design of rehabilitation treatments. As discussed in the two previous sections, construction data files can provide a great deal of this type of information.

4-3.02.06 PAVEMENT MANAGEMENT DATA

Pavement Management Systems (PMSs) require data to trigger rehabilitation actions, as well as the necessary level of repair. This information is used to prepare budgetary planning documents, to ensure that adequate levels of funding are available into the future, and/or to illustrate the impacts of anticipated funding levels on overall pavement condition. The following types of information are needed to sustain a PMS.

1. Pavement Quality Index. Evaluating the existing condition of pavements is the foremost need of a PMS. The evaluations of pavements in a network, such as Minnesota's pavement network, have to be expressed in a common form to allow a comparison of the serviceability of the different pavements. This comparison is done by the Department through the use of a Pavement Quality Index (PQI). The PQI is defined by Equation 4-3.1 as follows.

\[ PQI = \sqrt{SR \times RQI} \]  
Eq. 4-3.1

where

SR = Surface Rating
RQI = Ride Quality Index

Following is a description of the distress survey that goes into the determination of the PQI in Minnesota.

a. Surface Rating. Mn/DOT utilizes the survey procedure described in the "Pavement Management Surface Rating Manual" to collect pavement distress information. This surface rating system can be used for bituminous, concrete, and bituminous-overlaid concrete pavements. Data is collected by the Pavetech van, which video tapes the pavement surface and the actual survey is performed at the workstation.

Data are collected annually on about 50 percent of the system. The sample size is 150 m (500 ft) in each direction every mile.
At the present time, the annual survey does not require the manual computation of the Surface Rating (SR) for either bituminous or concrete pavements. The procedure, however, is described in the Pavement Management Surface Rating Manual. It determines a numerical rating ranging from 0.0 to 4.0, with 4.0 being the rating for a pavement with no distress. It is discussed in greater detail in Section 4-3.03.01.

The automated Pathway Services van provides many advantages to a highway agency. Primarily, these include the safety and efficiency of collecting data at or near traveling speeds, the consistency of data obtained by photography of deterioration as it develops, and the resulting historical visual record.

b. Ride Quality Index. This value is calculated by correlating the International Roughness Index (IRI), which is measured by the Pathway Van, into the Ride Quality Index (RQI). This correlation was developed by a large panel of raters. The RQI is a numerical rating ranging from 0.0 to 5.0, with 5.0 being the rating for a perfect ride. It gives an indication of the rideability of a pavement from the perspective of the traveling public. It is discussed in greater detail in Section 4-3.03.02.

2. Construction As-built. Newly constructed pavements should also be evaluated in terms of serviceability rating standards prior to acceptance by the Department. Several ongoing studies are currently developing methods for relating certain critical pavement properties at construction (smoothness, strength, thickness, mixture variables) to their impact on the long-term performance of the pavement. Incentives and disincentives can then be distributed to the contractor, depending on whether the as-constructed values exceed or fall short of design values. All incentives and disincentives should be tied to the relative impact of the variable on the performance capabilities of the pavement.

3. COPES. The Concrete Pavement Evaluation System (COPES), as developed under NCHRP Project 1-19, was intended to be a means of storing a large amount of data to improve the knowledge of concrete pavement design, construction, and maintenance. As the study developed, six state-level demonstrations were conducted, including one in Minnesota. The COPES database is still being used in Minnesota, although it has been modified and is now in a FOCUS PC database format.

The COPES database includes data elements in six areas. The first area, uniform section information, includes network inventory data, such as District, surface type, previous surface, date of last construction, county, number of lanes, slab thickness, and whether or not the highway is divided.

Very comprehensive joint information is included in the second area of the design data. This includes transverse joint spacing, skewness, presence of dowels, detailed dowel design, the construction method used for transverse and longitudinal joints, tie bar design, joint sealant, joint dimensions, and shoulder/lane joint information.

The third area includes information relating to the reinforcing steel used in the concrete pavement. Included is the type of rebar, method of rebar placement, rebar yield strength, and transverse and longitudinal bar diameter and spacing.

Concrete data is featured in the fourth area of the design database. This area contains mix design data, compressive and flexural strength test results, material types, paving procedure, curing method, and finishing techniques.

The last two areas contain information on the base/subgrade, shoulder, and drainage. Data elements include base type, subgrade type, stabilized or unstabilized base thickness, shoulder surface type, shoulder width and thickness, base type, and type/location of any drainage elements.
4. Soils File. Existing soils files can be used to supply much of the needed information regarding the existing pavement subgrade. The COPES database permits storage of an extensive amount of information regarding subgrade material characteristics. Data relating to AASHTO soil classification; subgrade strength tests; swell potential; frost susceptibility; optimum, lab, dry density and moisture content; measured in-situ dry density and moisture content; plasticity index; and liquid limit can all be obtained from materials reports.

5. Friction Number. Friction testing must be performed at frequent intervals in order to ensure the greatest potential for safety. Early friction and skid tests were conducted by locking the wheels of an automobile and measuring the distance traveled while sliding to a stop. This method of testing is no longer feasible on today’s high volume roadways.

Most highway agencies measured skid through the use of a locked-wheel trailer throughout the 1960s and 1970s. This device features a primary unit that carries recording equipment and, in most instances, the water supply for wetting the pavement. A trailer, equipped with transducers to measure either the force required to pull the locked wheel or the torque required to lock the wheel, follows behind. The speed of the vehicle and the trailer weight are typically constant in these tests. A computer integrates the force/torque-time relationship and calculates a skid number, which can be loosely defined as the coefficient of friction, or "friction factor," multiplied by 100.

The most modern equipment features a fifth wheel on the primary unit instead of a trailer. This modification limits the calibration steps required to checking only the speedometer and the force/torque transducer.

6. Deflection Data. In order to predict the remaining life of pavements for pavement management and to identify feasible rehabilitation alternatives, reasonable assessments of the current strength of each of the pavement layers must be obtained. Non-destructive testing (NDT) has become the standard for determining such material property characteristics.

A known load is applied to the pavement surface and the resultant deflections under the load are measured in most of these tests. The values obtained are used to backcalculate estimates of layer moduli and load-carrying capacity.

There are many different types of NDT equipment in use today. Types of loading include static loading conditions, vibration loading, and instantaneous impulse loading, the latter of which has been found to more closely simulate the effect of a moving wheel load. Mn/DOT currently owns and operates several impulse loading testing vehicles, more commonly known as Falling Weight Deflectometers (FWD).

The FWD is a trailer-mounted device that drops a known mass onto a load plate on the pavement surface and records the deflection of the pavement at various distances from the point of impact. The mass can be dropped from different heights to produce the loading required by the specific pavement type. Doubling the height of the fall quadruples the energy of the drop at impact.

The FWD must be stationary while the test is being performed; therefore, traffic control may be necessary for tests near traffic. Deflection measurements are recorded and transferred directly to the on-board computer in the support van automatically. Tests are usually performed at 150 m (500 – ft) intervals in the outer wheel path of the bituminous pavement sections being analyzed. Concrete pavements are typically tested along the transverse and longitudinal joints, in one corner, and in the center of the slab.

At the network level, NDT data can be used to identify potential sites for pavement rehabilitation, to determine relative priorities among projects, or to determine the differences in pavement behavior caused by such factors as climate, traffic, or material
types. In most cases, a network-level analysis is used to rank sections in relation to each other in order to help determine rehabilitation priorities.

At the project level, NDT results are used to design maintenance and rehabilitation strategies; therefore, a larger number of tests are conducted. The number of tests required depends on the level of reliability desired in the final design. For these types of projects, homogeneous sections are usually identified and classified as analysis units. NDT results may be used to determine the boundaries of these sections.

Additional discussion on FWD deflection measurements can be found in Section 4-3.03.04.

The measured FWD test results are used as the basis for a comprehensive analysis to determine the engineering properties of the pavement layer materials. Several analysis methods are available for the back calculation of modulus values from deflection data. These include layered elastic and finite element computer programs, each of which has its own advantages and disadvantages.

Several layered and linear elastic computer programs have been developed for pavement design. These include CHEVRON, ELSYM-5, and BISAR. BISAR is a proprietary program that requires a license from the Shell Oil Company before being run; the other two programs are in the public domain. Back calculation programs that utilize the CHEVRON linear elastic techniques are MODULUS, CHEVDEF, and EVERCALC. Another back calculation program, ELSDEF, utilizes the ELSYM-5 program. BOUSDEF and ELMOD use the method of equivalent thicknesses and Boussinesq theory to perform backcalculations of FWD data.

Linear elastic analysis is based on five basic assumptions. The first is known as Hooke's Law, i.e., stress is directly proportional to strain in each pavement layer, and the proportionality constant is the modulus. Second, each layer is assumed to be homogeneous and isotropic. In other words, no cracks, voids, or open spaces should be present. Third, the analysis assumes that the pavement extends infinitely in both the horizontal and vertical (downward) directions. The fourth assumption is that the pavement surface is free from any stress or strain outside the loaded area of the NDT device. Lastly, the fifth assumption is that the vertical stresses, shearing stresses, and displacements are continuous across the interface of the pavement layers.

Finite element computer programs are also available to analyze pavement data; however, the selection of correct input data for their non-linear analysis requires experience and good engineering judgment.

Mn/DOT has several layered elastic computer programs available to perform the flexible pavement back calculation of modulus values. These programs include MODULUS, BOUSDEF, EVERCALC, and ELMOD. The ELMOD program is a proprietary software package developed by Dynatest, the manufacturer of the FWD apparatus used by Mn/DOT.

For concrete pavements, ILL-BACK, ELMOD, ELCON and EVERCALC are examples of software that can be used to back calculate the slab elastic modulus and subgrade modulus. The soil support k value can be indirectly determined.

The results of these back calculation analyses can be converted into useful values for pavement design. Seasonal variations for asphaltic concrete surfaces are taken into account during the analysis, as are any correction factors that need to be applied to adjust for subgrade strength due to wetter conditions at certain times of the year. Typically, Young’s modulus, the Portland cement concrete (PCC) Dynamic Modulus, the PCC modulus of rupture (as determined from the dynamic modulus), and the static modulus of
subgrade reaction (determined from the subgrade resilient modulus, \(M_r\)) are used in any further analysis and design.

7. Traffic. Refer to Section 4-4.0.

4-3.03 FIELD RECONNAISSANCE

Correct operating procedures must be followed in order for the collected survey data to be valuable for pavement management. The objective of this section is to discuss the field procedures that should be followed for the successful collection of pavement data.

4-3.03.01 PAVEMENT DISTRESS

The procedures that should be followed for the Pavement Management Surface Rating Evaluation are discussed thoroughly in the "Pavement Management Surface Rating Manual." The road is videotaped by the Pathway van, which is a survey vehicle that captures the video from four different cameras at highway speed. The actual survey is performed at a workstation by a trained operator.

The Manual recommends that the selection of areas to survey should be based on the following guidelines for each pavement segment being rated.

- Ratings are to be taken at locations where the number of lanes or surface type changes, as well as other intermediate locations as determined by the District. These locations are referred to as "D" records. In addition, ratings should be taken at each reference post between D records, unless the reference post is less than 0.5 km (0.3 mi) from a D record. Ratings at reference posts are designated as "M" records in the PMS.

- On two-lane roadways, the first 150 m (500 ft) at each record location should be rated in the increasing reference post direction.

- For all roadways other than two-lane roadways, ratings are taken for 150 m (500 ft) in each direction at each record location. In the increasing direction, the rating is taken for the first 150 m (500 ft) in the outside lane. In the decreasing direction, the rating is started at a record location and moved 150 m (500 ft) forward toward the next record location in the outside lane. The values obtained between any two records are always recorded on the form at the lowest record location, no matter the direction of travel.

4-3.03.02 SERVICEABILITY

Pavement serviceability measurements provide an indication of the functionality of a highway pavement. Developed during the AASHO Road Test, the Present Serviceability Rating (PSR) is a subjective rating that designates the condition of the pavement at an instant in time. The PSR is determined by a panel of individuals who rate the pavement on a scale from 0.0, which indicates an "impassible" road, to 5.0, which indicates a "perfect" pavement. When the rating is correlated with objective measurements made on the pavement surface (thereby eliminating the need for a rating panel), the resultant value is generally referred to as the Present Serviceability Index (PSI).

Mn/DOT calculates PSR (in 2006 PSR was changed to the Ride Quality Index) ratings in a slightly different manner. The objective measurement is performed by the Pathway van, which produces an International Roughness Index (IRI) value. This IRI is then converted into the RQI by two correlation equations, one for concrete and one for bituminous.

4-3.03.03 FRICTION NUMBER

Friction numbers are greatly influenced by many factors, including the weather conditions, the pavement surface texture, tire speed, temperature, and inflation. Skid resistance is measured using a locked-wheel skid tester as specified by ASTM E 274. The test should be performed at 64 kph
(40 mph). The coefficient of friction, which indicates the amount of friction between the vehicle
tire and pavement surface, is multiplied by 100 to determine the skid number.

4-3.03.04 DEFLECTION MEASUREMENTS

Mn/DOT owns and operates several Dynatest Falling Weight Deflectometers. As discussed in
Section 4-3.02.06, the amount of deflection testing required depends almost entirely on the
purpose for which the data is being collected. If the testing is being performed to obtain an overall
assessment of the load-carrying capacity of the pavements within the state, or if NDT is being
performed to prioritize rehabilitation sections, a lesser test frequency may be utilized than one in
which a rehabilitation design is being developed.

The FWD is an impulse loading device that exerts a force similar in magnitude and duration to
that of a moving wheel. It does this by dropping a weight onto a load plate of known dimensions
that sits on the pavement. The magnitude of the load can be changed by varying the size of the
mass and its drop height. The resulting pavement deflection is measured by eight to ten seismic
deflection transducers spaced up to 2 m apart in a straight line from the load.

Test spacing is often 30 to 60 m (100 to 200 ft) for project-level testing and 0.16 km (0.1 mi) for
network-level testing. Testing is generally performed within the outer wheel path of the outer lane
for bituminous pavements. For concrete pavements, test locations are at the center of the slab for
determination of the layer modulus values, at the corner for void detection, and at joint locations
for determining load transfer efficiencies across the joints. At least three different load levels are
required to evaluate potential loss of support beneath slab corners. Mn/DOT usually uses drop
heights that induce 26.7, 40.0, and 53.4 kN (6,000, 9,000, and 12,000lbf) loads. A 40 kN (9,000 –
lbf) load is all that is necessary for routine testing.

The strength characteristics of asphaltic concrete pavements are temperature dependent, meaning
that they change as temperatures change. At higher temperatures, the modulus of an asphaltic
concrete mix decreases. As the mixture cools it becomes stiffer, resulting in higher moduli values.
Due to this effect, deflection measurements from asphaltic concrete pavements must be
normalized to a standard temperature. This requires the recording of pavement and air
temperatures at the time the testing is taking place.

Concrete pavement testing is also affected by temperature due to warping and curl of the slab.
Subgrade strength also varies seasonally mostly due to the change in moisture conditions.

FWD testing should not be conducted during the winter season when subgrades may be frozen.
Conservative test results will be obtained by performing the FWD testing during the spring
months when the subgrade is thawing and typically at its weakest.

4-3.03.05 DRAINAGE

Water within the pavement structure is a major contributor to pavement deterioration. It is
therefore extremely important to evaluate the effectiveness of the pavement drainage system in
evaluating pavement performance and rehabilitation options.

There are several drainage components that must be evaluated in a comprehensive pavement
evaluation. These include cross slopes, the condition of the drainage outlets, the presence of any
pumping through cracks and/or joints, faulting at joints or cracks, and the presence of standing
water in ditches. The following areas should be checked as a part of a pavement evaluation in
order to determine the condition of the drainage mechanisms within the pavement structure.

1. Pavement Surface. Pavement distress is most often caused by traffic loading, a
construction or material defect, or moisture/drainage issues. The presences of certain
distresses, commonly identified as part of the Pavement Management Surface Rating
Survey, are important indicators of the presence of water within a pavement structure.
For example, the presence of any pumped material along the side of concrete pavement joints or cracks is a strong indicator that there is a moist subgrade that is pumping its way out as loads are applied to the pavement. With time, this will lead to the formation of a void under the slab that may induce cracks or other problems under heavy traffic loading. Other distresses, such as stripping in AC pavements and D-cracking in PCC pavements, are also strong indicators that water is present in the pavement.

An effective surface drainage study should search for any signs of excessive water in the pavement structure. The presence of the above-mentioned distresses should be noted in order to induce further pavement evaluation studies prior to an overlay design. Cross slopes should also be noted to determine the effectiveness with which water is drained off of the pavement surface into ditches.

2. Ditches. Ditch conditions can provide a good indication of the effectiveness of a drainage system. If a ditch is clogged with weeds, debris, or other material, water cannot flow as was originally designed. The presence of standing water in a ditch also indicates that the ditch is not fulfilling its intended function. The distance from the pavement surface to the bottom of the ditch is also important, as it is an indication of the drainage distance and the overall capacity of the drainage system.

Additionally, if ditch slopes are flat, or if a reverse slope exists, water will tend to soak into the subgrade soil and saturate it. This limits the ability of subsurface moisture to drain away from the structure and may soften the subgrade and reduce the load-carrying capacity of the pavement.

3. Culverts. Culverts should be inspected and maintained regularly. Large flow periods often carry brush, branches, and other large objects that can clog the entrance to a culvert and cause flooding. Therefore, the presence of any standing water or debris should be noted in a culvert evaluation. In addition, the condition of the grates and lead-in ditches should be noted.

4. Subsurface Drains. The condition and operation of any in-place subsurface drain on the project (pavement edge drain, subcut drain, old tile drain, ground water control, etc.) should be evaluated. Improper functioning of such drains can lead to the conditions described above. Look for plugged, crushed, or totally absent discharge points; settlement/distress along shoulders over drain locations; presence of white carbonate or rusty iron deposits at discharges; water standing on or staining of bituminous shoulders; or any other signs of improper operation.

4-3.06 MAINTENANCE INPUT

Another valuable source of information pertaining to pavement performance is maintenance records for a given pavement section. Notes taken by maintenance personnel are often more up to date than the pavement condition information stored in the PMS. Historical maintenance data, typically obtained from a maintenance management system, can also provide an insight into the ability of a pavement design to carry out its intended function.

4-3.04 TESTS

Material characterization is another important type of information to assess the overall condition of a pavement network. These test results are used to supplement NDT data and provide information on the quality of a specific material when researching rehabilitation strategies. The following tests provide valuable information to the rehabilitation designer at the project level.

4-3.04.01 EXTRCTIONS

Extractions of the asphalt materials in the pavement layer allow assessment of certain material properties. These include the consistency of the asphalt binders, the ductility, and the amount of asphalt present in the mix.
4-3.04.02 GRADATIONS

It is important to know the current gradation of the base material in order to assess the overall pavement performance. Most importantly, gradation tests will assess the stability of the base and its ability to drain water.

4-3.04.03 MOISTURE AND DENSITY

Tests that provide an indication of the moisture content and density of the material are also an important part of a pavement evaluation. These tests can provide an indication of material deficiencies that will need to be addressed prior to the application of a rehabilitation treatment.

4-3.04.04 STRENGTH TESTING

Material strength testing is an important supplement to the results of NDT. The R value and $M_r$ provide a good indication of the ability of the pavement to withstand anticipated loads.

4-3.05 SUMMARY

As discussed in this section, it is necessary to determine key information about a pavement so that a comprehensive pavement evaluation can be conducted. Based on this evaluation, a rehabilitation designer can assure that the cause and extent of the deterioration will be assessed and prevented from reoccurring in the future. Results from previous office studies (Section 4-3.02), field studies (Section 4-3.03), and testing (Section 4-3.04) should all be used in the pavement management process.
4-4.0 TRAFFIC ANALYSIS

4-4.01 PURPOSE

Traffic analysis is an essential part of project feasibility studies, project selection, and project path analysis as well as in determining the type and sizing for roadway facilities and in studying the relationship between past traffic and anticipated pavement life. Since the scope of this manual encompasses only the geotechnical and pavement design aspects of Mn/DOT's program, the following sections will discuss only sources of traffic data and the process of forecasting cumulative Equivalent Single Axle Loads (ESALs). Please contact the Traffic Forecast and Analysis Section for information regarding additional uses of traffic data and methods to produce traffic forecasts for purposes not covered in this manual.

4-4.02 OFFICE STUDIES

Most traffic analysis begins with an effort to quantify and understand current and past traffic volumes, characteristics, and patterns as they pertain to a specific project location. Traffic data has been routinely collected by Mn/DOT, county, and municipal agencies for a multitude of purposes. Annual and bi-annual summary reports of traffic data are available through the Traffic Forecast and Analysis Section. Traffic forecasts and other special traffic studies can be requested from the same section when additional information is required. Short descriptions of the various types of traffic data, data collection equipment, reports, and the ESAL forecasting process are contained in the following sections.

4-4.02.01 CONTINUOUSLY COLLECTED TRAFFIC AND WEIGHT DATA

Over 160 continuous traffic volume collection sites are in operation throughout the state; most are located on the trunk highway system. These continuous sites are equipped with inductance loops in the pavement and utility cabinets along the right-of-way that contain circuitry to power the systems, convert the signals from the pavement sensors into vehicle data, and permit the transfer of lane and time specific data via telemetry. Inductance loop sites are typically referred to as Automatic Traffic Recorders (ATRs).

An increasing number of continuous sites are being added with additional permanent weighing-in-motion (WIM) devices that permit the recording of axle weights, classification of vehicles, vehicle speed, and vehicle length for each lane and for predetermined time periods. These are typically referred to as WIM sites and represent Mn/DOT's continued support of the Strategic Highway Research Program in cooperation with AASHTO. In the future, inductance loops and other sensors that have been installed as parts of centralized traffic control systems may double as ATRs, further enhancing knowledge of traffic volume characteristics.

Data from these continuous sites currently provides the basis for determining the statistical variability of counts of shorter duration and for determining time-based factors to adjust short counts to estimate Annual Average Daily Traffic (AADT). A more detailed description of the short duration count and adjustment program can be found later in this section. As more WIM sites are installed throughout the state, analysts will incorporate more continuous vehicle classification data into new systems designed to adjust short duration vehicle class counts.

Axle weight data obtained at continuous WIM sites has furthered our understanding of how ESAL factors vary in time and space. Additionally, vehicles are weighed without delay or knowledge of the weighing, which eliminates bias that could be attributed to the measurement process itself. On the other hand, calibrated WIM installations have, observe errors of ten percent or more for individual axles and four percent or more for gross weights according to field studies comparing highly precise static weights of five-axle tractor, semi-trailer trucks and correlated weights from WIM. Initial scale calibration is attained when the average axle weights of heavy test vehicles, as measured by the WIM equipment, equal known axle weights.

Various reports are available for continuous traffic data depending upon the instrumentation at each site and method used in polling the data. An analyst can obtain hourly data if research
warrants such detail. Routinely generated reports have included the "ATR Data Summary" and the "Weighing-In-Motion Data" reports. Both reports contain AADT, average monthly volume information, and day of the week average volume information. Weighing-In-Motion reports also contain volume and ESAL factor information by specific vehicle classification distinctions, but they do not contain "Nth" highest hourly volume and directional distribution information as in the ATR Data Summary reports.

4-4.02.02 SHORT DURATION COUNTS AND EXPANSION PROGRAMS

Over 45,000 short duration counts are taken at selected points on the trunk highway, county state aid highway, county road, municipal state aid, city street, and township road systems. These counts, together with short duration count expansion programs, provide the basis for AADT and Heavy Commercial Average Annual Daily Traffic (HCADT) flow maps and/or documentation of trends in traffic for certain types of roadways. While other short duration counts are made by the Department (i.e., 12-hour turn movement counts), only those short counts that are integral to the production of AADT and HCADT flow maps and trends are discussed in this section.

AADT flow maps are produced every two years for the trunk highway system and every four years for the county road system. In the Minneapolis/St. Paul metropolitan area, county road AADTs are also available every two years. HCADT flow maps are available for the trunk highway system only (HCADT represents commercial vehicles with six tires or more).

Short duration sampling has traditionally been limited by human and equipment considerations. Time periods of 16 and 48 hours remain the most practical time periods for manual and portable systems, respectively. Short duration sample sites are chosen by analysts from the Traffic Forecast and Analysis Section and selected count requests are sent to District Office personnel for counting between the months of April and October of each year.

The overwhelming majority of short duration, traffic volume data collection sites are counted with portable pneumatic-tube counters for a period of 48 hours. Results from each count are sent to analysts working for the Traffic Forecast and Analysis Section. Here the counts are recorded, adjusted to AADT, and transcribed onto work maps in preparation for flow map creation. Factors are applied to correct for the day of the week, month of the year, and vehicle classification mix during this process. ATRs, singly or in groupings based on time/volume similarities, provide the data from which year-specific, time-related, adjustment factors are calculated.

The vehicle classification count program provides the basis for axle correction factors that convert the total number of "axle hits" recorded by the pneumatic-tube counting equipment to an estimated number of vehicles (see Table 4-4.1 for a partial key to vehicle classification). Axle correction factors were first applied to trunk highway pneumatic-tube counts in 1986. No axle correction factors are applied to county road counts when AADTs are calculated on those systems.
### Table 4-4.1. Vehicle classification.

<table>
<thead>
<tr>
<th>Type Number</th>
<th>Illustrated Example</th>
<th>Vehicle Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="Passenger Car" /></td>
<td>Passenger Cars</td>
</tr>
<tr>
<td>2</td>
<td><img src="image" alt="Panel and Pickups" /></td>
<td>Panel and Pickups (under 1 ton)</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="Single Unit - 2 axle, 4-tire" /></td>
<td>Single Unit - 2 axle, 4-tire</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="Single Unit - 2 axle, 6-tire" /></td>
<td>Single Unit - 2 axle, 6-tire</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="Single Unit - 3 axle and 4 axle" /></td>
<td>Single Unit - 3 axle and 4 axle</td>
</tr>
<tr>
<td>6</td>
<td><img src="image" alt="Tractor semitrailer Combination - 3 axle" /></td>
<td>Tractor semitrailer Combination - 3 axle</td>
</tr>
<tr>
<td>7</td>
<td><img src="image" alt="Tractor Semitrailer Combination - 4 axle" /></td>
<td>Tractor Semitrailer Combination - 4 axle</td>
</tr>
<tr>
<td>8</td>
<td><img src="image" alt="Tractor Semitrailer Combination - 5 axle" /></td>
<td>Tractor Semitrailer Combination - 5 axle</td>
</tr>
<tr>
<td>9</td>
<td><img src="image" alt="Tractor Semitrailer Combination - 6 axle" /></td>
<td>Tractor Semitrailer Combination - 6 axle</td>
</tr>
<tr>
<td>10</td>
<td><img src="image" alt="Trucks with Trailers and buses" /></td>
<td>Trucks with Trailers and buses</td>
</tr>
</tbody>
</table>
Vehicle classification counts are taken at over 1,000 locations in the state during a six-year cycle. Approximately 95 of these locations are sampled every two years, with approximately half of those sites being visited twice. A count duration of 16 hours (two eight-hour shifts of 6 a.m. to 2 p.m. and 2 p.m. to 10 p.m.) is a standard sampling period for the vehicle classification count program. Adjustments are made to the raw vehicle classification data using factors calculated from continuous vehicle classification data so that the effects of weekends and the eight remaining hours in a 24-hour day are accounted for. Reports containing raw and adjusted vehicle classification count data are available each year from Traffic Forecast and Analysis Section personnel.

4-4.03 CUMULATIVE EQUIVALENT SINGLE AXLE LOAD FORECAST PROCESS

4-4.03.01 PROCEDURE

The process of forecasting cumulative Equivalent Single Axle Loads (ESALs) for use in pavement design and selection is one that contains four major parts. This process provides a common framework for all ESAL forecasts in the state. District traffic forecasters, the Traffic Forecast and Analysis Section, and consultants working for Mn/DOT can all participate in the production of ESAL forecasts depending upon a particular project's schedule, complexity, and staff commitments. The four parts of this process are:

- Determination of two-way Average Annual Daily Traffic (AADT)
- Determination of two-way vehicle classification volumes
- Determination of flexible and rigid ESAL factors
- Determination of the design-lane distribution of ESALs

An electronic spreadsheet called MNESALS is available from personnel in the Traffic Forecast and Analysis Section to assist in the ESAL calculation. The spreadsheet operates on DOS-based personal computers and uses LOTUS 1-2-3, version 1.0 or higher. Please refer to this spreadsheet and its user's manual for details regarding specific forecast calculations.

Simply following the process described in the upcoming section does not, however, guarantee that the forecasts are adequate. The analyst must choose correct AADT and vehicle classification volumes, lane distribution factors, and ESAL factors for the current year, for the year the highway opens (the base year), and for 20 years after opening (the design year). As with any other aspect of the roadway design process there will always be a degree of uncertainty associated with the analyst's estimates and projections. The Traffic Forecast and Analysis Section staff will offer assistance to analysts performing ESAL forecasts and approve forecasts that are procedurally and methodologically sound.

4-4.03.02 DETERMINATION OF TWO-WAY AADT

The first part of the ESAL forecasting process provides the analyst with a basic constraint for the current year and each of the forecast years. Regular traffic counts and AADT estimation throughout the state have provided the analyst with a reasonable historical record of highway use. Since step two of the ESAL forecasting process requires that AADT be separated into different vehicle types, the determination of current and forecast AADT sets relative limits on particular vehicle classification volumes.

The Analyst performing an ESAL forecast must first evaluate AADT and/or Heavy Commercial Average Daily Traffic (HCADT) forecasts that may already have been approved during the Preliminary Design phase of a project's development. If no AADT forecasts exist for a project, the analyst determining AADT can employ any or all of the following AADT forecasting methods depending on the location, scale, complexity and importance of the forecast. The analyst may
obtain detailed descriptions of these methods and data collection techniques associated with each method from Traffic Forecast and Analysis Section personnel.

- Inferred growth rate
- Project AADT as a function of population, employment, or other independent variables
- Least squares projection using historic AADT. (Trunk highway AADT's prior to 1986 generally require axle correction factor adjustment.)
- Analysis of trends and patterns within a travel corridor
- Use of computer generated travel demand estimates

Mn/DOT traffic flow maps (available in the Transportation Building, St. Paul) provide current estimates of AADT for the trunk highways, county road systems, and the municipal state aid system. If necessary, the Analyst can request additional AADT estimates by contacting the Traffic Forecast and Analysis Section staff.

### 4-4.03.03 DETERMINATION OF TWO-WAY VEHICLE CLASSIFICATION VOLUMES

The second step of the ESAL forecasting process provides the analyst with volume estimates for each classification of vehicle for the current, base, and design years. The number of vehicle classifications depends upon the number of uniquely defined, average ESAL factors. In Minnesota there are eight sets of average ESAL factors that are generally used in ESAL forecasts. Number of axles and body configuration usually provide the basis for defining vehicle classifications when quantifying ESAL factors.

Occasionally, the analyst will choose to deviate from the eight vehicle classifications when additional average axle weight and axle configuration data is available. By making the distinction between fully loaded trucks in one vehicle classification category (maximum weight per axle permitted) and the trucks remaining within the same category, the analyst can substitute two classification categories for the original category in an ESAL forecast. In this way, the analyst can use knowledge of local trucking characteristics and haul direction to substantiate the use of project-specific ESAL factors.

Since each road segment in the state has a distinct mix of vehicle types, this step of the ESAL forecasting process requires that the analyst evaluate existing vehicle classification data for the highway project segments close to the project. Vehicle classification site listings and maps are available from personnel in the Traffic Forecast and Analysis Section. If no data exists on or near the project, the analyst should request that additional vehicle classification data be collected. If data cannot possibly be collected, the analyst may refer to Table 4-4.2 for values that may be used to estimate vehicle classification volumes.
Table 4-4.2. Vehicle classification volumes. Revised February 1, 1997

<table>
<thead>
<tr>
<th>VEHICLE CLASS PERCENT OF AADT</th>
<th>Analysis of 1983-1989 Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Classes</td>
<td>Trunk Highways Greater Minnesota</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>Autos, pickups</td>
<td>89</td>
</tr>
<tr>
<td>2 ax, 6 tire SU</td>
<td>2.7</td>
</tr>
<tr>
<td>3 + ax SU</td>
<td>1.5</td>
</tr>
<tr>
<td>3 ax TST</td>
<td>.1</td>
</tr>
<tr>
<td>4 ax TST</td>
<td>.2</td>
</tr>
<tr>
<td>5 + ax TST</td>
<td>6.1</td>
</tr>
<tr>
<td>Buses, Trucks w/Trailers</td>
<td>.4</td>
</tr>
<tr>
<td>Twin Trailers</td>
<td>.1</td>
</tr>
<tr>
<td>Total Number of Sites</td>
<td>N = 837</td>
</tr>
</tbody>
</table>

SU = Single Unit Trucks  
TST = Tractor Semi-Trailer  
ax = axle

In forecasts involving new alignments, the Analyst occasionally needs additional data to define truck classification and travel patterns. Additional data requests should be made to staff in the Traffic Forecast and Analysis Section to ensure that acceptable data collection methods and adjustment procedures are used.

After determining current vehicle classification volumes for a site on a proposed highway project, the analyst needs to determine how the volumes for each classification may change in the future. If historical data from the vehicle classification data record suggests that each vehicle classification volume as a percent of AADT has remained relatively stable through time, then the analyst can usually assume that future vehicle classification volumes can be estimated by multiplying each vehicle classification percent of current AADT by the AADT for the future year. Considering a different example, if historical vehicle classification data or anticipated land development along a proposed highway project suggests that passenger vehicles will increase or decrease proportionately faster than truck classifications, then the analyst can project truck classification volumes differently when compared to the AADT projections depending on the assumptions guiding the analysis. The analyst must document the assumptions that are part of the forecasts regardless of the method used.
4-4.03.04 DETERMINATION OF FLEXIBLE AND RIGID ESAL FACTORS

The third part of the ESAL forecasting process involves the use of average vehicle ESAL factors (formerly known as Sigma N-18 factors). These factors are measured and averaged over a year at one or more weigh-in-motion (WIM) data collection sites. Flexible pavement ESAL factors (also known as BESALs) for each axle are calculated using a structural number of five and a terminal serviceability of 2.5. Rigid pavement factors (also known as CESALs) are calculated using D=8 and a terminal serviceability of 2.5. The 1986 American Association of State Highway and Transportation Officials (AASHTO) "Guide for Design of Pavement Structures," Appendix D contains ESAL factors for additional axle configurations, structural numbers, slab thicknesses, and terminal serviceability values.

Most WIM sites are located on roadways with ten-ton weight limits and no springtime restrictions. However, TH 99 has a seven-ton springtime axle weight restriction. As can be seen in Table 4-4.3, average ESAL factors for each vehicle classification can vary significantly depending upon where the data is collected. Unless detailed axle weight, commodity and truck body type, and haul direction data is available, the analyst should use the default ESAL factors from Table 4-4.3.
Table 4-4.3. Average ESAL factors by vehicle classification from WIM. Revised February 1, 1997

<table>
<thead>
<tr>
<th>Flexible ESAL Factors for the Design-Lane</th>
<th>TH 99</th>
<th>I-494</th>
<th>I-94</th>
<th>TH 2</th>
<th>I-94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars, Pick-ups</td>
<td>.0007</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>2 ax 6 tire SU</td>
<td>.25</td>
<td>.26</td>
<td>.13</td>
<td>.22</td>
<td>.26</td>
</tr>
<tr>
<td>**3+ ax SU</td>
<td>.58</td>
<td>.51</td>
<td>.63</td>
<td>.44</td>
<td>.71</td>
</tr>
<tr>
<td>3 ax TST</td>
<td>.39</td>
<td>.26</td>
<td>.21</td>
<td>.55</td>
<td>.36</td>
</tr>
<tr>
<td>4 ax TST</td>
<td>.51</td>
<td>.57</td>
<td>.35</td>
<td>.47</td>
<td>.50</td>
</tr>
<tr>
<td>5+ax TST</td>
<td>1.13</td>
<td>.92</td>
<td>1.14</td>
<td>1.00</td>
<td>1.74</td>
</tr>
<tr>
<td>*(6 ax TST)</td>
<td>.78</td>
<td>.42</td>
<td>.74</td>
<td>.64</td>
<td>.69</td>
</tr>
<tr>
<td>T w/tr, buses</td>
<td>.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTC buses</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin Trailers</td>
<td>2.40</td>
<td>.49</td>
<td>.77</td>
<td>2.16</td>
<td>1.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rigid ESAL factors for the Design-Lane</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars, pick-ups</td>
<td>.0007</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>2 ax 6 tire SU</td>
<td>.24</td>
<td>.25</td>
<td>.12</td>
<td>.21</td>
<td>.25</td>
</tr>
<tr>
<td>3+ ax SU</td>
<td>.84</td>
<td>.73</td>
<td>.93</td>
<td>.62</td>
<td>1.09</td>
</tr>
<tr>
<td>3 ax TST</td>
<td>.37</td>
<td>.25</td>
<td>.20</td>
<td>.53</td>
<td>.34</td>
</tr>
<tr>
<td>4 ax TST</td>
<td>.53</td>
<td>.60</td>
<td>.35</td>
<td>.49</td>
<td>.52</td>
</tr>
<tr>
<td>5+ax TST</td>
<td>1.89</td>
<td>1.52</td>
<td>1.90</td>
<td>1.66</td>
<td>2.94</td>
</tr>
<tr>
<td>*(6 ax TST)</td>
<td>.80</td>
<td>.51</td>
<td>.89</td>
<td>.77</td>
<td>.83</td>
</tr>
<tr>
<td>T w/tr, buses</td>
<td>.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTC buses</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin Trailers</td>
<td>2.32</td>
<td>.47</td>
<td>.73</td>
<td>2.09</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Vehicle Classes:
SU = Single Unit Trucks
TST - Tractor Semi-trailer
ax = axle
WIM = Weighing-in-Motion (fixed sites)
T w/tr = Trucks with trailers
MTC = Urban transit buses

Data Taken From Years:
a = 1985, 1990
b = 1982-1985, 1990
c = 1990
d = 1984, 1985, 1990

* - This vehicle class is not usually considered separately in an ESAL forecast.
**- Use 0.91 if the route is a sugar beet hauling route.
The default ESAL factors were determined after analysis of data taken from the lane at each WIM site that records the highest total ESALs. Analysis of historic ESAL factors from the WIM sites supports the premise that ESAL factors for individual vehicle classifications are relatively stable in Minnesota. However, roadways that serve points of transfer between modes of transport can experience fluctuating average ESAL factors for trucks from year to year depending upon the transport mode and market demands. Additionally, 20-year cumulative ESAL forecasts are increased by 12 percent in anticipation of future relaxations in the axle load limit laws.

4-4.03.05 DETERMINATION OF THE DESIGN LANE DISTRIBUTION OF ESALS

The fourth part of the ESAL forecasting process requires the Analyst to quantify how the ESALs are distribution amongst lanes. Based on data from vehicle classification sites, lane distribution studies, and WIM data analysis the Traffic Forecast and Analysis Section recommends that the analyst performing an ESAL forecast use a design lane factor of 1, 0.9, or 0.7 for one, two, or three lanes in a single direction, respectively. Two-way factors of 0.5, 0.45, and 0.35 should be used for two-, four-, and six-lane facilities, respectively.

Please remember that factors and values found in these sections are subject to change each year. If you have requested copies of tables or spreadsheets in the past, please note the date associated with the tables and spreadsheets to determine whether you have the most current versions.

4-4.03.06 SAMPLE CALCULATION

The following calculation, shown in Table 4-4.4, assumes that all values have been judged to be accurate and reasonable. Moreover, the procedure shown should be followed only if the analyst does not have access to the MNESALS electronic spreadsheet available from personnel in the Traffic Forecast and Analysis Section. The spreadsheet will produce accurate calculations for a cumulative 20-year ESAL. The following process approximates the calculation performed in the spreadsheet.
**Table 4-4.4. Sample ESAL calculation.**
Revised February 1, 1997

Example 20-Year Design Lane Cumulative ESAL Calculation
(Use only if you do not have access to the MNESALS electronic spreadsheet)

<table>
<thead>
<tr>
<th>Vehicle Classes</th>
<th>Base Year AADT</th>
<th>Flexible ESAL Factors</th>
<th>Base Year ADL</th>
<th>Design Year AADT</th>
<th>Design Year ADL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars and Pick-ups</td>
<td>1207</td>
<td>x .0007 = .8</td>
<td>1690</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>2 ax, 6 tire SU</td>
<td>98</td>
<td>x .25 = 24.5</td>
<td>137</td>
<td>34.2</td>
<td></td>
</tr>
<tr>
<td>3+ ax SU</td>
<td>34</td>
<td>x .58 = 19.7</td>
<td>48</td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>3 ax TST</td>
<td>6</td>
<td>x .39 = 2.3</td>
<td>8</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>4 ax TST</td>
<td>8</td>
<td>x .51 = 4.1</td>
<td>11</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>5+ ax TST</td>
<td>120</td>
<td>x 1.13 = 135.6</td>
<td>168</td>
<td>189.8</td>
<td></td>
</tr>
<tr>
<td>Buses, trucks w/trailers</td>
<td>25</td>
<td>x .57 = 14.2</td>
<td>35</td>
<td>20.0</td>
<td></td>
</tr>
<tr>
<td>Twin Trailers</td>
<td>2</td>
<td>x 2.40 = 4.8</td>
<td>3</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>1500</td>
<td></td>
<td>206</td>
<td>2100</td>
<td>288.9</td>
</tr>
</tbody>
</table>

ADL = Average Daily Load

(Base Year ADL + Design Year ADL) / 2 = (206 + 288.9) / 2 = 247 (rounded)

Number of days in 20 years x 247 = 7300 x 247 = 1,804,335

Design Lane Factor (if 4 lane) x 1,804,335 = .45 x 1,804,335 = 811,951

Load limit increase factor x 811,951 = 1.12 x 811,951 = 909,385

Cumulative 20-Year Design Lane Flexible ESAL (rounded) = 909,000

Procedures for calculating a cumulative 20-year Design Lane Rigid ESAL are the same as above except rigid ESAL factors are used in place of the flexible ESAL factors.
REFERENCES

American Association of State Highway and Transportation Officials, Testing Standards, Washington, D.C.


