# 6-501 PORTLAND CEMENT CONCRETE

## 6-501.1 GENERAL

Concrete is a mixture of aggregate (coarse and fine), cement, water, and admixtures, which are substances that modify the characteristics of the concrete. The primary advantage of concrete is its high compressive strength. However, the tensile strength of concrete—pulling the concrete apart—is very low. Reinforcing steel is added to concrete to give it tensile strength. Important characteristics of reinforcing steel include strength of the steel used, size or diameter of the steel bar, and the location of the steel within the concrete. Reinforced concrete combines the compressive strength of concrete and the tensile strength of reinforcing steel.

The design of a structure is based on materials, especially concrete and reinforcing steel, performing in a certain manner. During construction, the ability of these materials to behave as anticipated by the designer relies on a closely controlled mix of aggregates, cement, water, and admixtures incorporated into the work as required by the specifications.

By varying the amounts and types of components of the concrete mixture, the characteristics of the concrete can be altered to achieve the results required by the design. Common types of modified concrete used in Nevada are high early strength, high performance, and self-consolidating.

### 6-501.1.1 HIGH EARLY STRENGTH CONCRETE

As the name implies, high early strength concrete cures, or hardens, faster than standard concrete. High early concrete is made with cement specifically designed to achieve design strength quickly. High early concrete is used when the finished concrete must be used soon after it is placed.

A common use for high early concrete is on an existing roadway that must quickly be reopened to traffic. In this situation, high early concrete allows traffic to use the roadway as soon as four hours after finishing, compared to three days or more with standard concrete.

### 6-501.1.2 HIGH PERFORMANCE CONCRETE

High performance concrete is a term that generally describes concrete that has an extended life expectancy because of modifications in the mix design, placement, and curing. The American Concrete Institute defines high performance concrete as concrete that meets special combinations of performance and uniformity requirements that cannot always be achieved routinely when using conventional components and normal mixing, placing, and curing practices. High performance concrete may be a high-strength concrete, but this comes only as a by-product of requiring a durable concrete.

Historically, durable concrete was achieved by specifying air content, cement content, and water-cement ratio. With high performance concrete, durability is determined by an additional variable: permeability. Because durability characteristics are more difficult to define than strength characteristics, specifications often use a combination of performance and prescriptive requirements, such as permeability and a maximum water-cement ratio.

Low permeability is desirable in a durable concrete such as high performance concrete. If the concrete cracks, it loses the benefits of low permeability, and the concrete durability diminishes. To reduce cracking, the contractor cures the concrete by supplying sufficient moisture during the curing process. One of the best methods for controlling moisture loss is the wet cure method, which is typically used for high performance concretes. Contractor quality control is important to achieve the desired results in producing and placing high performance concrete.

### 6-501.1.3 SELF-CONSOLIDATING CONCRETE

Self-consolidating concrete flows easily into tight and constricted spaces without segregating and without mechanical consolidation. To reduce segregation, self-consolidating concrete must be fluid, yet stable. To achieve a flowable mix, use smaller, finer-graded aggregates with admixtures. The required level of fluidity depends greatly on the particular application. Generally, the higher the required flowability of the self-consolidating concrete mix, the higher the amount of fine material needed to produce a stable mix. In some cases, a viscosity-modifying admixture can be used instead of, or in combination with, an increased amount of fine aggregate to stabilize the concrete mixture.

Bridges may require a large amount of reinforcing steel in a confined space. Because of this congestion of reinforcing steel, conventional concrete may not consolidate completely within the forms and around the reinforcing steel. Additionally, the use of mechanical consolidating tools is constrained or physically prohibited. In such situations, the specifications may require the use of self-consolidating concrete.

When using self-consolidating concrete, carefully consider the forms. Because the material constrained by the forms is more fluid than conventional concrete, the concrete may create greater pressure on the form. The contractor should consider the additional pressure, called liquid head, during design of the forms. Additionally, form construction must result in a watertight, leakproof barrier to confine the concrete. .

## 6-501.2 CONCRETE AGGREGATE

Concrete aggregate consists of sand and gravel. For a good concrete mix, aggregate should be clean, hard, free of absorbed chemicals or coatings and other fine materials that could deteriorate concrete. Aggregates account for 60 to 75 percent of the total volume of concrete. Concrete aggregates are classified as either fine or coarse. Fine aggregates typically consist of natural sand or crushed stone with particles smaller than 3/8-inch. Coarse aggregates range in size from 3/8-inch to two inches.

Aggregate processing consists of crushing, screening, and washing the aggregate to obtain proper cleanliness, gradation, and other characteristics. Once processed, the aggregates are handled and stockpiled in a way that minimizes segregation and degradation, and reduces contamination. Aggregates strongly influence concrete's freshly mixed and hardened properties, proportions, and economy. Consequently, aggregate selection is an important process. Although some variation in aggregate properties is expected, following are characteristics to consider when selecting aggregate:

- Grading
- Durability
- Particle shape and surface texture
- Abrasion and skid resistance
- Unit weights and voids
- Absorption

Grading refers to the distribution of the aggregate particle sizes. Aggregate grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. During concrete aggregate production, the aggregate is stored in stockpiles. The contractor is responsible for constructing stockpiles that provide aggregates required by the specifications. Proper stockpile construction consists of the following:

- Minimizing segregation. Avoid high, cone-shaped stockpiles.
- Minimizing equipment on the aggregate stockpile because the concrete aggregate can break down, changing the gradation and introducing foreign particles.
- Separating the stockpile from other materials to avoid contamination and to maintain the integrity and gradation of the concrete aggregate.
- Monitoring the effect of weather on stockpiled aggregates. Mist during extreme heat and protect from high wind to maintain proper moisture conditions, saturated surface dry (SSD) conditions. During cold temperatures, protect aggregate from freezing.

As the contractor produces concrete aggregate, the aggregate is stockpiled using methods to preserve the quality and to ensure that sufficient quantities are available to complete the planned concrete production for the day. Contractors should dedicate stockpiles to specific projects and clearly identify the project where the aggregate will be used.

### 6-501.3 ADMIXTURES

Admixtures are chemical ingredients that are added to the concrete mixture immediately before or during mixing. Admixtures are used primarily to do the following:

- Modify the properties of concrete to improve workability
- Modify the properties of hardened concrete
- Preserve the quality of concrete during mixing, transporting, placing, and curing

Successful use of admixtures depends on the use of appropriate methods of batching, delivering, and placing concrete. Most chemical admixtures are supplied in ready-to-use liquid form and added to the concrete at the plant or at the jobsite. Certain admixtures, such as pigments, expansive agents, and pumping aids, are used in extremely small amounts and are usually added to a batch by hand using pre-measured containers. Because admixtures can be incompatible with each other, a new mix design may be required. Confer with the Materials Division for guidance.

The following factors determine the effectiveness of an admixture:

- Type and amount of cement
- Water content
- Aggregate characteristics
- Mixing time
- Timing of admixture introduction into concrete mix
- Time between addition of admixture and placement of concrete
- Slump
- Concrete temperatures
- Atmospheric temperature
- Manner in which admixture is introduced to the mix

Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture—reducing the water-cement ratio, adding additional cement, using a different type of cement, or changing the aggregate and aggregate gradation.

Following are five general classes of chemical admixtures:

- Air-entraining – Air-entraining admixtures are used to place microscopic air bubbles into the concrete. Air entrainment is used principally to improve resistance to freezing when exposed to water and deicing chemicals. The microscopic air bubbles relieve internal pressure on the concrete by providing tiny chambers for the expansion of water when it freezes. Air-entraining agents improve the workability and durability of concrete.
- Water-reducing – Water-reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio, which increases the strength of the concrete without increasing the amount of cement.
- Retarding – Retarding admixtures, which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. Retarding admixtures allow a longer period between concrete production and placement. Retarders may also be used when a longer set time is required. High temperatures often cause an increased rate of hardening, which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.
- Accelerating – Accelerating admixtures increase the rate of early strength development, allowing finishing operations to begin sooner. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather, allowing required chemical reactions to take place so the concrete can harden. Accelerating admixtures do not prevent freezing of the concrete.

- Plasticizers (superplasticizers) – Plasticizers, also known as superplasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent. Superplasticizers are added to concrete with a low-to-normal slump and water-cement ratio to make high-slump, flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little vibration or consolidation. The effect of superplasticizers lasts approximately 30 to 60 minutes, depending on the brand, dosage rate, handling, and weather. After the effect of the superplasticizer wears off, workability of the concrete decreases rapidly. Because superplasticizers have a short effective life, superplasticizers are usually added to concrete at the jobsite. Superplasticizers)

All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring.

Corrosion-inhibiting admixtures are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used for concrete structures, such as marine facilities, bridges, and parking garages that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while alkali-silica reactivity inhibitors aid in controlling durability problems associated with alkali-silica reactivity. Workability enhancers, such as viscosity modifying admixtures, are used in self-consolidating concrete to increase flowability and decrease aggregate segregation.

In addition to admixtures that alter the characteristics of a concrete mix, other products can also be used to change concrete characteristics. Flyash, slag, and silica fume are by-products of industrial processes, are less expensive than cement, and have properties similar to cement. These materials are substituted for cement and modify the concrete mix as follows:

- Flyash
    - Enhance workability
    - Reduce bleed water
    - Reduce slump loss
    - Increase the long-term strength
    - Reduce permeability
    - Increase the durability
    - Reduce the potential for sulfate attack
    - Reduce the heat of hydration
    - Reduce the potential for alkali-silica reactivity

- Slag
  - Increase workability, finishability, and pumpability
  - Increase compressive and flexural strength
  - Reduce permeability
  - Increase resistance to chloride intrusion and corrosion
  - Mitigate moderate to severe sulfate attack
  - Reduce the potential for alkali-silica reactivity
  - Reduce thermal stress in mass concrete through lower heat generation
- Silica Fume
  - Reduce permeability
  - Increase the resistance of concrete to chloride penetration

For additional information on admixtures and additives, refer to the FHWA website, http://www.fhwa.dot.gov/infrastructure/materialsgrp/admixture.html.

### 6-501.4 PROPORTIONING

Carefully proportioning and mixing concrete ingredients produces a strong and durable concrete. A concrete mixture with insufficient paste to fill all the voids between the aggregates is difficult to place and produces rough, honeycombed surfaces and porous concrete. A concrete mixture with excess cement paste is easy to place and produces a smooth surface, but it is susceptible to increased shrinkage cracking and spalling.

A properly designed concrete mixture possesses the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate, and 15 to 20 percent water. Entrained air in many concrete mixes may also take up another 5 to 8 percent.

Concrete ingredients are proportioned to make the most economical use of available materials, meeting specifications to produce concrete of the required workability, durability, and strength. Because the mixture must meet multiple objectives, increasing one ingredient may achieve one objective, but detract from another. Achieving optimum concrete proportions requires balancing the characteristics of each component and the physical and chemical characteristics of the components in combination. Initial proportioning of component material (mix design) is based on the theoretical characteristics of the components. The final proportions are often established by adjustment in the field and must remain consistent with the approved mix design and specifications.

Water plays an important role in the chemistry of concrete. Although the specifications state the water quality requirements, follow the guideline that if water is suitable for drinking (potable), then it is acceptable for mixing in concrete. Water is required for chemical reactions that transform cement and aggregates into concrete. Cement and water form a paste that coats each particle of stone and sand. Through a chemical reaction called hydration, the cement paste hardens and strengthens. During hydration, chemical energy is converted to heat, commonly called the heat of hydration. The character of the concrete is determined by the quality of the paste. The strength of the paste, in turn, depends on the ratio of water to cement. The water-cement ratio is the weight of the mixing water divided by the weight of the cement. High-quality concrete can be produced by lowering the water-cement ratio without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete, provided the concrete is properly placed, consolidated, and cured.

Aggregates from different sources may produce significant differences in concrete strength even though the amounts of water and cement remain constant. Cement quality may vary between manufacturers. Although components of the mix are variable, variability of the aggregates influence concrete strength more than changes in the quality of the cement.

Different types of cement are manufactured to meet various physical and chemical requirements. Cement is manufactured in five standard types.

- Type I
  - Type I cement is commonly used on construction projects. It is used to construct such things as buildings, bridges, pavements, and precast concrete products.
- Type II
  - Type II cement is used when the structure will be in contact with sulfates. Type II cement has a moderate resistance to sulfate attack. It generates less heat at a slower rate than Type I cement.
- Type III
  - Type III cement is commonly called high early strength cement because it causes concrete to set and gain strength rapidly. Type III is chemically and physically similar to Type I, except that its particles have been ground finer.
- Type IV
  - Type IV cement has a low heat of hydration and develops strength at a slower rate than other cement types, making it ideal for use in dams and other massive concrete structures where there is little chance for heat to escape.
- Type V
  - Type V cement is used in concrete structures that will be exposed to severe sulfate action, typically where concrete is exposed to soil and groundwater with a high sulfate content.

Each of the standard types of cement can be modified to respond to specific environmental conditions. When a standard type of cement is modified, a letter designation is added to the standard type designation, such as Type IP or Type IA. The “P” indicates the addition of pozzolan, and “A” indicates air-entraining characteristics in the cement.

After the components are combined into a concrete mix, two factors that are commonly used to evaluate and monitor the concrete mixing process are cement factor and water-cement ratio. Concrete is typically measured in cubic yards. Cement factor is the amount of cement, measured in pounds, in one cubic yard of concrete. Cement is sometimes measured in sacks per cubic yard (one sack of cement weighs 94 pounds). NDOT specifications typically require cement factors that range from five sacks per cubic yard (470 pounds per cubic yard) to eight sacks per cubic yard (752 pounds per cubic yard). Although concrete strength is influenced by several factors, the cement factor is a measurement that identifies the amount of cement incorporated into the concrete mix.

To monitor the cement factor during concrete production, the inspector must record the weights of the various ingredients. Because the cement factor is measured in weight of cement per volume of concrete, mathematical conversions must be made to determine the actual cement factor of the mix. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for an example of determining an actual cement factor. The cement factor is calculated for every load of concrete that is incorporated into the work. The cement factor is recorded on NDOT form 040-025, "Transit-Mix Concrete Delivery Form."

The water-cement ratio helps to monitor the appropriate amount of water in the concrete mixture. It is a design criterion that influences the final properties of concrete by measuring the weight of water to the weight of cement in the mixture. It provides control over two opposing, yet desirable, properties: strength and workability. The advantages of a low water-cement ratio are as follows:

- Increased strength
- Lower permeability
- Increased resistance to weathering
- Reduced shrinkage cracking tendencies

The less water used, the better quality of concrete, provided it can be consolidated properly. A mixture with a high water-cement ratio will be more workable than a mixture with a low water-cement ratio. A less workable mixture (low water-cement ratio) results in a stronger concrete. A water-cement ratio is chosen to give the best result for a given situation. This is not an entirely free choice because the water-cement ratio must be about 0.25 to complete the hydration reaction. Typical values of water-cement ratios are between 0.35 and 0.45 because they give a good amount of workability without sacrificing a lot of strength. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for an example of how to determine the water-cement ratio.

On NDOT projects, the contractor develops a concrete mix design and submits it to the Resident Engineer, who reviews and submits it to the Materials Division for final approval. The Materials Division sends a memorandum to the Resident Engineer stating the acceptance or rejection of the mix design. The Resident Engineer notifies the contractor of the acceptance or rejection of the mix design.

Producing a concrete mixture requires balancing several objectives and managing materials to produce the desired outcome. Aggregates, cement, water, and admixtures are combined to produce a concrete mix that achieves the design objective. Key measurements used to monitor the concrete mixture are the cement factor and the water-cement ratio. Not only are the materials and the proportioning of the materials important, the mixing plant and its operation can affect the quality and durability of the concrete.

### 6-501.5 MIXING PLANT

The contractor is responsible for the plant and its operations. Although the plant is the contractor's responsibility, the inspector observes and monitors the plant operation to verify that the mixing plant conforms to the requirements of the specifications and that components of the concrete mixture are consistent with the approved mix design. NDOT requires concrete mixing plants and transit mixing trucks to be certified by the National Ready Mixed Concrete Association (NRMCA). The NRMCA is a national association of ready mixed concrete producers and plant operators. NRMCA certification of concrete production facilities provides a system for establishing that production facilities of ready-mixed concrete plants are satisfactory. To receive certification, a plant is inspected to assess compliance with an industry checklist. Certifications are valid for a specific period. The inspector must check that the NRMCA certification is current for the plant producing the concrete. The Nevada Bureau of Weights of Measures must also certify the plant scales.

Concrete is produced several different ways, and the characteristic of each type are as follows:

- Transit-Mixed – Raw ingredients are loaded directly in the transit mixing truck. The mixer drum is turned at a fast speed while the materials are loaded. Once loaded, the concrete is mixed in one of two ways:
    - Jobsite – The drum is turned at slow speed (agitating speed) while traveling to the jobsite. At the jobsite, the concrete is completely mixed at a high speed (mixing speed) for 70 revolutions.
    - Plant site – The drum is turned at mixing speed for 70 revolutions, and then checked for consistency. The transit mixing truck rotates the drum at agitating speed during transit to the jobsite.
- Shrink-Mixed – Raw ingredients are partially mixed in a plant mixer and then discharged into the drum of a transit mixing truck to complete the mixing. Central mixing plants are often used to shrink mix, or partially mix the concrete. The amount of mixing in the transit mixing truck depends on the application of the concrete and delivery constraints.
- Central-Mixed – Raw ingredients are completely mixed in a plant mixer before being discharged into a hauling truck. The hauling truck, either a dump truck or transit mix truck, is used primarily to transport the mix.
- Volumetric-Mixed – Raw ingredients are stored separately in a truck-mounted, volumetric mixing unit. These mobile mixing units can supply freshly mixed concrete in fairly precise quantities for small-volume placements. The unit consists of a truck with bins of sand, coarse aggregate, cement, water, and admixtures. The Construction Division must approve the use of volumetric mixing units.

Of these mixing types, the central-mixed process provides the fastest production time and better control of materials. Additionally, when transit mixing trucks are used for mixing purposes, the consistency of the concrete mixture can be variable because each truck and operator can have different mixing characteristics and capabilities. Regardless of the type of mixing process, the inspector should become familiar with the plant and its operation before concrete production begins. By becoming familiar with the plant, the inspector can effectively monitor the quality and quantity of the materials and mix.

Before concrete is produced each day, a gradation test and a moisture test are taken. The test results are reviewed to verify the consistency of the aggregate and to confirm compliance with specification requirements. Field testers, or the plant inspector, conduct moisture tests to calculate the maximum allowable water that may be added to the mix. Table 5.1 in Section 5, Sampling and Testing, of this *Construction Manual* lists the appropriate frequencies.

Concrete mix designs state the proportion or quantity of each component of the mix: course aggregate, fine aggregate, water, cement, and admixtures. The proportion of materials is based on an aggregate moisture condition in which the aggregate is saturated with a dry surface (saturated surface dry, SSD), which is the condition assumed for the mix design. The component batch weights must be adjusted to reflect the condition of the moisture content of the aggregate in the field. Adjusted batch weights can be calculated using the Worksheet for Calculating Water in Concrete Aggregate. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for a copy of the worksheet and an example calculation. Concrete mixing plants are typically computerized and the mixing plant computer prints the concrete mix batch weights, based on SSD conditions. Although the mixing plants are computerized, inspectors still must calculate adjusted batch weights for aggregate.

Based on the adjusted batch weights for aggregate, the inspector calculates the maximum amount of water that can be added to the mix. The amount of water that may be added to the mix—at the plant, at the structure, or both—is the difference between the maximum allowable water established in the mix design and the free water available from the moisture in the aggregates. Aggregate moisture greater than the SSD moisture is free moisture. By using the mix design and the daily moisture content test results, the inspector uses the Worksheet for Calculating Water in Concrete Aggregate to calculate the maximum allowable water that can be added to the mix. Following is an example of how to calculate maximum allowable water that can be added to a mix:

Theoretical (from mix design):
Water = 275 lbs per cubic yard, based on SSD condition
Total absorbed water in aggregate = 87 lbs, in SSD condition

Field conditions (from moisture tests):
Total water in aggregate = 190 lbs, actual conditions

Calculation:
Free water = 190 lbs – 87 lbs = 103 lbs

Maximum allowable water = 275 lbs – 103 lbs = 172 lbs
Converting to gallons = 172 lbs / 8.333 lbs per gallon = 21 gals per $yd^3$

For a typical 8 $yd^3$ load, the maximum allowable water would be 21 gals x 8 $yd^3$ = 168 gals

After calculating the maximum allowable water, the inspector notes this information on NDOT form 040-025, “Transit-Mix Concrete Delivery Form.” The inspector also notes on the form the actual water added at the plant, admixtures, and additional information relating to the plant operation. The form is prepared for each load and given to the transit truck driver, who gives it to the inspector at the structure. The inspector confirms that the total water does not exceed the maximum allowable water noted on the form.

Not only are the mixing and proportioning of the materials important, weather conditions during concrete placement can constrain and affect the quality and durability of the concrete.

## 6-501.6 WEATHER

### 6-501.6.1 GENERAL

Weather conditions during placement and curing can affect the quality of concrete, even though weather may not be extreme. The inspector should be aware of the following general considerations to reduce the effects of weather during concrete placement:

- Pre-wetting surfaces that will be in contact with freshly placed concrete to reduce water loss from concrete
- Limiting transit time to reduce the potential of stiffening of the mixture, typically within 90 minutes of introducing mixing water to the cement and aggregates
- Limiting concrete temperatures to less than 90°F during placement to maintain workability and to reduce water demand
- Placing curing seal as soon as possible after finishing to reduce evaporation
- Limiting finishing time to reduce migration of water to the surface, leading to additional evaporation
- During finishing, adding of water to the surface by fogging or misting should be minimal; application of water by sprinkling is not allowed because it leads to inconsistencies in the mixture which can lead to scaling or cracking
- Monitoring concrete surface temperature to determine if corrective measures are needed to offset the effects of weather

Cold weather, hot weather, and windy conditions can all affect the quality of concrete. During the spring and fall seasons, temperature differentials can be significant and require special attention. Coordination between the Resident Engineer, inspector, and contractor ensures that the contractor's planning for weather conditions provides sufficient protection of the concrete during placement and curing. At the time of concrete placement, the contractor must closely monitor the weather forecast and the temperature of the concrete. Having sufficient materials available before placement begins increases the options available for protecting the concrete. Wind accelerates the loss of moisture from newly placed concrete. Constructing windbreaks to protect fresh concrete reduces the effect of wind. The following sections describe the effects of cold and hot weather on concrete and precautions that the contractor takes to ensure that the concrete cures as desired.

### 6-501.6.2 COLD WEATHER

Cold weather concreting is common throughout Nevada, even in the southern Nevada climate. Every cold weather application must be considered carefully to accommodate unique situations. The American Concrete Institute defines cold-weather concreting as "a period when for more than three successive days the average daily air temperature drops below 5°C (40°F) and stays below 10°C (50°F) for more than one-half of any 24 hour period." Such temperature conditions can lead to problems with concrete freezing before it hardens or delayed cure time due to reduced heat of hydration.

During cold weather, the primary objectives of concrete placement are as follows:

- Prevent concrete from freezing
- Assure concrete reaches sufficient strength for loading or form removal
- Maintain normal curing conditions
- Limit rapid temperature changes

During cold weather, humidity can be lower than it is during hot weather. The lower humidity can cause greater moisture loss than during hot weather. Therefore, the contractor must protect concrete from moisture loss during cold weather concrete placement and curing.

During cold weather, the placement and curing of the concrete requires close observation by the inspector. Before the contractor places concrete in cold weather, the inspector checks that the temperature of surfaces in contact with the concrete are above freezing and that the contractor has removed snow, ice, and frost. Materials to be embedded in the concrete, such as reinforcing steel, should have temperatures above 40°F. The temperature differential between the coldest or warmest part of the surface and the delivered concrete must be less than 30°F. When concrete is placed on steel structures, the contractor may heat the under side of the structure to reduce the temperature differential. The contractor should never place concrete on a frozen surface. To protect the surface from freezing before concrete placement, the surface can be covered with insulated blankets a few days before concrete placement.

Concrete's exposure to cold weather will extend the time required for it to gain strength. In structures that will carry large loads prior to completion of the curing process, the concrete temperature must be maintained at a minimum of 50°F to accommodate stripping of forms and shoring and to permit loading of the structure.

Never allow concrete to freeze during the curing period. As concrete cures, it produces heat. Some concrete may need protection to reduce the heat from escaping while it cures; more severe temperatures may require supplemental heat, such as heaters. The contractor should not apply heat directly to the concrete surface; heat the air, not the structure. Monitoring concrete temperature during cold weather requires a recording thermometer, as described in the specifications.

If the specifications require a Concrete Quality Control Plan, the plan should address the following cold weather considerations:

- Maintain specified temperatures throughout the entire operation. Fresh concrete has temperature requirements as well as the hardened concrete.
- Protect individual components used in concrete from the adverse effects of cold weather.
- Protect aggregate stockpiles from freezing, so that frozen aggregate is not introduced into the mix. Use insulating blankets and steam to keep aggregate from freezing.
- Warm reinforcing steel and beams before placing concrete to preclude differential temperatures in the concrete.
- Heat mixing water, either at the plant or in the trucks. Take care to use water that is not too hot.
- Typically, do not heat cement; merely protect it from the elements.
- Follow the manufacturer's recommended temperature ranges, as liquid admixtures are susceptible to degradation from extreme temperatures.
- Use insulating blankets to protect underlying base materials and the forms from freezing
- Use insulating blankets to protect freshly placed concrete from cold weather.

6-501.6.3 HOT WEATHER

When mixing, transporting, and placing concrete, it is important to understand the effects of hot weather, low humidity, solar radiation, and wind on concrete properties and construction operations. Hot weather can result in rapid moisture loss on the surface of recently placed concrete, resulting in plastic shrinkage cracking and accelerated setting time. Hot weather can also speed up cement hydration and create the potential for cracking in large concrete structures. Although hot weather–related problems usually occur in the summer, the combination of low humidity and high winds can also lead to rapid moisture loss, even during winter months, particularly in arid climates. Generally, high humidity reduces the effects of high temperatures.

In hot weather, the following conditions can cause problems during concrete mixing or placement:

- Water demand
- Rate of slump loss, which increases the tendency to add water at the jobsite
- Rate of setting, resulting in difficult handling, finishing, and the risk of cold joint

Improper curing during hot weather can cause the following problems with the concrete:

- Decreased strength
- Increased rate of evaporation, causing shrinkage and thermal cracking
- Decreased durability from cracking
- Increased permeability
- Increased potential for reinforcing steel corrosion due to increased cracking

The contractor can take a variety of precautions to reduce the effects of hot weather on concrete. The precautions used for a specific situation depend on the conditions when the concrete is placed. According to the American Concrete Institute, if the temperature at the time of concrete placement will exceed 77°F, precautions must be taken to address the effects of hot weather. The contractor's Concrete Quality Control Plan, as described in Section 6-502.2, should incorporate precautions that reduce the effects of high temperatures. The precautions may include some or all of the following:

- Maintain specified temperatures throughout the operation. Both fresh concrete and hardened concrete have temperature requirements.
- Reduce the delivery time.
- Moisten subgrade, steel reinforcement, and forms before placing concrete.
- Erect temporary wind breaks to limit wind velocities and sunshades to reduce concrete surface temperatures.
- Cool the components of the concrete to reduce its initial temperature. Follow these temperature-reducing guidelines:
    - Reducing the aggregate temperature two degrees reduces the concrete temperature one degree.
    - Reducing the water temperature four degrees reduces the concrete temperature one degree.
    - Reducing the cement temperature eight degrees reduces the concrete temperature one degree.
- Substitute ice for a portion of the water in the concrete to lower the temperature. When substituting ice for a portion of the water, account for the ice in the mix.
- Use a concrete consistency that allows rapid placement and consolidation.
- Apply water to the outside of transit truck drums, being careful to keep water from entering the drum.
- Use water-chilling systems internal to the freshly placed concrete for large concrete placements.

- Protect the concrete surface during placement with plastic sheeting or evaporation retarders to maintain the initial moisture in the concrete.
- Provide sufficient labor to minimize the time required to place and finish the concrete, as hot weather conditions substantially shorten the time for the concrete to harden.
- Fog or mist the area above the concrete placement to raise the relative humidity and reduce the evaporation rate. Care must be taken not to allow accumulation of water on the concrete surface.
- Provide appropriate curing methods as soon as possible.
- Adjust the time of concrete placement during the day to take advantage of cooler temperatures, such as early morning or nighttime placement.

### 6-501.7 CURING

Curing is the process of controlling the concrete moisture content and temperature while the chemical reaction between cement and water (hydration)—which started during mixing—continues, and the concrete begins to harden. Proper curing is essential to quality concrete. Curing influences the properties of hardened concrete, such as durability, strength, permeability, and resistance to abrasion, freezing, thawing, and deicer chemicals. Proper curing is critical on large concrete surface areas exposed to the atmosphere. Improper curing can significantly reduce the strength of concrete. Section 6-501.6, Weather Limitations, provides guidance on temperature control.

Curing the concrete aids the chemical reaction called hydration. Although most freshly mixed concrete contains more water than required for complete hydration, any appreciable loss of water by evaporation can delay or prevent hydration. If temperatures are favorable (50°F to 75°F), hydration is relatively rapid the first few days after concrete is placed. Retaining water during the first 48 hours is important to the hydration process. Good curing prevents or reduces evaporation. The inspector monitors the environmental conditions during the curing period and records information on NDOT form 040-024, "Concrete Evaporation Rate and Cure Monitoring."

Using the subgrade or forms to restrain the concrete helps to maintain temperatures and control evaporation. For concrete exposed to the atmosphere, following are the two most common methods of curing:

- Wet cure method – This method, called the water method in the specifications, consists of applying water to the concrete for at least seven days after placing. Bridge decks and approach slabs, which typically use high performance concrete, require a wet cure of at least 10 days. To maintain moisture, the contractor places moist burlap or cotton mats on the concrete. On bridge decks and approach slabs, use of wet burlap and plastic coverings are required.
- Curing compound method – This curing method consists of applying a liquid chemical to the surface of the wet concrete, forming a membrane that retains moisture in the concrete. Apply curing compounds after finishing and immediately after the initial sheen dissipates. Where curing compound has been applied, protect the surface by minimizing foot traffic that could damage the membrane. Immediately repair damaged membranes.

Membrane-forming curing compounds are typically clear or white pigmented. Clear curing compounds may contain a dissipating dye (usually red) that makes it easier to see if the concrete surface is completely covered with the compound. The coloring disappears after several days. White pigmented curing compounds have the added benefit of light reflectivity, which helps keep the concrete cool, thereby improving the hydration process. White-pigmented curing compounds are used on concrete pavements where reflectivity aids in cooling the large surface areas exposed to the atmosphere.

Regardless of the curing method, the concrete may require supplemental heating or cooling to maintain favorable curing temperatures.

The reactions between cement and water are accompanied by escaping heat. A part of this heat escapes through the surface of the concrete mass, but some heat is retained, creating a rise in the internal concrete temperature. Excessive internal temperatures may reduce the concrete strength and create internal stresses that cause cracks. In large concrete masses that may be part of major bridge structures, internal cooling may be necessary to control increasing temperatures in the concrete. Chilled water, circulated through a network of pipes embedded in the concrete, controls the temperature and cools the concrete mass. Figures 6-501.1 and 6-501.2 show a cooling system and component piping for a footing prior to the placement of concrete.

Figure 6-501.1. Cooling System for a Mass Concrete Footing.

Figure 6-501.2. Component Cooling Pipes in Footing.

### 6-501.8 MAJOR AND MINOR CONCRETE

Depending on the size of the concrete structure being constructed, concrete items of work may be classified as Major Concrete or Minor Concrete. Although the physical characteristics of major and minor concrete are the same, major concrete is used on structures such as bridges and box culverts, and minor concrete is used on structures such as drop inlets and catch basins. Minor concrete has higher labor and forming costs associated with a relatively small quantity of concrete, in contrast to major concrete, which has costs distributed over a larger quantity of concrete. To account for small concrete quantities, the work item of “Minor Concrete” is used. The term “Minor Concrete” refers only to the work item and the manner of payment, not to testing, sampling, and inspection.

# 6-502 CONCRETE STRUCTURES

## 6-502.1 GENERAL

This section covers items related to constructing structures. Structures include bridges, grade separations, structure approach slabs, culverts, headwalls, endwalls, drainage inlets, and retaining walls. Structures can be constructed with concrete or steel. Even steel structures contain a number of components that are made with concrete.

A major structure, like a bridge, consists of the following components:

- Piles
- Footing
- Pier columns
- Pier cap
- Abutments
- Girders and diaphragms
- Bridge deck
- Parapet (bridge rail)
- Approach slab

Figure 6-502.1 shows the bridge components.

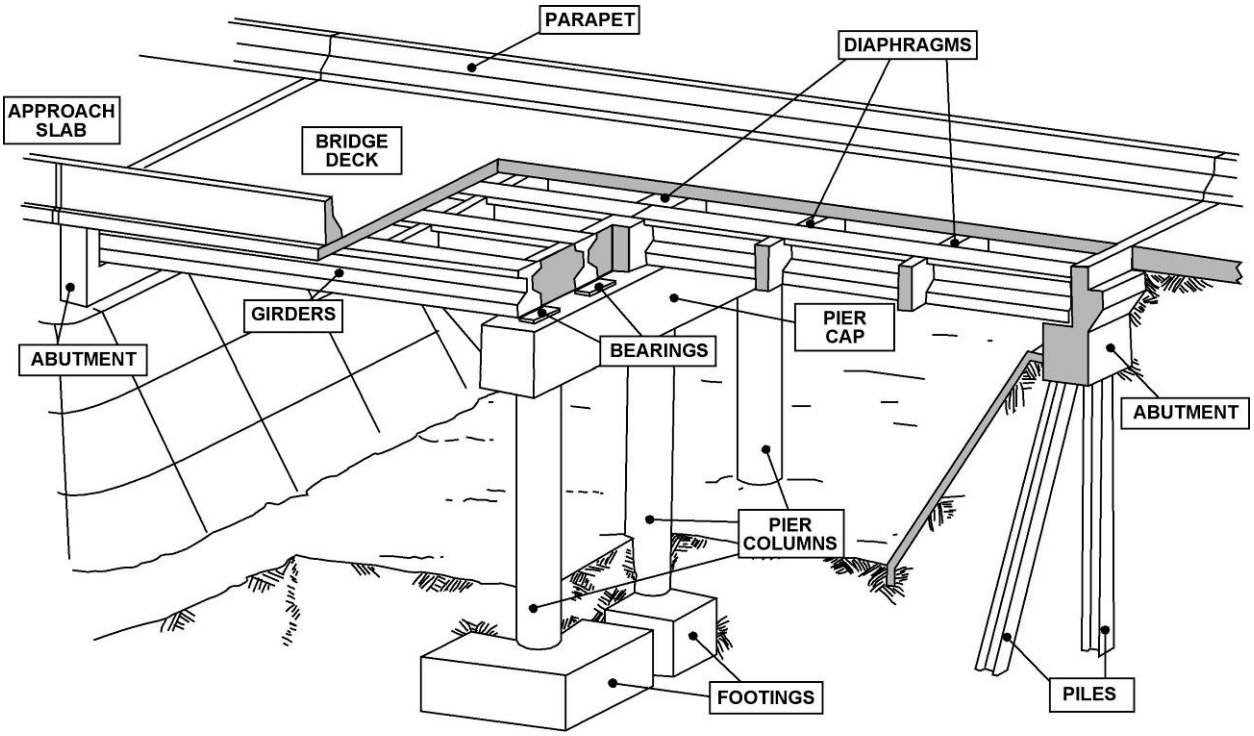


Figure 6-502.1. Typical Bridge Components.

The basic purpose of a bridge is to carry traffic across an obstacle or depression. The vehicles travel on the bridge deck, which is supported by the superstructure. The superstructure is supported by abutments at the ends of the bridge and columns between the abutments. Columns and abutments are supported by foundations, which rest on the soil. On the sides of the bridge deck are parapets that keep vehicles from straying off the bridge.

NDOT designs and constructs several types of bridges. The selection of the bridge type depends on the following criteria:

- Ability to maintain traffic during construction
- Construction time constraints
- Availability of construction materials
- Cost of construction materials
- Roadway geometry constraints
- Design complexity related to roadway geometry
- Environmental constraints
- Hydraulic constraints
- Subsurface characteristics
- Aesthetics
- Cost to maintain

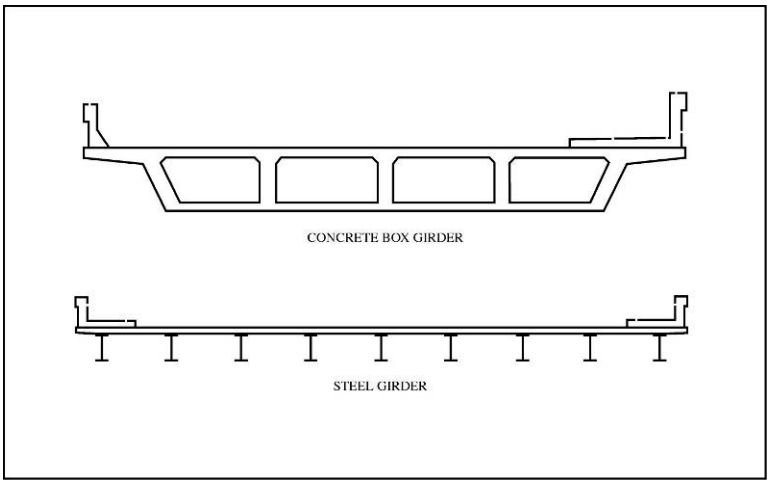


Figure 6-502.2. Common NDOT Bridge Types.

Most NDOT bridges are constructed of concrete or structural steel. Figure 6-502.2 shows the cross section of a typical concrete box girder and a steel girder bridge. Although timber structures still exist in rural areas where traffic volumes are low, new construction typically consists of cast-in-place concrete box girders (Figure 6-502.3), precast concrete girders (Figure 6-502.4), and structural steel girders (Figure 6-502.5). Cast-in-place concrete box girder bridges are the most common type of bridge in Nevada.

Figure 6-502.3. Cast-in-Place Concrete Box Girder Bridge.

Figure 6-502.4. Segmental Precast Concrete Box Girder Bridge Under Construction.

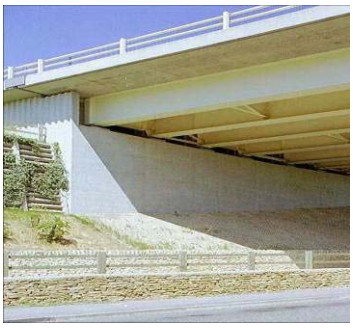

Figure 6-502.5. Structural Steel Bridge.

Many of the construction details required for concrete bridges apply to steel bridges. The difference between concrete bridges and steel bridges is that the superstructure of a steel bridge is made of steel.

Bridge construction begins with foundations constructed on prepared soil or aggregate base. A basic foundation is a large block of concrete, called a footing, which sits on the soil. If the soil does not have sufficient strength to support the design loads, a footing with more surface area is used, spreading the load over a larger area. This is called a spread footing. When the native soil does not have sufficient strength to support a spread footing, deep foundations are constructed to support the footing. Deep foundations are steel or concrete columns, called piles, placed in the ground. Deep foundations support loads through friction between the pile and the soil and through end bearing.

Columns and abutments are constructed on footings. The superstructure is constructed on the columns and on the abutment. Depending on the design, the superstructure may rest on the columns or be connected to them. Concrete structural members may be cast-in-place (concrete is placed in forms at the jobsite) or precast (concrete is placed in forms offsite, then transported to the jobsite). In Nevada, most concrete structures are cast-in-place. For cast-in-place concrete superstructures, a temporary framework supports the forms, equipment, people, and concrete when the superstructure is being built. This temporary framework is called falsework. Following construction of the superstructure, the bridge deck is constructed, followed by the parapets. After the concrete has reached a sufficient strength, the falsework and forms are removed.

Construction of major bridge structures are complex and require continuing coordination and communication among the Resident Engineer, inspector, testers, survey crew, bridge designer, and the contractor. Because of the complexity associated with constructing a bridge, poor materials or inferior construction methods can significantly impact quality and the safety of project personnel and the public. Therefore, the Resident Engineer, inspector, testers, and survey crew must thoroughly understand the bridge construction details to verify that the contractor constructs the project consistent with the plans and specifications. Unique situations may involve railroads, other utilities, environmental factors, or new construction techniques. Early coordination between the contractor, Resident Engineer, Structures Division, and third parties increases the understanding of all parties and provides greater efficiencies during construction.

### 6-502.1.1 SAFETY

During the construction of structures, personnel regularly handle and move materials and equipment. Therefore, everyone on the project must be alert to movement of materials and equipment. By being aware of surroundings, personnel avoid placing themselves in unsafe situations and reduce the chances of being struck by a moving vehicle, backing transit truck, construction equipment, or the traveling public.

A worker may be required to perform duties that require protection against falls. For construction projects, OSHA requires fall protection if a worker is at risk of falling six feet or more. However, regardless of the fall distance, fall protection is required when working over dangerous equipment, machinery, or traffic.

The contractor is required by specifications and by OSHA to develop a safety plan. The contractor submits a safety plan to the Resident Engineer for review and comment. NDOT employees must follow NDOT safety policies. NDOT safety policies provide direction on personal protective equipment. Personnel should wear personal protective equipment, such as gloves, foot and eye protection, protective hearing devices, hard hats, and respirators, to minimize exposure to a variety of hazards. Additionally, the contractor may require NDOT employees to comply with the contractor's safety plan.

When constructing structures, reinforcing steel is present throughout the structure jobsite. Reinforcing steel presents situations that require the full attention of workers and other field personnel. Field personnel must exercise care when walking on reinforcing steel to guard against twisted ankles and sprains. If inspectors and workers must walk on horizontal reinforcing steel, which is common in footings and bridge decks, they should only walk on the uppermost horizontal bar. Vertical reinforcing steel can also create safety problems. The contractor must cap exposed ends of reinforcing steel bars with blunt, protective caps that can protect a person who may fall on the steel.

### 6-502.2 BEFORE CONSTRUCTION

An inspector must thoroughly understand the plans and specifications relating to construction of bridges or other structures. The specifications will describe specific limitations or requirements associated with environmental permits or agreements with third parties, such as railroads or utilities. Additionally, coordinate with the contractor about the planned sequence of operations so that inspection and testing can be performed effectively and efficiently. An important part of communication and coordination is the Concrete Quality Control Plan that the specifications may require the contractor to prepare on projects with major concrete structures. The specifications require the contractor to prepare a Concrete Quality Control Plan that addresses the following items:

- Concrete production
- Quality control testing
- Transport
- Placement
- Finishing
- Curing
- Contingency plans for equipment breakdown or inclement weather

Because the Concrete Quality Control Plan responds to the unique requirements of each project, the Resident Engineer must verify that the contractor's plan conforms to the specific requirements of the project. It is acceptable for a contractor to submit a Concrete Quality Control Plans for an entire project, and then submit a supplemental plan that includes details for concrete placement at specific structures. After the contractor prepares a Concrete Quality Control Plan, the Resident Engineer reviews and approves it. During the review, the Resident Engineer may consult with the Construction Division, Structures Division, and Materials Division. If review comments require modification to the plan, the Resident Engineer provides the comments to the contractor who revises the plan and resubmits it for approval. The Resident Engineer must approve the plan before the contractor can place any concrete. The field crew should be familiar with the contents of the approved Concrete Quality Control Plan. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for an example of a contractor's Concrete Quality Control Plan.

For concrete structures, the contractor must perform engineering and surveying for various elements of the work.

- Engineering – The contractor engineers the form design, falsework, and other construction details relating to the means and methods that the contractor elects to use in the construction of the structure. Any engineering performed by the contractor must be stamped or certified as described in the specifications. The contractor's approved engineered drawings become the basis for the inspector to verify that the work is constructed as planned. Refer to Section 3-403.3, Submittals, of this *Construction Manual* for additional details.
- Surveying – The contractor performs the surveying needed to construct all parts of the bridge. The inspector confirms that the contractor completes the required surveying needed to construct the work. In addition, the survey crew verifies the accuracy of the contractor's surveying.

Falsework is the temporary structure that the contractor builds to support forms for the structure being constructed. The contractor is required to submit engineered drawings for falsework. The contractor should also include falsework erection and demolition plans. The Resident Engineer reviews the falsework drawings to determine if the drawings are complete and conform to the specifications. If the Resident Engineer finds the submitted drawings acceptable, the drawings are submitted to the Structures Division for review and approval. If the structure will cross a railroad, sufficient time should be allowed for review by the railroad company.

Following an initial review, the contractor may be required to revise the drawings or to submit additional information. Once approved, the contractor must erect the falsework in conformance with the approved drawings. Deviation from the approved falsework drawings is not allowed without prior approval from the Structure's Division. The inspector observes the construction of the falsework to verify conformance with the approved drawings.

During the Resident Engineer's review of the contractor's submitted drawings, the following should be considered:

- Confirm that the contractor's falsework drawings conform to the plans and specifications and that the drawings incorporate structure-specific details
- Determine if a falsework erection or a demolition plan is needed, and that a traffic control plan has been incorporated
- Verify that the falsework drawings include details to prevent falling debris, and protection of pedestrians and motorists
- Verify that the falsework drawings include details that would prevent water from dripping on pedestrians and motorists during deck curing

When inspecting falsework, the following should be considered:

- Confirm that soil compaction test results for falsework support elements conform to specifications
- Observe the contractor's installation of tattle-tales. Tattle-tales are devices used to monitor falsework settlement and movement. Confirm tattle-tale readings are taken prior to concrete placement.
- Verify that the contractor follows the approved safety plan and provides fall protection and other personal protective equipment during falsework installation
- Confirm that the contractor's Engineer of Record for the falsework reviews the falsework system onsite and provides written certification that the falsework system has been assembled according to the approved falsework drawings and approved revisions

All elements of bridge construction must strictly conform to the plan details, including reinforcing steel, steel spacing, steel clearances, and concrete dimensions. Project personnel cannot substitute or modify the plan details without prior approval from the Resident Engineer, who consults with the Structures Division. Even apparent minor modifications can significantly alter a structure's performance or behavior. For example, using reinforcing steel of a larger diameter than specified or increasing concrete dimensions can increase the rigidity and loading of the structure, conflicting with the structural designer's assumptions.

A pre-pour conference is required before concrete placement of any major structure. Required attendees include key NDOT personnel (including representatives from the Construction Division, Structures Division, and Materials Division), the contractor, concrete material suppliers, and other appropriate invitees of the Resident Engineer. Discussions at the pre-pour conference include key aspects of the concrete placement activities, such as mixing, finishing, curing, and traffic safety. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for a structures pre-pour conference agenda.

Before concrete placement, the contractor and inspectors make final preparations at the concrete mixing plant and at the structure site. Each location, mixing plant and structure site, typically has an inspector who monitors materials and operations. Section 6-501.5, Mixing Plant, describes mixing plant inspection.

As with the plant inspector, the inspector at the structure must be completely familiar with the plans and specifications to monitor the work and materials effectively. Before concrete arrives at the structure, the forms and reinforcing steel must be inspected. The testers must be familiar with the concrete mix design, and the materials specifications related to concrete.

Forms can be made of many types of materials, depending upon the type of construction, methods of placement, and in many cases, economics. Wood is the most common form material. Plywood is used extensively for forms. Lumber with knots, splits, warps, and other defects that may affect the concrete surface is not allowed. Lumber used in forming should have adequate strength and rigidity, as well as surface smoothness where required. Corrugated metal and prefabricated metal can also be used for forms. Fiber forms, shaped as circular tubes, may be used for constructing small columns of limited height

Bracing prevents forms from moving or becoming misaligned when they are supporting concrete, people, or equipment. If forms move or become misaligned, they must be corrected. Form oil or other approved coating is applied before the forms are placed. The contractor must be careful not to get the coating on reinforcing steel. Coating on the reinforcing steel will reduce the bonding between the steel and the concrete. The coating allows the forms to be removed without damaging the concrete.

When inspecting formwork, follow these tolerance guidelines.

| | |
|---|---|
| Variation from plumb or batter in the lines and surfaces of columns, piers, abutment, and girder walls | |
| In any 10-foot or less length: | 3/8-inch |
| Maximum for the entire length: | 1-inch |
| Variation in cross-sectional dimensions of columns, piers, girders, and thickness of walls and slabs | |
| +1/2-inch | |
| -1/4-inch | |
| Girder alignments (deviation from a line parallel to center line of girder measured between diaphragms) | |
| 1/2-inch up to 40-foot lengths | |
| 3/4-inch up to 60-foot lengths | |
| 1-inch greater than 60 foot-lengths | |
| Variations from the level of the grades indicated on the drawings in slabs, beams, horizontal grooves, and railings | |
| Exposed, in 10 feet: | 1/2-inch |
| Backfilled, in 10 feet: | 1-inch |
| Variations in footing dimensions | |
| Greater than specified: | No limit (does not apply to reinforcing steel placement) |
| Less than specified: | 5 percent of specified thickness up to a maximum of 1-inch |
| Variations of precast members | |
| Tolerances for precast members are in Section 503.03.10 of the specifications | |

Once the forms are in place, the contractor places the reinforcing steel. Before placement of the reinforcing steel, the contractor supplies samples and certificates of compliance. Reinforcing steel details in the plans describe reinforcing steel size (diameter), length, shape, and configuration. If the contractor wants to deviate from the details contained in the plans, he or she must submit shop drawings or bending diagrams to the Resident Engineer for review and approval. If reinforcing steel diagrams have been accepted, the inspector must have the current shop drawings to verify that proper reinforcing steel is placed at the prescribed locations in the structure. If the structure incorporates prestressing, refer to Section 6-503, Prestressed Concrete Members.

During placement, the inspector must monitor clearances between adjacent reinforcements and between reinforcing steel and forms. It is important that bars are placed and held in position as shown on the plans. Improper positioning of reinforcing bars can affect the strength of any concrete structure. Refer to Section 6-505.3 for allowable tolerances for reinforcing steel placement and for sampling requirements. On horizontal flat surfaces, such as bridge decks, the reinforcing steel is supported by a variety of supports-like wire frames, called chairs, or precast concrete blocks, called dobies. A layer of reinforcing steel is called a mat. Within a mat, as a piece of reinforcing steel, or bar, crosses over another, the bars are tied together with “tie wire.” The specifications state the amount of bar intersections that must be tied, depending on the spacing between adjacent bars. Refer to Section 6-505, Reinforcing Steel, for additional details. Refer to Section 6-503.2 for guidance on placement of post-tension ducts.

With forms and reinforcing steel in place, the inspector confirms that the equipment and tools that will be used in the placement, consolidation, and finishing operations are onsite and in good working order. On most parts of a structure, forms cover concrete surfaces that will be exposed. In these cases, the primary equipment is a vibrator used to consolidate the concrete. In the case of a bridge deck, the large surface area is exposed throughout the placement, consolidation, and finishing operations. To accomplish the operation efficiently, a self-propelled mechanical paving machine is used for bridge decks. The paving machine requires substantial setup and preparation. Once setup is complete, the machine is operated without concrete to confirm it will produce the required grade and depth. The inspector observes the trial run, and measures the distance between the bottom of the screed and the top reinforcing steel in the deck (top clearance), and the bottom of the screed and the form (deck thickness). Figure 6-502.6 shows a bridge deck paving machine in operation.

The key to a successful concrete placement and finishing operation is careful preparation. By inspecting materials, forms, reinforcing steel, and equipment, the bridge is prepared to receive concrete.

Figure 6-502.6. Bridge Deck Paving Machine.

### 6-502.3 DURING CONSTRUCTION

With the concrete plant beginning production, the inspector coordinates with the testers to confirm their availability. The inspector, through coordination with the contractor, estimates the projected quantity of concrete to be placed and the duration of the daily placement operation. By anticipating the quantity of concrete and duration of placement, the inspector can better coordinate activities associated with the operation.

Because transit-mix trucks cannot always access the specific location of the placement, the following alternative placement methods are available:

- Unloading the transit-mix truck into a pumping truck, which pumps the concrete to the forms for placement.
- Loading the concrete into a bucket with a minimum capacity of three cubic yards. The bucket is hoisted by a crane and moved to the placement location, where the concrete is released into place.

- Using a portable conveyor belt system.

Regardless of the placement method, the concrete cannot freefall more than five feet. Typically, a tremie is used to comply with this requirement.

Because the specifications contain time limitations on mixing and delivery, the inspector must know the limits for the type of mixing and delivery used for the concrete. For example, the time limitation for transit-mix delivery is 90 minutes from the time water is introduced to the mix until the mix is discharged. In contrast, for concrete mixed at a central plant and transported using non-agitating hauling equipment, the time limitation is 45 minutes from the time water is introduced to the mix until the mix is discharged. Time limits may be extended with the addition of admixtures. However, the effects of the admixture on the concrete must be considered during the mix design process. Admixtures can not be used without the approval of the Materials Division.

As the first transit-mix truck arrives, the inspector receives the Transit-Mix Concrete Delivery Form. From the Delivery Form, the inspector identifies the amount of water that may be added at the jobsite and completes appropriate sections of the form. The inspector visually inspects the mix for consistency. Typically, at this point, an initial slump test is conducted to confirm that the slump conforms to specifications. If the contractor wants to add water to increase the slump, the inspector may allow it if the Transit-Mix Concrete Delivery Form indicates that the maximum water content has not been reached and the maximum slump has not been exceeded.

Water can be added only before the truck begins unloading the mix for placement. If water is added at the jobsite, the drum must revolve 30 times at mixing speed to produce a homogenous mix. Additional revolutions must be at agitation speed, which is two to six revolutions per minute. The specifications describe the requirements relating to the addition of admixtures. The inspector observes admixtures being added at the jobsite and confirms that the required mixing takes place. Sampling and testing of concrete mixtures must be in accordance with Table 5.1 in Section 5, Sampling and Testing, of this *Construction Manual*. Samples taken for concrete testing must be from the middle third of a load.

When concrete mix is delivered by hauling trucks instead of transit-mix trucks, water and admixtures are added only at the mixing plant because hauling trucks are not equipped for mixing. As with transit-mix trucks, samples taken from a hauling truck are from the middle third of the load.

Immediately before the concrete is placed in the forms, all surfaces contacting the concrete are sprayed with water. Moistening the surfaces reduces the tendency of water being drawn out of the wet concrete, which negatively affects the hydration process. When the concrete is placed in the forms, the inspector should observe any movement or deflection of the forms or reinforcing steel. The inspector should also inspect the forms to confirm they are leak-proof.

Because an entire concrete structural element is rarely completed with a single concrete placement operation, joints are constructed at the end of the placement operation. These joints are called construction joints. The plans may identify locations for construction joints or the plans may identify locations where construction joints are prohibited. With approval from the Structures Division, the Resident Engineer may allow the contractor to place construction joints at other locations. Proper planning of the placement operation must address the planned joint locations. The Resident Engineer must thoroughly understand the plans to confirm that the contractor is placing construction joints at the proper locations.

Emergencies, such as equipment breakdowns or delivery complications, may arise that require joint placement at unplanned locations. Structures have a variety of stresses throughout all elements. In areas where stresses can be high, the quality and durability of the concrete must also be high. Construction joints are prohibited in areas that require high strength concrete. If the concrete stops at a point at which a joint is prohibited, the contractor may need to remove concrete to construct the joint in an acceptable location. Construction joints are prohibited in the following locations:

- Locations identified on the plans as “no splice” areas for reinforcing steel
- Locations identified on the plans as “no construction joint” areas
- Longitudinal joints (parallel to girders) at mid-points between girders or directly over girders
- Locations identified as negative moment areas (areas denoted with (-) in Figure 6-502.7), located on either side of piers

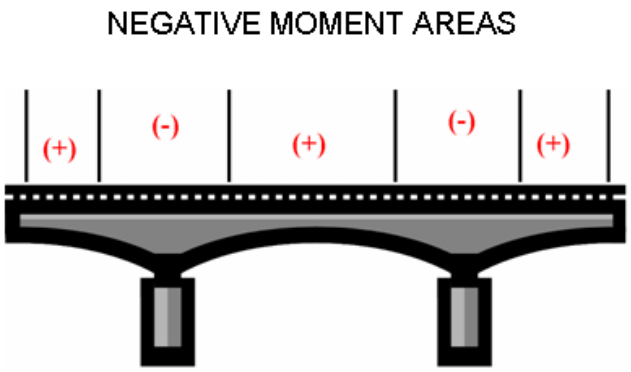


Figure 6-502.7. Negative Moment Areas.

Do not finish construction joint surfaces with a trowel. The joint surface should be straight and unfinished. The rough surface provides improved interlock between the hardened concrete and the newly placed concrete. When the daily concrete placement operation is complete, and joints are constructed, the curing process begins.

Surfaces exposed to the atmosphere must be cured properly to enhance the hydration process, as described in Section 6-501.7, Curing. The contractor must monitor the curing process, the temperature of the concrete, and the adequacy of the wet curing. The inspector should verify that the contractor is monitoring the wet cure operation and that excess water is being contained. Excess water can create environmental problems, interference with traffic, and freezing problems. For bridge decks, after sufficient curing, the deck surface is tested to determine smoothness and rideability. Grinding is required on areas of the bridge deck that do not conform to the specification requirements. Generally, grinding is not permitted until after a 14-day cure and the concrete has reached its specified 28-day compressive strength.

Allowing the forms to remain in place for at least seven days after concrete placement is another means of curing the concrete. If the forms are removed before the concrete has cured seven days, appropriate curing methods must be used on the exposed concrete. Forms are removed when the concrete has hardened sufficiently to prevent spalling or chipping during form removal. The proper time to remove forms depends on the atmospheric temperatures and humidity.

The condition of the concrete should be observed when forms are being removed. The inspector should stop the form removal if the concrete is being damaged. After removal of the forms, a curing compound is applied to the exposed concrete if the specified curing time has not been reached. Forms are always removed from columns before concrete is placed for the superstructure. Removing the column forms first allows the inspector to determine the condition of the concrete in the columns before the weight of the structure is placed on the columns. Bridges that utilize pre-stressed or post-tensioned beams or girders must be stressed before falsework or other support is removed. Refer to Section 6-503, Prestressed Concrete Members.

The inspector observes the workmanship and quality of the materials as soon as the forms are removed because this is the best time to detect any faults in the structure. All defects in exposed concrete must be corrected soon after the forms are removed. Surface areas damaged during form removal must be repaired in conformance with the specifications. The contractor should remove and replace unconsolidated concrete with appropriate concrete patching material as soon as possible.

### 6-502.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.

## 6-503 PRESTRESSED CONCRETE MEMBERS

### 6-503.1 GENERAL

Another reinforcing technique utilizes steel strands threaded through conduits or ducts contained in the completed concrete in conjunction with reinforcing steel. The steel strands are tightened, or tensioned, producing stresses in the beam or girder that counteract those created during the lifecycle of the structure. This reinforcing technique is called prestressing.

Prestressing concrete takes advantage of the concrete's compressive strength and overcomes its weakness in tensile strength. Bridges that utilize prestressed concrete can have longer spans than would be practical using only reinforcing bars to reinforce the concrete. Prestressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load. Each tendon consists of multiple steel strands. The clamping load produces a compressive stress in the structure that offsets tensile stresses that would otherwise exist when the concrete is loaded. On NDOT projects, prestressing is typically accomplished in two ways, pre-tensioning and post-tensioning:

- Pre-Tensioning – Concrete is cast around tensioned tendons. The cured concrete adheres and bonds to the bars. When the tension is released from the tendons, the tension is transferred to the concrete as compression by static friction. This method requires substantial anchoring points between which the tendon is stretched. The tendons are usually in a straight line. The bond between the tendons and the concrete protects the tendons from corrosion and provides for direct transfer of tension. Pre-tensioned elements are typically prefabricated in a plant and transported to the jobsite. Because pre-tensioned elements fabricated at a factory require transport, the size of the members is limited. Pre-tensioned elements may be beams, girders, foundation piles, pier caps, and columns.

- Post-Tensioning – Concrete is cast around plastic, steel, or aluminum ducts. The alignment of the ducts follows the areas where tension would occur in the concrete element. Concrete is cast around the ducts. The stressing tendons are fished through the ducts either before or after the concrete is cast. After the concrete has gained sufficient strength, hydraulic jacks, which react against the concrete member, tension the tendons. When the tendons have been stressed to the load specified by the design, the tendons are wedged in position, transferring stress to the concrete. The duct is then grouted to protect the tendons from corrosion and to transfer the load to the structure. Post-tensioning is used to construct a variety of bridge types.

### 6-503.2 BEFORE CONSTRUCTION

Representatives of the Structures Division inspect prestressing that is performed at an off-site factory or yard. For prestressing that is performed on-site, the inspector's responsibilities before the stressing operation are those as described in Section 6-502, Concrete Structures.

#### 6-503.2.1 PRE-TENSIONED GIRDERS

The Structures Division reviews and approves pre-tensioned girder shop drawings after they are submitted to the Resident Engineer. Girder construction can begin as soon as the shop drawings are approved. Typically, the Structures Division Nondestructive Testing Section provides inspection of the pre-tensioned girders. Depending on workload, consultants or the Resident Engineer's inspector may be required to perform inspection and testing. Inspectors assigned by the Resident Engineer must have the required ACI certification. Refer to Section 5-300, Tester Qualification Program, for additional information on materials tester qualifications. The Nondestructive Testing Section provides training on inspection and testing for assigned personnel. Because of the specialized nature of pre-tensioned girders, the Resident Engineer coordinates with the Construction Division and the Nondestructive Testing Section regarding inspection and testing of the pre-tensioned girders. The Resident Engineer should allow two weeks to coordinate personnel and to schedule travel and training, as required.

During the fabrication of pre-tensioned girders, an inspector samples and tests the materials to verify conformance to specifications and the approved mix design. When an inspector samples materials during the fabrication of pre-tensioned girders, the inspector must be ACI-certified. Refer to Section 5-300, Tester Qualification Program, of this *Construction Manual* for additional information on tester qualifications. The inspector also observes the fabrication of girders to verify the girders are constructed in conformance with the approved shop drawings. The girders must be properly sized, the reinforcing steel placed correctly, strands placed in the proper locations, and girders cured and handled in conformance with the specifications.

6-503.2.2 POST-TENSIONED STRUCTURES

The Structures Division reviews and approves post-tensioning shop drawings after they are submitted to the Resident Engineer. The post-tensioning shop drawings typically include the following details:

- Stressing duct locations
- Post-tensioning anchorages and system components
- Number of stressing strands per duct
- Post-tensioning force
- Grouting procedures
- De-tensioning procedures (to be used if de-tensioning is required)
- Acceptable strand losses per tendon, duct, and the structure
- Information on the calibrated pressure gauge and hydraulic ram to be used for post-tensioning operations

When the contractor places the ducts, the inspector must verify that the ducts are placed within 1/4-inch of the location shown on the approved post-tensioning shop drawings. Accurate placement of the ducts is important so that the structure performs as designed.

The stressing tendons or strands are delivered to the project before the stressing operation begins. The Materials Division must test samples of the strands before the material is incorporated into the work. Each spool containing strands has a fabrication number, called a heat number. The inspector must obtain and document the heat number of each spool delivered to the project and verify that each spool is tested and approved by the Materials Division. Each spool must be visually inspected to confirm that it is undamaged. Ducts must be clean of foreign material and debris, which is typically done by blowing air through the duct. The Resident Engineer's inspector should observe that post-tension ducts are properly located as detailed on the approved shop drawings and that system-specific reinforcing steel is properly placed. Before the ducts are enclosed by girder formwork, the inspector should verify that the ducts are not damaged. The primary responsibility of the Resident Engineer's inspector at the structure is to prepare the structure, forms, and materials so that the Structures Division prestressing inspector can begin oversight of the stressing operation.

Typically, the Structures Division Nondestructive Testing Section inspects and monitors the post-tension process. Depending on workload, consultants or the Resident Engineer's inspector may be required to perform inspection and testing. In these instances, the Nondestructive Testing Section provides training on inspection and testing for assigned personnel. When the Resident Engineer's inspector performs the inspection and testing, the Nondestructive Testing Section may still be present during portions of the work. Because of the specialized nature of post-tensioning, the Resident Engineer coordinates with the Construction Division and the Nondestructive Testing Section regarding inspection and testing of the post-tensioning activities. The Resident Engineer should allow two weeks to coordinate personnel and to schedule travel and training, as required.

During the post-tensioning activities, the inspector samples and tests the materials to verify conformance to specifications and the approved mix design. The inspector also observes that the post-tensioning activities conform to the approved shop drawings—the reinforcing steel is placed correctly, strands are placed in the proper locations; and the post-tensioning, concrete placement, and curing all conform to the specifications.

### 6-503.3 DURING CONSTRUCTION

The Structures Division inspector is supported by the Resident Engineer's inspector during the stressing operation. The Resident Engineer's inspector observes the loading of the strands into the ducts. As strands are loaded, the inspector documents the spool number and heat number of the strand loaded into each duct. On most NDOT prestressing projects, strands are loaded into the ducts after concrete is cast around the ducts. The contractor may, however, load the strands into the ducts first, and then cast the concrete. If the contractor loads the strands first, the contractor must protect the strands according to the specifications. The protection of the strands may include the application of an approved rust inhibitor. Typically a rust inhibitor is not used if stressing is planned to occur within 10 days after placement, unless inclement weather is anticipated. In either situation, the strands are not tensioned until the concrete reaches its specified strength. With the ducts loaded with strands, the contractor stresses the tendons in the sequence detailed in the approved shop drawings. After all tendons are stressed, each duct is grouted. Because of the equipment and activities, all personnel near the stressing operation must be aware of safety considerations.

### 6-503.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.

## 6-505 REINFORCING STEEL

### 6-505.1 GENERAL

Reinforcing bars are steel that has been milled into rods with cross-hatchings, called deformations, that help concrete bond with the reinforcing steel. Reinforcing steel is commonly called rebar. When exposed to deicing salts and other chemicals, rebar can corrode, leading to possible accelerated deterioration of the structure. To protect the steel from corrosive elements, reinforcing steel is coated with epoxy. Epoxy coated rebar is typically used in northern Nevada where deicing chemicals are commonly used on roadways. Reinforcing steel is classified by several characteristics. The principal ones are grade (strength of the steel) and diameter of the bar. Common grades of reinforcing steel are as follows:

- Grade 40: Minimum strength 40,000 pounds per square inch (psi)
- Grade 60: Minimum strength 60,000 psi
- Grade 75: Minimum strength 75,000 psi

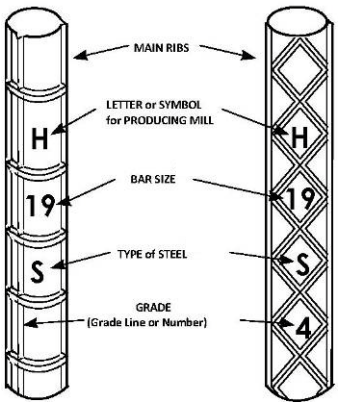


Figure 6-505.1. Reinforcing Bar Markings.

Reinforcing steel used in NDOT structures must comply with American Association of State Highway and Transportation Officials (AASHTO) M31 (Grade 60) or American Society for Testing and Materials (ASTM) standards (A706). The plans will state the type of steel to be used.

For reinforcing steel bars up to an inch in diameter, the size designation is based on the cross-sectional diameter of the bar, measured in eighths of an inch. Bars are marked with markings that identify producing mill, bar size, steel type, and grade. Most mills use metric bar size markings. Figure 6-505.1 shows typical bar markings. Table 6.1 describes common sizes of reinforcing steel.

| TABLE 6.1 – Standard Reinforcing Bar Designations | | | | | |
|---|---|---|---|---|---|
| Bar Designation Number | Metric Bar Designation Number | Nominal Bar Diameter (fractions of an inch) | Nominal Bar Diameter (decimals of an inch) | Weight (pounds per foot) | Cross Sectional Area (square inches) |
| 3 | 10 | 3/8 | 0.375 | 0.376 | 0.11 |
| 4 | 13 | 1/2 | 0.500 | 0.668 | 0.20 |
| 5 | 16 | 5/8 | 0.625 | 1.043 | 0.31 |
| 6 | 19 | 3/4 | 0.750 | 1.502 | 0.44 |
| 7 | 22 | 7/8 | 0.875 | 2.044 | 0.60 |
| 8 | 25 | 1 | 1.000 | 2.670 | 0.79 |
| 9 | 29 | 1-1/8 | 1.128 | 3.400 | 1.00 |
| 10 | 32 | 1-1/4 | 1.270 | 4.303 | 1.27 |
| 11 | 36 | 1-3/8 | 1.410 | 5.313 | 1.56 |
| 14 | 43 | 1-3/4 | 1.693 | 7.650 | 2.25 |
| 18 | 57 | 2-1/4 | 2.257 | 13.600 | 4.00 |

Reinforcing steel has deformations, or ridges, that bind it mechanically to the concrete with friction. Even with these deformations, reinforcing steel can still be pulled out of the concrete under high stresses. To prevent this type of failure, reinforcing steel is either deeply embedded into adjacent structural members, or is bent and hooked to lock it around the concrete and other reinforcing steel.

Each structure has unique bent bar requirements. The bent bar requirements are detailed in the plans. The details identify the type of steel, bar size, and the dimensions of the reinforcing steel. Figure 6-505.2 shows a typical bending diagram for reinforcing steel on an NDOT project. The bar is 2 feet 8 inches long and is to be bent with three legs—two 9 inches and the other 1 foot 2 inches. The identifying designation of the bar is W4028. The characters in the designation describe the following:

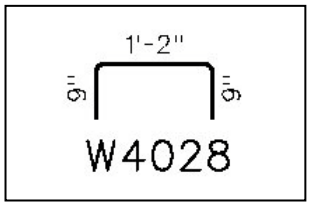


Figure 6-505.2. Example Rebar Bending Designation.

W: The bar will be placed in the wingwall.

4: Diameter of the bar (No. 4 bar – 1/2-inch or 0.50-inch diameter)

028: Length of bar, measured in feet and inches (2 feet, 8 inches)

Note: If the bar is to be epoxy coated, the designation would contain the letter E after the length (W4028E).

At times, reinforcing steel must be joined to create a continuous length of reinforcement. Joining one piece to another is called splicing. Reinforcing steel splices allow loads to be transmitted continuously along the total length of the joined reinforcing steel. The three methods of splicing are lap splices, mechanical splices, and welded splices.

- Lap Splices – Lap splices are the most commonly used splice and are typically used for smaller-diameter horizontal and vertical reinforcing steel. A lap involves two pieces of rebar overlapped to create a continuous line of rebar. The length of the lap varies depending on a number of things, including the concrete strength, the rebar grade, size, and spacing. Project plans state lap length based on the diameter of the reinforcing steel.
- Mechanical splices – Mechanical splices are typically used when space limitations prevent a lap splice or for larger-diameter horizontal and vertical reinforcing steel. Mechanical splices are proprietary and supplied by a number of manufacturers. A common type of mechanical splice is a threaded coupler in which two pieces of rebar are threaded and screwed into the coupler. The use of mechanical splices must be approved by the Structures Division.
- Welded Splices – Welded splices are typically used to splice two pieces of reinforcing steel with large diameters. The two pieces are welded end-to-end, called butt-welded. The use of welded splices must be approved by the Structures Division. Use of welded splices requires a submittal of welder's qualifications and welding procedures.

### 6-505.2 BEFORE CONSTRUCTION

In preparation of construction, the inspector observes the delivery and placement of reinforcing steel. When delivered to the project, the inspector obtains certificates of compliance for each heat, or production run, represented by the delivery. Also contained in the certification is information that allows for the determination if the steel complies with Buy America requirements. Refer to Section 3-403.3.1.4, Buy America Certification. In storage, the reinforcing steel should be protected from corrosive elements, including water and soil. Reinforcing steel is typically stored on wooden blocks, called dunnage, keeping the steel off the ground.

Depending on the steel's exposure to the elements, rust may form on the steel. While some rust is not detrimental, excessive rust may warrant cleaning of the reinforcing steel or rejection of the reinforcing steel if the cross-sectional area is reduced because of the rust.

### 6-505.3 DURING CONSTRUCTION

Inspecting reinforcing steel requires attention to the condition of the reinforcing steel and placement. The steel must be clean and free of foreign material and other debris, including grease. Bonded rust or mill scale can remain on the steel as long as the rust does not create section loss (Figure 6-505.3). Most loose rust will be removed by the handling of the steel during placement. A small amount of loose, powdery rust is not detrimental. The Construction Division can answer questions regarding the acceptable amount and type of rust.

Figure 6-505.3. Reinforcing Steel.

Cutting and bending bars affects the quality of the steel. Because heat alters the tempering of the steel, making it weak or brittle, heat should not be used to cut or bend steel. The contractor uses an abrasive saw to cut reinforcing steel. For uncoated reinforcing steel in non-critical areas, the contractor may use a torch for cutting, if approved by the Structures Division. The specifications do not allow the use of heat for bending reinforcing steel. If steel is bent at the jobsite, the contractor must submit field bending procedures for review and approval by the Structures Division.

Before placement of reinforcing steel, the contractor must supply two samples of each bar size, per manufacturer, per project, per year. If the Resident Engineer feels that the quality of reinforcing steel is questionable, the Resident Engineer may require the contractor to supply samples for each heat, or production run, delivered to the project. The steel samples are transmitted to the Materials Division using NDOT form 020-018, "Transmittal for Test Samples and Certifications." Refer to the *Documentation Manual* for information required on the transmittal. Certificates of compliance allow the contractor to incorporate the steel into the work, pending acceptable test results from the Materials Division.

The contractor must place the specified size and grade of reinforcing steel as detailed in the plans, including spacing with adjacent steel and clearance from forms, and quantity of bars. The Structures Division must approve all substitutions or other modifications to reinforcing steel. Even apparent minor modifications can significantly alter the performance or behavior of the structure. For example, using reinforcing steel of a larger diameter than specified in the plans can increase the rigidity and loading of the structure, conflicting with assumptions made by the structural designer. In general, reinforcing steel is placed in the forms at or within 1/4-inch of the location specified in the plans. Guidance on tolerances for placing reinforcing steel at various locations within a structure is shown below.

- Footings. Horizontal reinforcing steel is placed within 1/2-inch vertically of the bottom clearance shown in the plans and 1 inch from the side clearance shown in the plans. Reinforcing bars cannot deviate more than 1/2-inch from the location shown in the plans.
- Dowel Bars. Dowels are placed within 1/2-inch of the position shown in the plans.
- Columns. Vertical reinforcing steel is placed within 1/2-inch of the position shown in the plans. The side clearance must be within 1/4-inch of the clearance shown in the plans.
    - Column ties are placed within 1 inch of the position shown in the plans for a specific tie, accumulating tolerances between ties is not permitted.
    - Side form clearances for any tie must be within 1/4-inch of the clearance shown in the plans.
- Walls. Side form clearances must be within 1/4-inch of the location shown in the plans. Reinforcing steel spacing must be within 1 inch of its plan location for any one bar. Accumulating tolerances between bars is not permitted. Bar spacing may be shifted out of tolerance where necessary to clear a fixture. If bars are shifted to clear a fixture, the quantity of shifted bars in the affected area remains per the plans. Bars not shifted are placed within the specified 1-inch tolerance.
- Beams and Caps. Longitudinal reinforcing steel is placed with a bottom and top clearance within 1/2-inch of the vertical dimensions shown in the plans for all layers of reinforcing steel. The spacing from side forms is within 1/2-inch of the clearance shown in the plans. Stirrups are spaced and tied within 1 inch of the position shown in the plans, without accumulating tolerances.
- Deck Slabs. Top and bottom horizontal reinforcing steel must have top and bottom clearances within 1/4-inch of the location shown in the plans. Horizontal spacing, and end and edge clearances of reinforcing steel in the top and bottom mats must be within 1/2-inch of the dimension shown in the plans. Curb, sidewalk, and barrier reinforcing steel must be placed within 1/2-inch of the locations shown in the plans.
- Prestressing Reinforcing Steel. Tolerances for placement of prestressing reinforcing steel are located in Section 503 of the specifications.

The contractor maintains clearance between reinforcing steel and forms by using spacers separating the steel from the form. Spacers are made of concrete blocks, called dobies, or manufactured frames, called chairs. Figure 6-505.4 shows examples of reinforcing steel spacers and supports. During the placement of steel by the contractor, the inspector checks that splices are located and constructed in accordance with the plans and specifications.

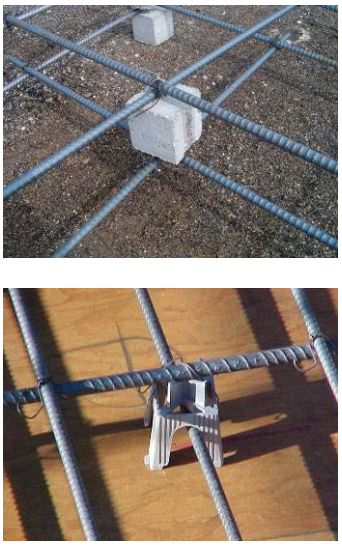

Figure 6-505.4. Typical Reinforcing Steel Spacers.

When lapping reinforcing steel for a splice, the contractor uses tie wire to connect the two pieces of steel together firmly. When rebar intersects another piece of rebar, connect the pieces using tie wire. The specifications state requirements relating to the amount of intersections to be tied. The inspector should refer to the appropriate specification relating to the type of structure being constructed. Regardless the amount of intersections required by the specifications, the rebar mat must be sufficiently stable to withstand activity associated with concrete placement, such as movement of workers and concrete being placed.

When placing epoxy-coated reinforcing steel, preserve the integrity of the coating. Where the epoxy coating is damaged or penetrated, recoat the area with an approved product. If stored for extended periods, the epoxy coated rebar must be protected from sun damage. Specially coated tie wire, supports, and concrete vibrators are required when using epoxy coated rebar.

### 6-505.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.

## 6-506 STEEL STRUCTURES

### 6-506.1 GENERAL

Few differences exist between concrete and steel structures. Both structures have concrete footings, columns, abutments, and decks. The only difference is that the superstructure is constructed with structural steel. Based on design and economic considerations, the bridge designer may specify that the superstructure be constructed with steel as opposed to concrete.

For bridges made of steel, the Structures Division oversees the inspection of the steel fabrication and the placement at the jobsite. Because the structural steel material, length, and configuration are unique for each bridge project, the steel elements are assembled at a fabrication plant. During the fabrication process, the Structures Division inspector is on-site to monitor the fabrication and testing activities. When complete, the structural members are transported to the jobsite. At the site, the Structures Division inspector should be present during the erection process, where the steel girders are put in place and connected to adjoining members.

Depending on the bridge construction and erection conditions, the contractor may have additional requirements, as stated in the specifications. A common requirement is an erection plan. The erection plan may be a separate plan or included as part of the shop drawings. The Resident Engineer and inspectors must have a thorough knowledge and understanding of the requirements stated in the plans and specifications.

### 6-506.2 BEFORE CONSTRUCTION

Because of the specialized nature of structural steel shop drawings and the need for timely review and approval to facilitate ordering materials, shop drawings for structural steel bridge girders are processed differently than other shop drawing submittals. Structural steel shop drawings are sent directly from the fabricator to the Structures Division or the designer of record, if a consultant designed the structure. Typically, the contractor and the Resident Engineer receive a copy of the transmittal letter or the transmittal letter and shop drawings. The Structures Division or designer of record communicates directly with the steel fabricator as necessary to resolve issues or concerns during the shop drawing review. The Resident Engineer receives copies of all correspondence, and the Structures Division sends copies of the approved shop drawings to the Resident Engineer.

Structural steel shop drawings detail all elements of steel girder fabrication, including the following:

- Material specifications
- Dimensions and sizes of plates and shapes
- Number and location of shear studs (for field installation)
- Cross frame/diaphragm details
- Stiffener and connection plate details
- Weld designations
- Welded shop splice/bolted field splice details
- Bolted connection details
- Camber of girders
- Painting details
- Procedures for shop handling and assembly

The level of detail in the shop drawings ensures that the steel members are fabricated and erected in accordance with the plans and specifications. After the Structures Division approves the shop drawings, the contractor must fabricate and erect the steel members in conformance with the approved drawings. Deviation from the approved shop drawings and erection plan is not allowed without prior approval from the Structure's Division. The inspector observes the erection of the steel to verify conformance with the approved erection plan.

When inspecting steel erection, the following should be considered:

- If steel is to be erected near traffic, confirm that the Resident Engineer has approved the contractor's traffic control plan
- Before the contractor begins erecting steel, confirm that the contractor has surveyed the elevations of the substructure and that the Resident Engineer's survey crew has verified the survey
- Check the elevation of the temporary supports and the falsework relative to the required cambers
- Check that the falsework is constructed in accordance with the approved shop drawings and that it is monitored daily by the contractor for tightness of bolts, wedges and cables
- Check the surface that will support the beam to confirm the following:
    - Bearing elevation is correct
    - Anchors are set accurately as detailed
    - Expansion bearings are properly placed for ambient air temperature
- Check that the structural steel stored at the jobsite is supported above the ground on skids, platforms, or other supports and properly drained and protected from corrosion
- Verify that the contractor follows the approved safety plan and provides fall protection and other personal protective equipment during steel placement
- Check that temporary bracing or blocking is in place during erection and remains in place until the structure is fully erected and connections are complete
- Significant deviations from the erection plan must be reported immediately to the Resident Engineer

All elements of steel erection must strictly conform to the erection plan, including steel placement, splices and field connections, and bracing and diaphragms. Project personnel cannot substitute or modify the plan details without prior approval from the Resident Engineer, who consults with the Structures Division. Minor modifications can affect the stability and performance of the structure, conflicting with the structural designer's assumptions.

Stay-in-place deck form systems are commonly used to form the bottom of the deck slab between steel girders. Connection details for stay-in-place deck form systems, overhang jacks (used to form the deck overhang beyond the exterior girder), safety railing, and any other construction items that may be attached to the steel girders must be included in the shop drawings.

Because of the technical aspects in the design, the Resident Engineer must consult with the Structures Division regarding any proposed field modifications. Welding, heating, or cutting of structural steel items on the jobsite are prohibited without approval of the Structures Division.

### 6-506.3 DURING CONSTRUCTION

Nondestructive Testing Section personnel, or their consultants, perform fabrication inspections. Observations by inspectors confirm that techniques used to fabricate structural steel girders conform to industry requirements. During fabrication inspection, Nondestructive Testing Section personnel document progress of the work and materials used for partial payments. This information is transmitted to the Resident Engineer for inclusion in progress payments.

The steel erector must submit an erection plan that details the procedures used to erect the steel members. The Structures Division must review and approve the erection plan. The plan describes the equipment, sequence, and other details of girder erection in the field. Nondestructive Testing Section personnel typically provide inspection during the erection process, which includes inspection and testing of bolting components. Nondestructive Testing Section personnel also inspect field painting of the girders.

### 6-506.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.

## 6-508 DRIVEN PILES

### 6-508.1 GENERAL

Figure 6-508.1. Pile Driving Operation.

A driven pile usually consists of a steel sheet pile, concrete-filled steel pipe, steel H-pile, prestressed concrete, timber, or a combination of materials. NDOT typically uses steel piles. Piles are made of preformed material having a predetermined shape and size that are installed by impact hammering or vibrating into the ground. Driven piles are typically used to support the foundation of structures. Figure 6-508.1 shows a pile driving operation.

### 6-508.2 BEFORE CONSTRUCTION

Before piles are driven, the contractor stakes the structure footing. The pile locations are then staked. The contractor submits a pile installation plan to the Resident Engineer, who provides a complete listing of equipment to be used in the pile driving operation, including the type of pile driving hammer and a wave equation analysis. The contractor's geotechnical engineer conducts the wave equation analysis, which incorporates design information from the plans and geotechnical report, and information pertaining to the contractor's proposed equipment. The wave equation analysis uses data and assumptions to develop a graph that relates theoretical blow counts and driving load resistance. A blow count is the number of blows that the hammer delivers to the pile to move the pile a given distance, typically one foot. The graph estimates the blow counts required to achieve the driving load resistance shown on the plans. The wave equation analysis can also help predict pile stresses and delivered hammer energy. The Resident Engineer submits the contractor's pile installation plan to the Materials Division Geotechnical Section for review and approval. The Geotechnical Section must approve all changes to the approved pile installation plan.

After the pile installation plan is approved, the contractor delivers the piles to the project and begins a dynamic load test, which validates or verifies the contractor's pile installation plan. The dynamic load test accomplishes the following:

- Verifies the driving load resistance of the pile
- Determines the ease or difficulty in penetrating through soil layers
- Evaluates the performance of the contractor's proposed pile driving system
- Determines the pile lengths required for production piles
- Establishes the driving criteria (number of blows per foot required to obtain design driving load resistance) for production pile driving

As piles are delivered to the jobsite, the inspector monitors delivery and storage. If steel piles are used, the inspector obtains the certificate of compliance for each production run. The inspector compares the specification requirements with the information contained in the certificate. Piles should be inspected to verify they are not damaged or flawed. The inspector should monitor the unloading of piles to verify piles are unloaded using the appropriate number of pick-up points and locations. Pick-up points are selected to prevent bending. Typically, the pile length requires a minimum of two pick-up points—at the one-third and two-thirds points of the pile length. The contractor must place piles on blocks, called dunnage, to prevent them from sagging and to protect them from corrosive elements, including water and soil. Place dunnage so that the piles do not sag.

The inspector should become familiar with the plan details related to pile driving, identify key elements of the pile installation plan, and identify key inspection elements of the specifications. When specifications require that the pile tip be protected, the inspector should verify that the protection is installed correctly. Two key elements of a pile installation are splice details and tip elevations. Because a pile length cannot be exactly determined before driving, piles might be spliced to achieve the length needed to develop the driving load resistance shown on the plans. The plans and specifications include splice details. A pile's tip is the leading end of the pile as it is driven into the ground.

The plans specify the minimum tip elevation and the design tip elevation. The minimum tip elevation is the minimum depth that the pile tip must be driven. The design tip elevation is the depth at which the driving load resistance is expected. Based on the data developed during the dynamic load testing, a tip elevation is established, which reflects actual conditions. The tip elevation established during the dynamic load testing can be above or below the design tip elevation, but it is always deeper than the minimum tip elevation shown on the plans.

### 6-508.3 DURING CONSTRUCTION

Coordination and communication among key personnel ensures pile driving progresses efficiently and without delays. The Materials Division Geotechnical Section staff plays a key role in pile driving. Because piles are the foundation on which the structure is supported, deviations from the plans or specifications may have significant impacts. The Resident Engineer should contact the Geotechnical Section when the specifications need clarification or when work or materials require approval. The Resident Engineer must keep the Geotechnical Section informed of the pile driving progress. If required, communicate daily with the Geotechnical Section to keep them adequately informed.

The inspector has a key role during the pile driving operation. The inspector communicates with other key personnel, observes the pile driving operation, records relevant information, and documents the pile driving activities. The inspector does not direct the contractor's pile driving activities, but if the inspector observes a potential for non-conformance, the inspector notifies the contractor of that potential. Notifying the contractor of the non-conformance potential allows the contractor to take corrective action and avoid having non-conforming work. Timely communications between the inspector and the contractor can eliminate delays to the contractor's operations.

Mark piles in one-foot increments before lifting the piles from the ground and driving them. Use the markings to monitor and document the length of pile driven into the ground. Pile driving can begin by either placing the pile tip directly on the ground or by driving the pile into a pre-drilled pilot hole. Check the specifications to confirm that pre-drilled pilot holes are allowed. Once the pile is placed under the pile driving hammer, and before driving begins, the inspector confirms that the pile is in the right location and at the proper angle to the ground. During pile driving, as the tip reaches the proper depth, the inspector verifies that the pile has reached the driving load resistance shown on the plans.

A driven pile reaches its proper depth when the bottom tip of the pile is driven at or below the minimum tip elevation shown in the plans. The pile capacity is the amount of vertical and lateral force that a pile is designed to resist for different loadings, such as scour and seismic events. The required blow counts needed to achieve the driving load resistance shown on the plans is estimated initially by the wave equation analysis. A dynamic load test is conducted while driving the first pile or piles, as stated in the specifications. The dynamic load test establishes the number of blows per foot, when the pile tip is below the minimum tip elevation shown on the plans, to attain the driving load resistance for each pile.

The inspector observes the pile driving operation and records the number of blows per foot, for each foot the pile is driven. When the tip of the pile reaches the minimum tip elevation and the target blows per foot is obtained, the inspector immediately informs the contractor that the driving requirements have been met. The pile is then cut off to the designated elevation. After successfully driving a pile, the contractor proceeds to the next pile. The next pile to be driven should not be adjacent to the last pile driven, but should be spaced some distance away in the pile grouping. Inspectors should review the specifications for specific restrictions and limitations on pile driving.

When piles are driven adjacent to each other consecutively, pore water pressure could build up in the underlying soil layers to the point that the pile would not drive any further, creating a condition called "false practical refusal." To alleviate false practical refusal, the contractor stops the pile driving and resumes the driving later (usually the next day), after allowing the pore water pressure to dissipate. In contrast to false practical refusal, practical refusal occurs when the pile cannot be driven any deeper without exceeding the target maximum number of blows per foot and possibly damaging the pile.

If a pile does not attain the specified driving load resistance when driven to the design tip elevation or the dynamic load test tip elevation, the contractor stops driving the pile and allows the pile to stand for a period without driving. This period is called a "set period." During the set period, soil resistance typically increases. When driving resumes, if the target blow count is still not achieved during restriking, a splice may be required to increase the pile length. When splicing is required on a pile, refer to the plans and specifications for requirements.

The contractor surveys the elevation of the top of the pile, referenced to a fixed datum, after installation and periodically thereafter as adjacent piles are driven. The purpose of the survey is to monitor the elevations of the pile tops. Driving a pile can cause upward movement of adjacent piles, commonly called "pile heave." If piles heave more than 1/4-inch, the contractor must re-drive the heaved pile.

During the pile driving operation, the inspector should be close enough to the hammer and pile to observe the operation and to count the blows per foot. Because the area around the pile driving operation can be hazardous due to the exhaust of the hammer, the overhead danger of the crane and the pile, and the noise of the operation, all personnel must wear appropriate safety gear, such as a hardhat and hearing protection. The inspector should be aware of the pile driving activities and have a route to escape if necessary.

During the pile driving operation, the inspector must complete NDOT form 040-059A, "Continuous Pile Driving Record," and NDOT form 040-058, "Piling Driving Record." The forms record key information such as the ground elevation and the number of blows to drive the pile a foot, for every foot the pile is driven. The inspector can and should enter much of the form data before the driving operations begin so he or she can pay full attention to the pile driving operation.

In addition to the pile driving forms, the inspector completes a daily inspector report, which documents the following:

- Pile driving activities
- Relevant communications
- Progress of operations
- Equipment and materials used in the work

Hammers for pile driving fall into two general categories: drop hammer and vibratory hammer. A drop hammer falls onto the pile under its own weight, transferring the driving force to the pile. A vibratory hammer rests on the top of the pile, vibrating the pile and temporarily negating the friction between the pile and the soil. The pile sinks into the subsoil under its own weight and the weight of the vibrator.

### 6-508.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.

## 6-509 DRILLED SHAFT FOUNDATIONS

### 6-509.1 GENERAL

Drilled shaft foundations provide support similar to driven piles. Shafts are drilled; reinforcing steel cages are placed in the shaft; and, concrete is placed in the shaft, encasing the steel. Because drilled shafts can have a greater diameter than driven piles, drilled shaft foundations are used when a bridge or structure requires greater support or when using driven piles is impractical. Drilled shaft piles are also referred to as Cast-in-Drilled-Hole, or CIDH, in the plans and specifications. Figure 6-509.1 shows construction of a drilled shaft foundation in which the reinforcing steel cage is being installed.

Figure 6-509.1. Drilled Shaft Foundation.

Methods of constructing the shaft, or bore, depend on the geology of the site. Use a “dry method” when dry, stable soils are anticipated. Use a “wet method” when unstable soils are anticipated or groundwater creates unstable conditions. Use a “casing method” when the dry or wet methods are inadequate in preventing soil caving or excessive deformation of the bore. Use either temporary or permanent casings with either the dry or the wet drilling methods, depending on the geologic conditions.

Consultants are retained by NDOT to perform crosshole sonic log (CSL) testing on drilled shaft foundations. CSL testing assesses the quality of the concrete placed in drilled shaft foundations. CSL testing requirements are described in the specifications. Typically, CSL testing requires the installation of two-inch diameter tubes in the concrete foundation. The tubes are secured in the foundation’s reinforcing steel cage before the cage is placed in the borehole. After the concrete is placed and cured, the consultant performs CSL testing.

### 6-509.2 BEFORE CONSTRUCTION

Before beginning work, the Resident Engineer, inspector, and testers must familiarize themselves with the plans and specifications. Concrete used for drilled shaft foundations has special requirements detailed in the specifications. The contractor must submit a mix design to the Resident Engineer for approval by the Materials Division. If assistance is needed, the Materials Division or the Construction Division can provide guidance. Before constructing drilled shafts, the contractor submits qualifications to perform drilled shaft construction, as required by the specifications. The contractor stakes the structure footing and excavates to grade before the shaft locations are staked. Each pile is assigned a unique identifier. A drawing that shows pile locations and designations is prepared as a reference document for project personnel. The contractor prepares a drilled shaft installation plan that describes the key personnel, equipment, and proposed operations. The plan also includes safety and fall protection provisions for contractor and NDOT personnel. The Resident Engineer submits the contractor's installation plan to the Materials Division for review and approval. The Materials Division must approve all changes to the approved installation plan.

### 6-509.3 DURING CONSTRUCTION

Throughout the construction of drilled shaft piles, the inspector continuously monitors the operation and documents activities and observations on NDOT form 040-060, "Drilled Shaft Inspection Report." Each drilling method begins with drilling the shaft, or bore. The inspector observes the drilling operation and uses NDOT form 040-060 to record the soil types and depths at which the soil types are encountered. With the wet method, the next step is to stabilize the borehole perimeter using water or slurry. With the casing method, a casing is installed by pushing or lowering into the borehole. After stabilization, the borehole is cleaned of debris and, with the dry method, seepage water is removed. The reinforcing steel cage is lowered into the borehole and concrete is placed into the hole.

Reinforcing steel is assembled into a cage that will be lowered into the borehole. The inspector must inspect the reinforcing steel cage to verify the appropriate number and sizes of reinforcing steel are used and that the construction conforms to the plans and specifications, including the number and placement of longitudinal bars. The specifications require that the contractor must tie every other reinforcing steel intersection twice, double tied. When the cage is complete, the inspector should evaluate the construction of the cage to confirm that the cage will not deform when placed in the borehole.

Before placement of reinforcing steel in the borehole, identify each cage to verify that the cage is placed in the correct borehole. The reinforcing steel cage must be lowered into the borehole within 30 minutes of cleaning the borehole. The cage is supported in the borehole until the concrete is completely placed. During the placement, the cage cannot touch the bottom of the borehole. Verify the elevation of the top of the cage, allowing for the appropriate cover between the steel and the top of the footing so that the ultimate elevation of the concrete is consistent with the plans.

With the cage properly placed in the borehole, the inspector must check to make sure that the material from the borehole perimeter has not dislodged into the borehole. If any material is dislodged, the contractor is required to remove the material before placing concrete. Report any dislodged material on NDOT form 040-060, "Drilled Shaft Inspection Report."

With the bore and reinforcing steel cage inspected and approved, the inspector observes the concrete placement. Concrete placement must begin within one hour of cleaning the borehole. Before concrete is placed, the contractor fills the crosshole sonic log tubes with water, which helps to equalize the pressure in the tube with the pressure from the concrete. Using a tremie, place concrete continuously from the bottom elevation to the top of the borehole, and continue after the borehole is filled until quality concrete is observed at the top of the borehole. Immerse the discharge end of the tremie at least five feet in the fluid concrete throughout the placement operation. During placement of concrete, the slump is closely monitored. The specifications incorporate special requirements relating to slump testing for concrete used in drilled shaft foundations. After the concrete is placed, cure the exposed concrete surface.

Crosshole sonic log tubes are used to test the concrete within three days of concrete placement. If any shaft has unacceptable crosshole sonic log test results, the contractor must submit a plan for corrective action. The Materials Division Geotechnical Section, or consultants retained by NDOT, performs crosshole sonic log testing. The frequency of the testing is based on the size and type of the drilled shaft. Coordinate testing through the Materials Division.

The inspector completes NDOT form 040-060, "Drilled Shaft Inspection Report," during the boring operation for each bore. This form provides a written record of activities, observations, and progress made during the construction of drilled shaft piles. Use the Drilled Shaft Concrete Volumes worksheet and information provided by the contractor to monitor concrete volumes in drilled shaft foundations. Refer to the Construction Division intranet site (SharePoint), http://sharepoint1/040/default.aspx, for a copy of this form.

### 6-509.4 MEASUREMENT AND PAYMENT

Measurement and payment are described in the specifications and the *Documentation Manual*.