# MATERIALS

## ASPHALT PRODUCTS

### Asphalt Cement:

Asphalt cement is the residue obtained by refining crude petroleum. Asphalt cement, when heated, becomes workable and adheres to fine coarse aggregate particles and binds them together.

NYSDOT uses the following grades of asphalt cement:

| | | | |
|---|---|---|---|
| AC | - | 2.5, 5, 10, 15 and 20* | *Standard grade for |
| PEN | - | 85-100*, 18-60, and 15-30 | standard mixes |

Grades are based on penetration and viscosity

Table 702-1 and 702-2 from the Spec. Book lists the asphalt cement grades, test limits and typical uses.

**Test Requirements:**

Viscosity - A measure of the flow characteristics (consistency). Viscosity is a fluid's resistance to flow ("fluid friction"). Viscosity is measured in a capillary tube viscometer.

Penetration - A measure of hardness and consistency. A sample is brought to a specified temperature and tested by allowing a loaded needle to penetrate it. The depth of penetration is measured.

Flash Point - The temperature to which asphalt cement may safely be heated without the danger of instantaneous flash in the presence of an open flame (asphalt cement gives off vapors that can ignite).

Solubility in Trichlorethylene - Determines the bitumen content (purity) of asphalt cement by measuring the insolubles left after dissolving a sample in trichlorethylene.

Softening Point - Used to determine the temperature at which a phase change occurs in asphalt cement. The ring and ball method is used for this test.

Ductility - A measure of an asphalt cement's adhesive qualities. The distance a briquette of asphalt cement is stretched before it breaks is measured.

Thin Film Oven Test - Measures the hardening of asphalt cement. Thin films of asphalt cement are subjected to a 325 deg. oven for five hours and then tested for penetration, viscosity and ductility.

**Liquid Asphalts (Cutback Asphalts):**

Cutbacks are made to reduce the viscosity of the asphalt when used at lower temperatures. They are manufactured by blending petroleum solvents with asphalt cement. Upon application of heat, the solvent evaporates leaving the asphalt cement residue on the surface of the aggregate or base. Based on the rate of evaporation, cutback asphalts fall into three groups:

Rapid Curing (RC) - Asphalt cement blended with a highly volatile diluent -- usually gasoline or naphtha. Used for tack coat or surface treatments.

Medium Curing (MC) - Asphalt cement blended with a medium volatile diluent -- usually kerosene. Used for prime coat or road mixing operations.

Slow Curing (SC) - Asphalt cement blended with a low or non-volatile diluent. Usually diesel fuel or oil. Used for prime coat or dust control.

NYSDOT uses only RC and MC cutback asphalts in the following grades:

RC - 30, 70, 250, 800, 3000
MC - 30, 70, 250, 800, 3000

Grades are based on viscosity.

**Table 702-3 and 702-4 from the Spec. Book have the Liquid Asphalt grades, test limits and uses.**

**Test Requirements:**

% Water - Percentage of water in the product.

Viscosity - Measure of flow characteristics.

Distillation - Determines the proportions of asphalt cement and diluent. Defines the rate of evaporation of diluent at different temperatures and how the cutback will cure.

Tests on Residue from Distillation

viscosity - measure of flow characteristics
ductility- measure of adhesive qualities
solubility - measure of the purity of the residue

Cutbacks are not used often because:

- They are not environmentally sound.
- The expensive diluents that are used to make them are wasted into the atmosphere.
- They are unsafe to use around flame and give off fumes.

**Emulsified Asphalts:**

Emulsified asphalts are made to reduce the viscosity of the asphalt when used at lower temperatures. They are manufactured by blending asphalt cement, water and an emulsifying agent. The mixture is passed, under pressure, through a colloid mill to produce small globules (0.001 - 0.01 mm) of asphalt cement. The emulsifying agent puts an electrical charge on the globules of asphalt cement so they repel each other and stay suspended in the water. Emulsions fall into three types depending on the emulsifying agent used:

Anionic - electro-negatively charged asphalt globules
Cationic - electro-positively charged asphalt globules
Nonionic - Neutrally charged asphalt globules

Anionic and cationic are primarily used in highway construction.

Aggregates have a positive, negative or mixed charge on the surface. Mixing a charged aggregate with an oppositely charged emulsion causes the asphalt globules to react with the aggregate surface. The reaction is an attraction which forces the water out from between them. The water evaporates and the asphalt which is coating the aggregate "sets." The setting rate is controlled by the type and amount of emulsifying agent. Emulsions fall into three categories based on how fast they set.

Rapid Setting (RS) - Has little or no ability to mix with aggregate. Used for surface treatments or penetration macadams.

Medium Setting (MS) - Mixes best with coarse aggregate. Used for cold mixes, penetration macadam or stabilization.

Slow Setting (SS) - Mixes best with fine aggregate. Used for slurry seals or stabilization.

NYSDOT uses the following emulsion grades:

Anionic RS-1, RS-2, HFRS-2, MS-2, HFMS-2, HFMS-2h, HFMS-2s, SS-1, SS-1h
Cationic CRS-1, CRS-2, SMS-2, CMS-2h, CSS-1, CSS-1h

- ° The number following the grade indicates the viscosity and hardness of the base asphalt cements.
- ° The letter “h” attached to the number indicates a harder base asphalt cement is used. The letter “s” indicates an emulsion for stockpile mixes.
- ° The “HF” preceding some of the grades indicates high float. High float emulsions have chemicals added which produce a thicker asphalt film on the aggregate.
- ° The letter “c” preceding the cationic grades simply indicates cationic.

**TABLE 702-5 from the spec book lists the anionic asphalt emulsion grades, test limits and uses.**
**TABLE 702-6 from the spec book lists the cationic asphalt emulsion grades, test limits and uses.**
**TABLE 702-9 from the spec book lists asphalt emulsion tack coat grades and test limits.**

<u>Test Requirements</u>

* Viscosity - measures flow characteristics.
* Storage stability - detects the tendency of asphalt globules to settle during storage.
* Demulsibility - for RS and MS emulsions indicates the rate at which asphalt globules will set. Expressed as a percentage of “set” asphalt globules.
* Cement mixing test - same as demulsibility test but performed on SS emulsions.
* Stone coating - visual measure of how well the emulsion coats the aggregate after washing with water.
* Sieve test - detects large asphalt globules by pouring an emulsion through a No. 20 sieve. Large globules do not coat properly.
* Particle charge test - used to identify cationic emulsions. An anode ( + electrode) and a cathode ( - electrode) are immersed in an emulsion and a charge is connected to them. If a layer of asphalt forms on the cathode, the emulsion is cationic.
* Residue by distillation - to determine the proportions of asphalt and water.
* Oil distillate - obtained by the amount of oil left from the residue by distillation test.
* Tests on residue from distillation
  - penetration - measure of hardness and consistency.
  - float test - test of consistency. Uses float cup testing apparatus.
* Tests on base asphalt
  - penetration - measure of hardness and consistency.
  - solubility in trichlorethylene - determines the bitumen content (purity) in base.
  - ductility - measure of the adhesive quality of the base.
  - flash point - the temperature to which asphalt cement may safely be heated without the danger of instantaneous flash in the presence of an open flame.

Portland Cement (Section 701-01)

Portland cement is a hydraulic cement which is produced by grinding and mixing cement clinker and gypsum together. Clinker mostly consists of calcium silicates, calcium aluminates and calcium aluminoferrites. Gypsum mostly consists of calcium sulfate. Many other ingredients are involved.

Depending on the composition of the clinker and amount of gypsum used, different types of Portland cement can be manufactured for specific purposes. Following are some of the different types of Portland cement:

Type 1 - normal *
Type 1A - normal, air entraining
Type II - normal, moderate sulfate resistance *
Type IIA - normal, moderate sulfate resistance, air entraining
Type III - high early strength *
Type IIIA - high early strength, air entraining
Type IV - low heat of hydration
Type V - high sulfate resistance *
White Portland cement (NYSDOT Type 6) *

*indicates used by NYSDOT

When Portland cement comes in contact with water, it chemically reacts. This reaction is called hydration. During hydration, each cement particle forms "tentacle like" growths that interconnect and give cement its hardened mass and strength.

Most of the strength development occurs within the first month if curing conditions (temperature and moisture) are favorable.

Aggregates (Section 703)

Aggregate - hard, inert materials such as sand, gravel or stone used for mixing with a cementitious material to form concrete.

NYSDOT uses only approved aggregate sources.  Sources are sampled and tested when:

* a new source wants approval
* a rejected source wants re-approval
* the last test for a source is two years old
* a change in the character of the processed aggregate occurs
* the location of the source of raw material is shifted or a change in the character of raw material occurs
* considered necessary by the Department

An approved source must submit an annual report which consists of:

* geologic source report (usually written by a geologist)
* plant flow information (equipment, products made, etc.)

Fine Aggregate

**TABLE 703-1 from the spec book lists the fine aggregate test limits for use in Portland cement concrete or bituminous concrete.**

Test Requirements:

* Magnesium sulfate (5 cycles) - measures an aggregate's resistance to disintegration due to wetting/drying action or freeze/thaw action.  A sample is submerged in magnesium sulfate for 18 hours.  It is then removed and dried.  Repeat this cycle five times.  At the end of five cycles, the sample is washed, dried, sieved and weighed.  The percent loss is calculated.
* Organic impurities - consists of the organic plate and gardener color tests.  Determines the presence of harmful organic impurities.  Samples are put in a solution and set for 24 hours.  The color of the sample and solution are compared to a reference solution.  A difference in color indicates the presence of organic impurities.
* Fineness modulus - indicates the "fineness" of an aggregate.  Computed from sieve analysis. Used in mix designs.
* Specific gravity - the ratio of the mass of the aggregate to the mass of an equal volume of water at the same temperature.  Used in mix designs.
* Absorption - amount of water absorbed by an aggregate.  Used in mix designs.
* % minus 200 - measures the material passing a #200 sieve.  Performed by weighing sample, washing sample with water until the water comes clean, drying and weighing the sample.  Minus 200 material affects the bond between cement paste and aggregate and the performance of asphalt concrete.

Course Aggregate

**TABLE 703-2 & 703-3 from the spec book list the test limits for stone and gravel products.**

Test Requirements:

* Magnesium sulfate (10 cycles) - same as fine aggregate
* Freezing and thawing (25 cycles) - measures an aggregate's resistance to disintegration due to 25 cycles of freezing and thawing  the percent loss by weight is calculated
* Los Angeles Abrasion Test - measures an aggregate's toughness and abrasion characteristics. Aggregates are graded, then put in a drum with steel balls and tumbled.  After tumbling, the aggregate is graded and the additional material passing the #12 sieve is recorded.  This percentage is the Los Angeles Abrasion Number
* Flat and elongated pieces - gives an indication of an aggregate's particle shape.  Particles are analyzed to determine the amount of elongated particles (3:1, 5:1) present.  Limits are set on allowable amounts.
* Crush count - measures an aggregate's angularity.  Particles are analyzed to determine the number of fractured faces.  Limits are set on minimum amounts.
* Specific gravity - same as fine aggregate
* Absorption - same as fine aggregate
* % minus 200 - same as fine aggregate
* Deleterious material - affects an aggregate's strength or strength of the material it is used in

Primary Sizes

Aggregates are crushed into certain sizes, known as primary sizes.  Typically, NYSDOT uses the Numbers 1A, 1, 2 and 3 sizes.

For Portland cement concrete, Number 1 stone or a blend of Numbers 1 and 2 stone with sand is used.  For asphalt concrete, a blend of all four primary sizes with sand may be used depending on the type of mix.

**TABLE 403-4 from the spec book lists the required gradation for primary size stone and gravel products.**

Skid Resistance

Proper skid resistance in pavements requires the use of high friction aggregates and proper design.  The skid resistance of a riding surface is dependent upon an aggregate's texture, resistance to wear and polish, shape and size.  The shape and size of an aggregate particle is controlled by the crushing operation and affects the macro-texture of the pavement.  The texture and wear resistance of an aggregate particle is controlled by its mineralogy; simply put, the hardness and shape of the minerals that make up the aggregate.  These qualities affect the micro-texture of the aggregate and are related to skid resistance.  NYSDOT uses a test to determine the quality of an aggregate's minerals.  An aggregate sample is weighed and subjected to hydrochloric acid. The amount of aggregate that dissolves is determined. The material that remains is a residue that is insoluble in HC1 acid. The test determines the percent of acid insoluble residue. Our standard mixes require a minimum 10% acid insoluble residue. Our rut avoidance and heavy duty mixes require a minimum 20% acid insoluble residue. The RA (rut avoidance) and HD (heavy duty) mixes have stricter requirements because they are used on higher volume roads.

Stripping

Stripping is failure of the adhesion between asphalt cement and aggregate. The adhesion between the asphalt cement and aggregate breaks down due to the presence of moisture. There are four theories to explain stripping.

Mechanical Theory - asphalt cement adheres better to aggregates with pores and a rough surface texture.

Chemical Reaction Theory - when asphalt cement coats an aggregate, a chemical reaction takes place that affects adhesion. The reaction is weaker with acidic aggregates.

Surface Energy Theory - asphalt cement is mostly neutral in charge (non-polar) and when it coats an aggregate, it must coat it thoroughly for good adhesion. Any water present adversely affects that adhesion.

Molecular Orientation Theory - most aggregates have a charge on their surface and asphalt cement is mostly neutral in charge. Water, on the other hand, has a charge and is strongly attracted to certain aggregates (granite, sandstone, quartz). The attraction can “strip” the asphalt cement from the aggregate.

Common ways to reduce stripping are by using non-strip susceptible aggregates, properly draining pavements or using chemical additives. Properly drained pavements reduce the cause of the problem but are not totally effective. Chemical additives give the asphalt cement a charge that is the opposite of the aggregate. This produces better adhesion between the asphalt cement and aggregate.

Bituminous Construction (Section 400)

Plants

All plants used for NYSDOT work must be approved annually. Approval includes, but is not limited to, automated proportioning and recording equipment, scales, meters, cold feed bins, bituminous control units, thermometric equipment, dust collector systems, safety requirements and inspection facilities (office and testing lab). There are two types of plants: the batch plant where material is made one batch at a time and the drum plant where material is made continuously.

x

Composition of Mixes

Mixes are submitted by the producer and approved by the Department. Top courses, heavy duty binder and rut avoidance binder are designed using the Marshall Mix Design Method. Marshall designs must meet the following requirements:

stability - 1500 lb. min.
flow - 8-18 (0.01 in.)
air voids - 3.0 - 5.0 % for standard mixes and RA and HD mixes
voids in mineral aggregate - 15.5 % for 6F, 6FRA, 6FHD
16.0 % for 7F, 7FRA, 7FHD
13.5 % for RA and HD binder

Marshall quotient (stability/flow) lbs./0.01 in. - 150 (for RA and HD only)

* Stability - maximum load carried by a compacted specimen
* Flow - vertical deformation of the sample measured from start of loading to the point at which stability begins to decrease.
* Air voids - air voids present in the compacted specimen.
* VMA - air voids present in the compacted aggregate.

In addition, the mix must fit within the gradation bands and asphalt contents specified for each mix type in **TABLE 401-1** of the spec book.

Primary sizes used in mixes:

top course: # 1A, 1
binder course: # 1A, 1, 2
base course: # 1A, 1, 2, 3

Stone size increases in the lower courses for better load carrying ability. The rut avoidance and heavy duty mixes were developed for high traffic volume roads with high truck traffic which are more prone to rutting. The mixes have different gradation requirements that provide better stone to stone contact and the specimen is compacted with 75 blows instead of 50 blows to simulate higher traffic.

Seasonal Requirements

**TABLE 401-2**
**TEMPERATURE AND SEASONAL REQUIREMENTS**

| Nominal Compacted Lift Thickness | Surface Temperature Minimum (Note 1 & 4) | Seasonal Limits |
|---|---|---|

| | | |
|---|---|---|
| 3" or greater | 40°F | None |
| Greater than 1" but less than 3" | 45°F | (Notes 2 & 3) |
| 1" or less | 50°F | (Notes 2 & 3) |

NOTES:

1. All temperatures shall be measured on the surface where the paving is to be placed and the controlling temperature shall be the average of three temperature readings taken at locations 25 +/- feet apart in accordance with the Department's written instructions.
2. Top Course shall be placed only during the period of April 1st up to and including the third Saturday of November in the counties of Duchess, Orange, Rockland, Putnam, Westchester, Nassau, Suffolk, and the City of New York.
3. Top Course shall be placed only during the period of May 1st up to and including the third Saturday of October in all counties except as noted in Note 2.

Cool weather affects the viscosity characteristics of asphalt cement. The asphalt cement's viscosity increases in cool weather and does not coat the aggregate properly.

Condition of Existing Surface

Prior to overlaying with asphalt concrete, the existing pavement surface must be cleaned, joints and cracks must be cleaned and filled and a tact coat (emulsion) must be applied. Cleaning the pavement and tact coating provides a bond between the overlay and existing surface. Cleaning and filling cracks and joints keeps water from getting into the pavement. Sometimes a truing and leveling courses is used to bring the existing pavement surface to a uniform transverse slope and longitudinal grade.

Pavers

Pavers must be self-powered units with a heated, activated screed or strike off assembly. Pavers must have a receiving hopper with sufficient capacity and automatic flow controls to place the mixture uniformly in front of the screed. Pavers must be equipped with automatic transverse slope and longitudinal grade screed controls which will adjust the screed to compensate for irregularities in the surface being paved.

tractor picture

**Figure 2**

Rollers and Compaction

Rolling should start at the low side of the mat and work toward the high side. Rollers can be a vibratory type of static steel wheel type or pneumatic tire type.

* vibratory type - must be equipped with a speedometer and speed control device and met the following requirements:
  nominal amplitude - 0.05 in. max.
  vibration frequency - 1500 vpm. min.
  drum width - 54 in. min. dual
  84 in. min. single
* static steel wheel type - must be 10-12 ton tandem three axle type or 8-10 ton tandem axle type
* pneumatic tire type - must have two axles with multiple wheels. Front and rear wheels must not follow in the same tracks. Tires must be smooth and of equal size and inflation. Also:
  maximum wheel load - 5600 lbs.
  tire compression on pavement - 80 +/- 5 psi.

maximum axle load - 22400 lbs.

Once the asphalt concrete has been placed, it must be compacted. The mat must be compacted while it is warm (above 180°F). Compaction should not be performed if rolling causes displacement, cracking or shoving. The mat should be allowed to cool if these problems occur. NYSDOT allows two compaction options for standard mixes:

* Option A - three roller compaction train. Initial rolling with a steel wheel roller. Intermediate rolling with three passes of a pneumatic type roller. Finish rolling with a steel wheel roller.
* Option B - vibratory compaction
  - base course - one vibratory roller
  - binder course and top course - one vibratory roller and one steel wheel roller

Vibratory compaction must meet these requirements:

**TABLE 401-3**
**REQUIRED NUMBER OF PASSES (MINIMUM)**

| Pavement Courses | Vibratory Roller: Vibrating Passes (1) | Vibratory Roller: Static Passes (2) | Steel-Wheel Tandem Finish Roller: Static Passes |
|---|---|---|---|
| Base(Open Graded-Each Lift) | 4 | 2 | Not Required |
| Base(Dense Graded) | 4 | 2 | Not Required |
| Binder(Dense Graded) | 2 | Not Required | 2 |
| Top (Dense Graded All Types) | 2 | Not Required | 2 |

NOTES:

1. The required number of vibrating passes shall be reduced by one-half (1/2) for dual vibrating drum rollers when the drums are tandem and are both in the vibrating mode.
2. The required number of static passes may be completed by the vibratory roller operating in the static mode. For heavy duty mixes, the contractor is responsible for the compaction procedure used. This is because the HD specification is performance based. The contractor is paid based on compaction results.

Joints

A bituminous material (tack coat) should be applied to existing pavement edges to provide bond. All joints should be offset by 6 in. from the joint in the lower course.

* Transverse - overlap the previously laid mat by 2-3 in. The overlap material should be 1/4 the compacted thickness of the course. Rake or broom the overlapped material onto the hot mat. The joint should be compacted with the roller perpendicular to traffic. The first pass

should have 6-8 in. of the drum on the hot mat.  Adjacent transverse joints should be staggered a minimum of 10 ft.

* Longitudinal - exposed edges longer than 100 ft. cannot be left at the end of the day.  Overlap the joint by 2-3 in.  The overlap material should be 1/4 the thickness of the course.  Rake or broom the overlap material onto the hot mat and compact the joint with most of the roller on the cold mat.

Quality Control

At the plant, as per Materials Method 5 booklet:  "Plant Insector's Manual for Bituminous Concrete Mix Production"

- Hot bin analysis (gradation)
- Asphalt cement sample
- Aggregate sample
- Temperature
- Air voids
- Extraction test
- Visual

At the job site, as per spec book **(Section 401)**

- Temperature
- Yield
- Visual

Surface Treatments

Surface treatments are made with high friction # 1 stone and asphalt emulsion.  For pavement, RS-2, HFRS-2 or CRS-2 emulsions are used.  For shoulders, RS-2, HFRS-2, HFMS-2 or CRS-2 emulsions are used.  The existing surface is cleaned, the emulsion is applied at a specified rate (0.35-0.50 gal./s.y.), the aggregate is applied at a specified rate (20-24 lb.s.y.) and rolled with a pneumatic tire roller.

Concrete Construction (Section 500)

Plants

All plants used for NYSDOT work must be approved annually.  Approval includes, but is not limited to, bins, weigh hoppers, scales, meters, automated proportioning and recording equipment and inspection facilities (office and testing lab).  There are two types of plants:  the batch plant, where material is delivered to a truck for mixing and the central mix plant where the concrete is mixed at the plant, put in a truck and delivered to the job site.

Transit Mixed Concrete is the primary method of delivery for DOT projects.
**TABLE 501-2 from the spec. book lists the criteria for concrete batching, mixing, hauling and discharge**.

501-3.01 Proportioning

Proportions of ingredients, except admixtures, for all Portland cement concrete mixtures shall be determined by the Department according to these specifications unless otherwise indicated in the contract documents.

Mixes

Mix designs are supplied by the Department to the producer.

**TABLE 501-3**
**CONCRETE MIXTURES**

NOTE: The criteria are given for design information and the data on fine aggregate fineness modulus of 2.80.
The mixture proportions shall be determined using actual conditions for fineness modulus and bulk specific gravities (saturated surface dry for aggregates). The proportions shall be computed according to the Department's written instruction.
A minimum compressive strength is not required by the specifications, but NYSDOT mixes are designed for a 28 day strength of 3000 psi.

The water/cement ratio (w/c) of a mix plays an important role in the strength of the mix. W/C ratio is calculated as pounds of water divided by pounds of cement.

**FIG. 7-1 Typical Trial Mixture or Field Data Strength Curves**

The use of any admixture, except air entraining agents, must be approved by the Department. Following are the admixtures used by NYSDOT:

* Air entraining - improves durability. Improves resistance to deicers. Improves workability.
* Water reducers - also known as superplasticizers. Improves compressive strength with reduced w/c. Improves workability with constant w/c. Can retard set.
* Retarder - delays setting which allows more time for placement and finishing.
* Accelerator - accelerates setting time and increases initial rate of strength development.
* Fly ash (pozzolan) - increases workability. Reduces bleeding and segregation. Improves pumpability. Lowers heat build up. Increases strength gain at later ages. Decreases

permeability.

* Micro-Silica (silica fume, pozzolan) - 100 times finer than cement. Increases strength. Reduces bleeding and segregation. Decreases permeability. Improves chemical and sulfate resistance. Improves abrasion resistance.
* Latex - improves workability. Reduces micro-cracks. Improves durability. Reduces permeability.

## Curing

The object of curing is to prevent the loss of moisture and control the concrete temperature. Temperature and moisture affect the rate of hydration.

For concrete pavement curing is achieved by using:

* Impervious membrane (spray type)
* Polyethylene curing covers
* Quilted covers

The curing period is four (4) days minimum from June 1 to September 15, six (6) days outside those dates. Concrete pavement can only be placed when air and surface temperatures are at least 40°F and rising. When the temperature is expected to fall below 35°F, hay, straw or blankets should be spread on the pavement. For structural concrete, curing is achieved by using:

* Curing covers
* Clear membrane curing compound (spray type)
* Continuous burlap wetting
* Wet burlap and curing covers

The curing period is a minimum of seven (7) days. Curing temperature must be maintained between 45-85°F. If curing temperature cannot be maintained between 45-85°F, the contractor can get permission for cold weather concreting. The curing temperature under cold weather concrete is maintained by:

* Provision of external heat (heat enclosure)
* Use of insulated forms

Quality Control

Plant: **(as per Materials Method 9.1 booklet: "Plant Inspection of Portland Cement Concrete")**

* gradation
* cement sample
* aggregate sample
* moisture test
* cleanness test
* admixture sample
* water sample
* fineness modules test

Job: **(as per Materials Method 9.2 booklet: "Field Inspection of Portland Cement Concrete")**

* temperature
* air content
* slump
* yield
* cylinders

Concrete Pavement

Pavement can be slip form paved or fixed form paved. Longitudinal joints are constructed with tie bars spaced at 3'-4". Transverse joints are constructed perpendicular to the direction of travel with transverse joint supports spaced at 12". Pavement panels can be 63 ft. mesh reinforced or 20 ft. unreinforced. Mesh should be placed 3" below slab surface and never deeper than mid-slab.

Pavement Management

The Department is involved in pavement management on the network level and project level. The network level involves gathering data on pavement condition, traffic, physical characteristics and classification (sufficiency manual). The data is used to plan the Capital Program (GOCP) based on the needs determined from the data.

The project level pavement management system involves deciding on what is the best treatment for a project. The Department published a two volume Pavement Rehabilitation Manual. Volume 1 is for pavement evaluations. This involves evaluating and documenting pavement distress on standard forms. Volume II is for treatment selection. With the data gathered from Volume 1, a number (2-3) of possible treatments are chosen to rehabilitate the pavement. The treatments are put through a life cycle cost analysis to determine which treatment is the most cost effective. The analysis includes the initial treatment, preventive maintenance and one future major rehabilitation treatment. The analysis is based on the present worth method.

## PURPOSE OF ASPHALT PAVEMENT

Asphalt Concrete - Hot Mix Asphalt (HMA)

Primary ingredients - asphalt cement & aggregate

I. Asphalt Binder

Asphalt Cement - product of refining crude oil and is also known as “binder” (not to be confused with binder, the intermediate paving course).

When hot, asphalt cement acts as a lubricant allowing aggregate particles to slide past each other and arrange themselves into the densest possible mixture.

When cool, asphalt acts as a binding agent, bonding aggregate particles together into a cohesive mass. Asphalt cement is impervious to water, so it functions as a waterproofing for the mixture.

Strength properties are dependent on temperature. Asphalt cement tests are performed at specific temperatures so test results can be interpreted properly.

Asphalt behavior depends on time of loading. Different load durations yield different results.

Asphalt Cement is visco-elastic material
Viscous fluid at temperatures $> 100°C$
Elastic solid at temperatures $< 0°C$ (when loaded, it changes shape and when unloaded, it returns to original shape)

Between 0°C and 100°C, asphalt cement exhibits both viscous and elastic properties.

Asphalt reacts to oxygen.
Oxidized asphalt cement becomes harder and more brittle.

Oxidation occurs more rapidly at higher temperatures.

Asphalt can be modified by additives or heat to alter or improve properties and enhance long term performance.

Most modifiers attempt to reduce temperature dependency, oxidative hardening or moisture susceptibility of asphalt mixes (anti stripping agents).

## II. Aggregate

Natural - mixed from glacial or river deposits “bank run” or “pit run” aggregate.

Processed or manufactured - quarried, crushed and sized sometimes washed.

RAP - recycled asphalt pavement which is
existing pavement, removed and processed.

Aggregates provide a strong stone skeleton in asphalt concrete to resist repeated load applications.

Cubical, rough-textured aggregates are better than round and smooth because they provide a better aggregate interlock with less sliding of particles over one another.

The ability of asphalt concrete to resist shearing and resulting deformation is better with the use of crushed aggregate.

To increase strength of aggregate structure, the % of crushed faces and gradation limits should be specified.

## III. Asphalt Mixture Behavior

Primary forms of asphalt concrete distress are:

* Permanent Deformation - rutting
* Fatigue Cracking - caused by repeated heavy loads
* Low Temp Cracking - asphalt cement becomes brittle at low temperatures

A. Permanent Deformation - accumulation of small amounts of deformations which occur each time a load is applied.

Causes: Weak subbase - too many repeated heavy loads cause subbase and/or subgrade to deform below the asphalt layer. Asphalt concrete is flexible and won’t bridge large deformations in subgrade.

* Asphalt or subbase layer is too thin. Subbase and/or subgrade can also be weakened by water intrusion.

Weak Pavement Pavement too low in shear strength to resist repeated heavy loads.

Results: Rutting becomes safety hazard - ruts fill with water causing hydroplaining or ice to form.

Rutting is more prevalent in the summer due to high temperatures softening the asphalt cement.

To prevent rutting - use cubical and rough textured aggregate like crushed stone, graded in a manner to develop a dense mass with particle to particle contact.

Particles lock together and react as large single elastic mass rather than individual particles. When the load is removed, the asphalt cement helps the particles move back to their original positions.

Aggregate structure is directly related to an asphalt concrete mat's ability to resist permanent deformation.

B. Fatigue Cracking

- appears in wheel paths with repeated heavy loads
- early sign of fatigue cracking - intermittent longitudinal cracks
- fatigue cracking is progressive - eventually longitudinal cracks will join and cause transverse cracks to form alligator cracking.
- extreme fatigue cracking leads to disintegration and the formation of potholes when the pieces are dislodged by traffic

Causes:

Stiffer HMA mixtures are more prone to fatigue cracking.

Poor subgrade and poor drainage result in excessive deflection of the pavement and can be a cause of deflection cracking.

Fatigue cracking can just be an indication that the useful service life of the asphalt pavement is complete. If this coincides with the design life, it's not a premature failure.

If it occurs prior to the end of the design life, it can indicate that the pavement was subjected to more and/or heavier loads than the pavement was designed to carry.

To Avoid Fatigue Cracking:

- accurate prediction of the number of heavy loads.
- keep subgrade dry - proper drainage will help prevent rutting caused by wet subgrade.
- thicker pavements.
- don't use paving materials that are weakened by the presence of moisture. Use asphalt cement that doesn't strip from aggregate.
- paving materials that are resilient enough to withstand normal deflections.
- use asphalt cement that is able to resist tensile stresses.
- use asphalt cement that is resilient or able to withstand many load applications at levels less than the maximum tensile strength without cracking.
- soft asphalts have better anti-fatigue properties than hard asphalts.

C. <u>Low Temperature Cracking</u>

Intermittent transverse cracks at a consistent spacing.
(not reflection cracks or asphalt pavement over Portland cement concrete pavement where the transverse joints work and result in cracking in the asphalt overlay)
<u>Causes</u>:
Low temp cracks form when pavement shrinks in cold weather and tensile stresses develop. At some point along the pavement, the tensile stress will exceed the tensile strength of the asphalt and the pavement cracks.

Some engineers believe that low temperature cracking is due to the cumulative effect of many cycles of cold weather.

Hard asphalt cement is more prone to low temp cracking than soft binders.

Asphalt cement excessively oxidized due to many air voids is more prone to low temperature cracking.

<u>To Prevent Low Temp Cracking</u>:

- use soft asphalt cement
- use asphalt cement that is not prone to aging (oxidizing)
- maintain low air voids in mix so it is not prone to being oxidized
- soft asphalts have high penetration and lower viscosity than hard asphalts

**PORTLAND CEMENT CONCRETE**

Concrete - stone-like material obtained by permitting a carefully proportioned mixture of cement, sand, gravel or other aggregate and water to harden in forms of the shape of the desired structure.

Fine and course aggregate make up most of the mix

| | |
|---|---|
| Class A concrete - substructures | 360 kg/m3 cement |
| | 165.6 kg/m3 water |
| | 836.5 kg/m3 sand |
| | 961.9 kg/m3 stone? |

Cement and water interact to bind aggregate particle into a solid mass

Advantages of Concrete:

- Inexpensive raw materials and processing
- High compressive strength
- Good for structure subject primarily to compression
- Excellent formability

Disadvantages:

- Low tensile strength
- Relatively brittle

Steel can be used to reinforce concrete so that it can resist some tensile loading.

Advantages of Reinforced Concrete:

- Low cost
- Good weather and fire resistance
- Good compression strength
- Excellent formability
- Tensile strength
- Durability

Hydraulic, cement is used for structural concrete
Water reacts with cement in a chemical process called hydration that gives off heat

Portland Cement - only hydraulic cement used in DOT

NYSDOT uses Type 1 and Type 2 cement, usually Type 2
Type 3 is used when a high early strength is required (non-chloride accelerated)
Class F uses Type 2 cement

Water mixed with cement forms a soft paste that gradually stiffens (sets) and hardens (cures) to form a solid.

Set generally occurs 2-4 hours after water is added to the cement, but hydration continues to proceed deeper into cement grains for a long time afterward.

Concrete shrinks as it dries

W/C ratio determines strength of concrete

DOT mixes w/c 0.38 - Class F Hi early
0.46 - Class A

As w/c increases, so does the strength of paste

Heat of hydration in large concrete placements causes the temperature of the mass to rise and the volume to expand. This is followed by cooling and contraction. This introduces stresses into the new concrete which has not yet reached its full strength and it can cause cracking to occur.

Aggregates - 70 - 75% of hardened volume

More tightly packed aggregate increases strength and weather resistance. Gradation of the aggregate is important.

Aggregates must be free of impurities such as loam, silt and organics. These reduce the bond between the aggregate and the cement paste. Aggregates must be durable, strong and weather resistant.

Fine & Coarse Aggregate
Fine Aggregate < 6.3 mm
Gradation listed in Section 703.07 of the specifications.

Coarse Aggregate NYSDOT uses two coarse aggregate gradations: CA1 & CA2 - Table 501-2 of the specifications.

Test and Requirements:

Fine aggregate magnesium sulfate loss 30% for PCC, 45% for Bit. Con.
Coarse aggregate mag sulfate 18% 10 cycles
Freeze thaw 10% 5 cycles
L. A. abrasion
Flat and elongated
Crush count - fractured faces

Concrete Unit Weight - 2240 - 2400 kg/m3.

Concrete Field Tests:

- slump is measure of consistency and indication of water content
- air content is required for durability

Admixtures:

Used to provide concrete with special properties to

- improve workability
- accelerate or retard set
- improve durability
- protect against corrosion
- add color

Air Entraining Agent - most important admixture

- improves workability & durability
- improves resistance to freezing and thawing
- decreases strength (this can be offset by reducing w/c ratio)

Usually 90% of water is introduced into the truck barrel at the plant
Amout of mix water must be adjusted to compensate for moisture content of the aggregates.

Mix 6-18 rpm   Discharge within 60 minutes for pavement or 90 minutes for structural concrete.

Types of Mixers:  Central, Transit and Truck
Central   mixed in plant and mix is agitated while being transported in truck
Transit   material including water loaded into truck at plant and mixed while truck is in transit.  Transit used most by NYSDOT
Truck   material, except water loaded into truck at plant.  Water added at site and mixed (used when job site is a long way from plant)

Conveying:
Wheel barrels, buggies, conveyor crane and hopper buckets, pump conveyors

Avoid segregation - less than 1.5 meter drop into forms
- vibrators are not to be used to move the concrete horizontally

Compaction - power driver vibrators, usually internal, prevent honey combing caused by large air bubbles trapped in the mix.

Structural design based on 28 day strength usually 21 Mpa (3000 psi) for cast-in-place concrete

70% of strength, 15 Mpa +/-, usually achieved after 7 days

Concrete strength gain depends on moisture and temperature

Curing - maintaining proper conditions for strength gain during the time following placement

Concrete can lose 30% of strength through improper curing (loss of water too quickly or permitting concrete temperature to drop below 5 °C).   NYSDOT requires curing temperatures between 7° and 30° Celsius.

Allowing concrete in cure to freeze can reduce its strength by as much as 50%.

Concrete should be protected from excessive water loss for 7 days by:

Curing - protect concrete for 7 days from losing water by:

- keeping forms in place
- keeping poly-lined burlap coverings in place
- keeping burlap coverings continuously wet - especially for decks

Shrinkage cracks reduced by:

- controlled proper curing
- reduce water content in fresh concrete
- no use of water in finishing
- controlling temperature changes

**NEW MATERIAL PRODUCTS**

QC/QA ASPHALT CONCRETE PRODUCTION:

- Specification Section 402 (Quality Control Asphalt Concrete) applies to all projects let after May 23, 1996.
- Prior to this Department staff or consultants hired by NYSDOT performed testing on asphalt concrete.
- Primary tests were gradation type tests performed on aggregate before it was mixed with the asphalt.
- Voids total mix is a better predictor of performance - used for volumetric mixes.

Under Section 402

- Certification of all technicians (Quality Control Technicians and Quality Assurance Technicians)
- Producers responsible for all QC testing during HMA production
- Payments bonuses/penalties are used to encourage production of high quality HMA
- NYSDOTs QA procedures are used to determine specification compliance
- Bonus/Penalty dependent on Quality Adjustment Factor generated by QC test results at plant
- Used for all HMA production (standard Marshall mixes and superpave mixes)

SUPERPAVE:

- SUperior PERforming asphalt PAVEments - is a mix design system not a mix.
- Superpave is a collection of mix design options and levels. The appropriate mix is selected based on the site conditions and needs.
- Developed to overcome three primary problems with asphalt concrete pavements: Rutting, Fatigue Cracking and Low Temperature Cracking.
- Uses performance graded - PG binders. Physical properties tested using 4 performance related tests performed at the most severe conditions a pavement can be expected to experience.

SUPERPAVE, cont'd.

- PG 64-28 - binder has adequate properties at temperatures at or exceeding 64 Degrees Celsius and at -28 Degrees Celsius or lower.
- ESALs - Equivalent Single Axle Loads - predicted number of 80kN loads a pavement will carry in its service life. Calculation based on AADT, % trucks, growth rates and service life.
- ESAL zones used by NYSDOT. LO.3, L1.0, L3.0, L10.0, L30.0, L100 million ESALs.
- L0.3 & L1.0 million ESAL mix designs: similar to standard mixes for lower volume roads.
- L3.0 and L10.0 million ESAL mix designs: similar to RA (rut avoidance) mixes for mid volume roads.
- L30.0 and L100.0 million ESAL mix designs: similar to HD (heavy duty) mixes for high volume roads and interstates.

SUPERPAVE Gyratory Compactor - SGC more accurately simulates how asphalt concrete is compacted by compaction equipment and traffic.

- Specimen height is checked at 3 points N initial, N design and N maximum.
- N is the number of gyrations.
- N "Initial" represents compaction after the first pass of the breakdown roller.
- N "Design" - construction compaction completed (4% VTM).
- N "Maximum" at the end of pavements service life (2% VTM).
- N values determined by ESALs, established during project design (special note page)

SUPERPAVE Density Monitoring:

- Superpave has 3 levels of field density monitoring that are stipulated in the specs.
- The "y" digit in the spec. item designates the density requirements (see attached superpave item number reference sheet).
- A '5' digit or "50 series" is a HD (heavy duty) specification that requires daily random core sampling. The tonnage placed can then have a penalty or bonus applied against it, according to test results.
- A '6' digit or "60 series" is a RA (rut avoidance) specification that requires daily random nuclear density gauge testing.

  The nuclear gauge limit is calibrated based on core samples. The density readings are then correlated to real pavement densities. No penalties or bonuses are applied.
- A "T" or "TO series" is a standard type specification that requires daily random nuclear density gauge testing. The density readings are only numbers for the equipment being used. No penalties or bonuses are applied.
- See attached superpave review sheets for related density monitoring details.

SUPERPAVE Friction Requirements:

- Superpave has 2 friction aggregate requirements based on traffic volume.
- The "z" digit in the spec. item designates the friction requirements (see attached superpave item number reference sheet).
- A "1" digit denotes a "FX" aggregate and a "2" digit denotes an "F" aggregate requirement (see HMA pavement frictions section below).
- These designations are currently being revised by E.D.-99-01.

HMA Pavement Friction:
In asphalt concrete, pavement friction is provided by the coarse aggregate (+ 1/8 inch) of the top paving course.

Carbonate aggregates (limestone and dolomite) polish under the effects of traffic.

- If primary aggregate was Carbonate (AIR greater than 10%) then blending with Non-carbonate (AIR greater than 80%) Material required. NC Material greater than 20% of + 1/8 inch material.

Non-carbonate nubs resist, polishing giving pavement a macro texture which provides pavement friction.

Wappinger dolomite (AIR 9% - 14%) was acceptable for use as friction aggregate. Recent studies show that this polishes under traffic giving FN 40 numbers less than 32.

New FX top course items for AADT less than 8000. Crushed limestone and crushed dolomite coarse aggregate must have AIR greater than 20% and 17% respectively, otherwise, it must be blended with non-carbonate aggregate.

High Performance (HP) Concrete:
To provide longer lasting bridge decks, a concrete mix with lower cracking potential and reduced permeability was developed.

- Class H concrete (for pumping applications) is modified with pozzolans (flyash) and microsilies.
- The fly ash at 80 kg/$m^3$ (135#/cy) and microsilica at 25 kg/$m^3$ (40#/cy) are substituted for Portland cement. The Portland cement content is therefore reduced from 400 kg/$m^3$ to 300 kg/$m^3$ (500#/cy).
- Maximum w/c is 0.40.
- Lowers heat of hydration and corresponding risk of shrinkage cracks.
- Permeability decreased.
- 28 day strength increased.
- Very workable mix.
- Must be loaded properly to prevent “Balling”.

Class DP using Class D aggregate (CA1) is used where aggregate must squeeze into narrow openings, i.e. overlays where rebar mat is exposed and exodermis bridge decks.

Deck Sealing:
Reduces ingress of chloride bearing water into the concrete without affecting the concrete’s ability to breathe or transfer water vapor.

- Most effective in protecting new (green) decks from first winter’s salting.
- Concrete is “mature” after 1 year and capable of protecting itself.

Sealer should be applied after 14 days wet cure, preferably after transverse saw cut grooving and before opening to traffic but definitely before de-icing chemicals are applied to bridge deck.

Crack Sealing:
- Moratorium in 1995.
- Wide band application used and abused creating slippery pavement especially dangerous for motorcyclists.
- New spec. developed.
- New material ASTM D3405.
- Routing used to prep cracks.
- Narrow band application only.
- No longitudinal cracks to be sealed within the lane ... for now.
- No sealing of map cracked areas.

Crack sealing can extend service life of a pavement especially if used one to two years after paving. Prevents water and incompressibles from invading reflection cracks.

Metrics:
All HMA & PCC plant automation systems installed or updated after 10/1/96 must be “metric capable” (including scales, digital readout, recorded quantities and temperature).

Dual units, interchangeable system (English to Metric) w/flip of switch or simple computer command or metric only systems are acceptable.
- All automation systems must be “metric capable” by Y/2000.
- Until then, hand conversions can be used where required. Conversion factors in E.I. 96-05.
- Factors are given to the $10{,}000^{th}$s place.

Steel reinforcing bars are using soft conversion. Actual bar size not changing but number system will change, i.e. a #5 bar ($5/8^{th}$s inch diameter) will now be called 16 bar (15.9 mm diameter).

## THEORY OF CONCRETE

Concrete is composed of a coarse and a fine aggregate bound together by cement. Cement is an artificial mixture of limestone and clay which has been burned to incipient fusion and then ground to powder.

In properly designed and constructed concrete, each particle of aggregate is completely surrounded by paste and there are no voids between particles of aggregate. The aggregate is considered to be an inert filler, its purpose being to provide bulk and reduce cost. The paste (cement and water) acts as a binding agent which cements the aggregate particles into a solid mass. The requirements of the paste are strength, durability and resistance to passage of water required by the job.

The binding qualities of the paste are set up by a chemical reaction when water is added to the cement. This chemical reaction requires favorable temperature and moisture conditions. A satisfactory concrete cannot be produced when outside temperatures are either too high or too low. The lower limit given by the specifications is 40°F. There is no upper spec. limit. When temperatures are below 40°F, concrete shall not be placed.

The chemical reaction between the cement and water at first has a very fast pace, then it slows down and continues almost indefinitely under favorable conditions. Since one of the conditions is sufficient moisture, the best quality concrete is achieved under water.

Another precondition of good paste is the water-cement ratio. The water-cement ratio indicates the number of gallons of water used per bag of cement. In all cases, more water than the amount required to produce the best quality concrete is used to improve workability and reduce cost. With more water, additional aggregate can be used. These apparently good results are more than offset by the fact that more water cuts down the paste's quality as a binding agent and its resistance to the elements.

Being such a big part of concrete, the aggregate plays an important part in the design of concrete. The aggregate should be graded for economy of paste and it should be hard and durable.

The resistance to freezing and thawing cycles is severely impaired when too much water is used in the paste. This is readily seen on old concrete structures, whose tops are crumbling because water rose to the top. This is due to the fact that the aggregates are heavier than water. Thus, whenever there is an excess of water (water that did not combine with the cement to form a paste) the heavier aggregates settle toward the bottom forcing the excess water upwards. This is known as "water gain." The extreme case of water gain is "laitance" or a formation of scum which, when dry, will spall and peel. "Water gain" will carry excess water and fine aggregate toward the top of the structure. This, when the water evaporates, results in a honeycomb concrete with poor resistance to freezing and thawing, since it has an abnormal amount of voids that will absorb outside moisture.

One of the biggest problems in concrete pavement construction is the action of winter chemicals on concrete. The repetitive use of calcium chloride and other salts weakens the top of the pavement to such a degree that it starts crumbling. Even the best of concrete cannot withstand this chemical action. Experience and experimentation have proven that air entrained concrete is far superior in this respect than normal concrete.

Where the concrete structure is exposed to the weather or other severe conditions, impermeability is of the utmost importance. This is achieved by using less water and a longer curing time. Curing alone will not make the concrete impermeable.

STRENGTH OF CONCRETE

The specification for concrete most often requires a strength of 3000 lbs/psi. This is commonly known as 3000 pound concrete. The strength is determined by making test cylinders and crushing them at the end of a 28 days curing period.

The required strength of concrete is largely dependent on the water cement ratio and the curing time. With an increase in mixing water, the compressive and the flexural strength of the concrete decreases. Only a limited amount of water can combine with the cement. Therefore, it follows that when there is an excess of water, the water will be taking up the space that should have solid materials, thus making a less dense concrete.

Theoretically, the amount of water to be added should be just enough to make a sufficient amount of cement paste to coat the fine and coarse aggregates. In practice, this will produce a harsh and hard to manipulate mix. Enough water should be used to make the mix workable. With the use of mechanical vibrators the amount of water can be reduced without impairing the workability of the mix.

As previously stated, the strength of concrete increases with age. Concrete in cure has to have sufficient moisture and the proper temperature. If concrete is allowed to dry out during its curing period, strengthening stops. In a case where moist curing has ceased, the strengthening of concrete goes on for a short time but then stops completely. Even after a considerable time lapse; however, the resumption of moist curing results in further strengthening of the concrete.

Temperature affects the chemical reaction between cement and water. The most favorable curing temperature is between 70°F and 80°F. If temperatures drop below freezing when the concrete is being cured, strengthening stops and the concrete may be damaged by the expansion of its water due tofreezing.

TYPES OF CEMENT

Portland cement is manufactured from properly proportioned limestone or marl with shale or clay added. The raw materials are pulverized, proportioned and fed into rotary kilns where they are calcinated at 2700 degrees to form clinker. The clinker is then pulverized and a small amount of gypsum is added to regulate the curing time. The finished product, is so fine that all of it will pass #200 sieve.

When water is added to the cement, a paste will result which first will set, then harden indefinitely changing the cement into an artificial stone. This setting and hardening is brought about by a chemical reaction usually known as hydration. In chemical terms, this is known as an exothermic reaction because it gives out heat while setting.

Portland cement - Type 1. This is normal, general purpose portland cement used on all structures, where special properties of the other cement are not required. That is: where sulphate action is absent and where setting of concrete will not generate an objectionable amount of heat. (Present specs. Allow the mixture of types 1 & 2 in the same silo.)

Modified Portland - Type 2 has a lower heat of hydration also an improved resistance to sulphate action. Used in mass concrete such as large piers, abutments or dams, where large quantities of setting concrete would produce too much heat. This type is also used when mild sulphate action is present, as in sewer structures. (When mass concrete is poured in lower temperatures, Type 1 could be used).

High Early Strength - Type 3 sets fast, achieving high strength at an early age. Used where forms have to be removed as soon as possible or where concrete has to be put into early use. It is also used when concrete is poured in low temperatures, resulting in economy. (Concrete heating process can be discontinued sooner).

Low Heat - Type 4 is used on very large structures such as large gravity dams. It produces very little heat while setting but develops its strength slower. Prevents detrimental flash set in mass concrete.

Sulphate Resistant - Type 5 is used in special cases, such as in Western states, where sulphate action producing alkali soils are prevalent.

Air Entertainment - now achieved with a liquid additive at the batch plant. The concrete made with such an additive contains billions of minute uniformly distributed and completely separated air bubbles per cubic yard. These minute voids prevent the accumulation of water in large voids, which on freezing would expand and damage the concrete. Air entrainment offers resistance to frost action and cycles of wetting and drying and provides high immunity to surface scaling that results when chemicals are used to melt pavement ice.

Air entrainment causes some reduction of the ultimate strength (about 10%) as compared with the normal concrete of the same water cement ratio. Air entrainment has the same effect on the strength as the same volume of extra water. But since air entrained concrete is more workable, particles of the aggregate can more easily slide over each other the amount of water can be reduced. Thus, the decrease in strength due to air is offset by the increase due to the reduction of water.

Also, the air entrained in concrete increases its volume resulting in a reduction of the cement factor (barrels of cement per cubic yard of concrete produced).

When air entrained cement is used, it has to be assumed that a certain amount of air will be entrained. While many factors will affect the amount of entrained air, actual % air can be controlled by the dosage of A.E.A.

There are two distinct groups of the offenders of air entrainment. The first group, over troweling and too much vibration of a freshly poured concrete, attacks and reduces the air entrainment by breaking up the air bubbles. It also reduces the quality of concrete. The second group, while being beneficial to good quality concrete, has an adverse effect on the air entrainment. A good quality concrete has to have low slumps (be relatively stiff) but the air is most readily entrained at a 6 to 7 inch slump. To produce good concrete, the outside temperatures have to be relatively high, yet, higher temperatures will inhibit air entrainment. These problems may be overcome by adjusting the dosage of A.E.A.

Air contents are specified:

| | |
|---|---|
| Class A - 6% | Class E - 6% |
| Class B - 5% | Class F - 6% |
| Class C - 6% | Class G - 5% |
| Class D - 7.5% | Class H - 6% |

Tolerance ± 2%

When different cements are not available, somewhat the same results are achieved by using artificial means. High early strength is attained with richer mixes; reduction of heat in hydration - by using lean mixes and artificial cooling; prevention of sulphate attack - by providing adequate drainage.

Liquid retarder is used to retard the hydration. Bleeding is overcome by using more cement or more sand in the fine agg.; segregation by placing concrete at a slower rate or using vibrators.

Calcium chloride is used to accelerate setting. It is either in solution, in which case it is a part of the mixing water or as crystals that are added to the aggregate. In the latter case, care should be taken to prevent the contact of such agg. with the cement until such time as the batch is dumped into the mixer.

N.Y.S. Spec's Admixtures shall be added to the batch in solution as a portion of mixing water.

Calcium chloride should not comprise more than 2% of the cement by weight.

## QUALITY CONTROL OF INGREDIENTS

Portland Cement is usually packed in paper bags weighing 94 lbs. and considered to contain 1 c.f. by loose volume. Sometimes cement is measured by the barrel - 4 bags or 376 lbs. When storing the cement all precautions should be taken to prevent contact with moisture. Free air circulation should not be allowed inside the storage area.

The water used should be free of acids, alkalis, oils and especially of organic matter. The safest supply is drinking water.

The aggregate should be hard, durable and free of foreign matter such as clay, mica, salts and organic matter. Shale, laminated stone and most charts are not desirable.

Aggregate shall be rejected if they fail to conform to gradation requirements. Unless otherwise specified on the plans or proposal, only crushed stone, crushed gravel or crushed slag shall be used as coarse aggregate.

The ideal aggregate is cube shaped. The sharp, elongated agg. require more fines and at the same time more paste to produce a workable mix. Sands should not contain a high percentage of sharp elongated particles.

## STORING AND HANDLING THE AGGREGATE

Most of the aggregates are washed or screened to remove the deleterious materials. Sometimes it is necessary to blend finer materials with coarser sands. This is done by feeding the fines into the stream of coarser material. The blending should never be done by placing alternating layers of fine and coarse aggregates.

The stockpiles (of the same type of agg.) should not be conical. They should be constructed by placing approximately uniform layers upon each other. When dry, fine agg. is dropped from buckets or conveyor belts. Care should be taken that the finer particles are not blown by the wind.

Stockpiles deemed non uniform in gradation or containing visible concentration of fines shall be rejected. Stockpiles shall be formed on prepared bases. The base shall be constructed of the same material as is to be stockpiled on concrete, metal or wood floor. If ordered, stockpiles for fine agg. shall be allowed to drain for a sufficient time to stabilize moisture content.

To avoid a buildup of fine agg. in the corners of the bin, a vibrator is sometimes installed. This is particularly true for fine agg. batchers.

The vibrators shall be so arranged that no significant vibrations are transmitted to the scales or other plant equipment during the time when fine materials are weighed. The agg. should be dropped vertically into the bins. A slanted discharge or discharge against the walls of the bin causes segregation.

Storage bins should be kept almost full. When a bin is allowed to be nearly depleted, the opening of the discharge chute will create a vortex in the middle of the bin thus “sucking in” a high percentage of fines.

## DESIGN OF CONCRETE

Concrete should be designed to produce the most economical mix that will give satisfactory work ability and the required end product.

The water-cement ratio depends largely on the purpose for which the concrete is designed. That is: the strength desired and the amount and type of exposure to be expected.

Where a smooth finished surface of concrete is desired or where the concrete will have to be deposited in a high, thin wall, a higher percentage of fine agg. is desirable. This produces a better work ability and cohesion, thus precluding the chance of honeycombing and water gain at the top of the structure. The presence of an adequate amount of fines is more important in wet than in stiff mixes, in lean mixes than in rich ones.

The concrete mix having a higher percentage of coarse agg. is more economical than that having a high percentage of fines. This is obvious since a coarser agg. presents less surface to be coated with the paste.

In determining the most economical combination of aggs. the trial mixes are most practical. For large jobs as well as where unusual agg. is encountered or where the strength of concrete is of vital importance, the trial mixes are made in a laboratory. In other cases, it is made in the field.

In making trial mixes, enough water should be added to produce the desired slump, regardless of whether this would be more than the prescribed amount or less.

For all practical purposes, the total weight of dry material (cement, stone, sand) is proportional to the water-cement ratio. Consequently, if less than the specified amount of water is used, the weight of the dry materials may be increased in proportion to the difference between the water use and that specified. If more water is used, the adjustment is in the opposite direction.

CONSISTENCY

With a given amount of cement paste, more aggs. are used in stiff mixes than in fluid mixtures, thus resulting in economy. However, this is sometimes offset by a higher cost of placing.

The consistency of concrete should always be suitable for a special job. Thin members or heavily reinforced require more fluid concrete. “Plastic” concrete is readily molded but changes its shape only slowly, when forms are removed immediately after placing. Also, it does not crumble but flows sluggishly without segregation. Neither the very stiff, crumbly nor the very fluid, watery mixes are regarded as being plastic. Plasticity is a desirable quality of a concrete mix.

The ease or difficulty of placing concrete is referred to as its work ability. A stiff but plastic mixture with large agg. has a good work ability in wide, open forms while the same mixture has a poor work ability in a narrow, high form or where reinforcing is closely spaced.

The slump test is used as a measure of consistency but it should not be used to compare mixes of different proportions or of different kind and size of aggregate. A change of slump under uniform operation conditions indicates a change in the character of materials, the proportioning or the water contents.

Slump Test. The testing device shall be made of #16 gage galvanized metal and shall have a shape of the frustum of a cone with the base 8" in diameter, the top 4" in diameter and the altitude 12". The mold shall be provided with foot pieces and handles.

Samples shall be taken from the mixer during discharge by passing a scoop or a pail through a discharge stream of concrete. This operation to start at the beginning of discharge and to continue till the entire batch is discharged. (To insure a representative sample). In the case of paving concrete, samples may be taken from the batch immediately after depositing on the subgrade. At least five samples shall be taken from different portions of the pile. The location of the batch of concrete thus sampled, shall be noted for future reference.

The sample, thus obtained, shall be taken to the site of the molding (in the pail) of the specimen and mixed with a shovel until it is uniform in appearance.

The “slump cone” shall be dampened and placed (with the larger diameter down) on a flat, moist nonabsorbent surface. Then the concrete shall be placed from the pail into the cone. This is done in three layers, each approximately one third the volume of the cone. As each spoonful of concrete is placed into the cone, the scoop shall be moved around the top edge of the cone to insure symmetrical distribution of concrete within the cone. Each layer shall then be rodded with 25 strokes of a 5/8 in. rod, approximately 24" in length and tapered for a distance of 1" to a spherically shaped end having a radius of 1/4 in. The strokes shall be distributed in a uniform manner over the cross-section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel so that the cone is exactly filled. The cone shall be immediately removed from the concrete by raising it carefully in vertical direct.

The consistency shall be recorded in terms of inches of subsidence of the specimen.

Slump is specified for each class of concrete and also for the type of placement.

Slumps Specified:

| | | |
|---|---|---|
| Class | A - 2 ½" - 3 ½" | E - 3"-4" |
| | B - 2"-3" | F - 2"-3" |
| | C - 1 ½" - 2 ½" | G - 7"-8" |
| | D - 2 ½- 3- ½ | H - 3-4" |

| PLACEMENT | DESIGN RANGE | MAX. SLUMP |
|---|---|---|
| Slipform Pavement | 1 ½- 2 ½ | 2 ½ |
| Form Pavement | 1 ½- 2 ½ | 3 |
| Structural Slabs | 3-4 | 4 |
| Ftgs. Headwalls greater than 18" Thickness | 2-3 | 3 ½ |
| Piers, pedestals, rigid frames or arches, box culverts, walls less than 18" thick, general purpose struct. | 2 ½- 3 ½ | 4 |
| C.I.P. piles | 2 ½- 3 ½ | 5 |

| PLACEMENT | DESIGN RANGE | MAX. SLUMP |
|---|---|---|
| Tremie (6" min. slump) | 7-8 | 9 |
| H.E. Pave. | 2-3 | 3 |
| Struct. 3" thick or less | 2 ½- 3 ½ | 3 ½ |

Correction for moisture in the agg. The aggs. nearly always have some amount of free moisture (moisture that is not absorbed by the agg. particles). The fine aggs. such as natural sands most often contain 2 to 6% of free moisture by weight. This free moisture must be considered as a part of the mixing water and, therefore, subtracted from the specified amount to be used in the mixture. In no event shall the free moisture content of the fine agg., at the time of batching, exceed 8% of its saturated, surface dry weight.

MEASURING THE MATERIALS

If a sacked cement is used, only full sacks should be used. When just part of a sack is needed for the batch, the partial bag should be weighed instead of using volume measurement.

When cement is delivered in bags for use in any item, the batch shall be so proportioned as to use only full bag batches (i.e. the use of a fraction of a bag of cement will be prohibited).

The bulk cement is always weighed for each batch.

A volume measurement of agg. cannot be depended upon since a small amount of moisture, which is always present in sand, causes it to fluff up, bulk. This bulking depends on the amount of moisture and the grading of agg. The finer sands bulk more than the coarser sands. The more water the greater the amount of bulking. For this reason, the weight measure of the agg. is an accepted practice.

Different sized aggs. are weighed separately. The weight batchers are placed under the storage bins; a single batcher for each size of agg. or multiple batchers that can weight several size aggs. at the same time cumulatively. In a single batch bin arrangement the batch truck moves from bin to bin; in a multiple batcher all the compartments of the truck are filled from the same bin having separate compartments for different agg. The batcher can be equipped with springless dials to indicate not only the weight but also the amount of discharge and any irregularities in flow.

N.Y.S. requires all concrete batching to be done from a completely automated plant, with recordation of all steps in the process. In addition, admixes must be batched from a system that is tied into the automation as specified.

501-3.02: Concrete Batching Plant Requirements

1. Each plant must be approved by the Deputy Chief Engineer, Technical Services Subdivision.

2. Bins must be adequate in number and separation for sizes of aggregate to produce the class of concrete desired. Cement bins must protect cement from moisture. Types 1 & 2 may be mixed, other types must be kept separate.

3. Separate weigh hoppers for aggs. & cement; cement weigher protected from moisture and release of excess dust. Discharge chutes not suspended from any part of the weigher and must

not lose or hold back materials.

4. Scales must be springless dial type, conform to National Bureau of Standards Handbook 44. Accuracy within 0.1 of full scale or one grad., whichever is less. Repeating dials must match master, or primary, within one grad. Vibrators must not affect scales. Plant scales tested by competent technician, annually prior to use, every 90 days, when plant is moved, or whenever ordered. 10 standard 50# wts. must be available.

5. Proportioning by automatic proportioning device. Automatic weighing, cycling and monitoring system: Must accurately proportion by weight or by volume for admixes and water in proper order, control cycle sequence, time mixing operations for central mix plants, within tolerance. Auxiliary interlock cutoff circuits will interrupt and stop batching when an error occurs. When aggs. are weighed cumulatively, tolerance applied to total agg. batch. When aggs. are weighed simply, tolerance applies to each individual weight. Tolerances are:

| | | |
|---|---|---|
| Cement | ± | 1% (by weight) |
| Aggs. | ± | 2% (by weight) |
| Water | ± | 1% (by weight or volume at C.M. plants only) |
| Adm. | ± | 3% or ± 1 oz., whichever is greater (by vol. or wt.) |

System must be capable of selecting and proportioning three classes of concrete in two batch sizes (at least) interlocked so that:

1. No inlet gate may open when discharge gate is open.

2. Discharge gate cannot be opened while inlet gate is open or until batch weight is reached.

3. New batch cannot be weighed until scale is entirely empty and scale has returned to zero.

6. Admixture dispensing: At least two systems required, each equipped with a bypass valve for obtaining a calibration sample. Each system must be interlocked with the automated system so that:

   1.A discharge gate cannot be opened until the preset quantity has been batched or discharged.

   2.Recordation of presence of admix shall be dependent upon completion of discharge.

Admixes must not come into contact with each other prior to mixing. They must be dispensed in a manner that will ensure uniform distribution (into the sane or water).

7. Recordation: There shall be a digital or graphical recording instrument. Recordation must show:

   1.Individual agg. identification and quantity.

   2.Cement identification and quantity.

   3.Water quantity (C.M. plants).

   4.Presence and type of admix.

   5.Time and date of batch.

   6.Mix identification.

   7.Batch number.

When dry batches are hauled by truck, the partitions, dividing the truck into the compartments, should be high enough and tight enough to prevent intermingling or loss of the materials, either during transit or during the operation of dumping the batch into the mixer.

Truck bodies or batch boxes (compartments) used to transport cement and concrete batches shall be equipped with waterproof tarpaulins for protection against rain and wind.

CONCRETE DESIGN

1. For each class of concrete, the cement factor, % sand of total aggs., water-cement ratio by weight, air content in per cent, slump range in inches, type of C.A. gradation, and primary use are specified. These criteria allow no margin for variations. It is only necessary to correct for the variation in sand fineness modulous from 2.80 by correcting the basic % sand by the actual F.M. minus 2.80 times 10 and calculating for a one c.y. batch.

DEPOSITING

In concrete pavement construction the forms and the subbase are sprinkled just before pouring to prevent absorption of mixing water by a dry subgrade and forms. Such a loss of water could cause rapid setting and shrinkage of concrete at the time when concrete does not have enough strength. Sprinkling should be done far enough ahead of the paver so that there are no puddles but a uniformly moist fine grade.

There shall be 500' minimum of forms laid and ready to receive concrete at all times. (Ahead of the paver).

Temperature of plastic concrete should be between 60 and 70 degrees when placed.

When metal longitudinal joints are used, they shall not be continuous through the transverse joints.

It is extremely important that a bond between the portion of the dowel on one side of the joint and the concrete be prevented or the joint will not close. By painting and oiling the dowels, 90% of the bond is eliminated.

Concrete is considered to be cured after 4 days, traffic can be allowed on it after 10 days.

Bridge slabs shall not be subjected to full loads before 28 days of curing.

In structural concrete forms shall be clean, tight and adequately braced. They shall be so designed that they will withstand a pressure resulting from a weight of 150 pounds per c.f. In addition to that, horizontal forms shall be able to withstand 50 lbs. of live load per square foot. Forms should be either lacquered or oiled with form oil to facilitate their removal. Forms for support surfaces such as arch centers, centering under beams, tops of culverts shall be kept for at least 8 days. Forms for bridge slabs shall be kept for 10 days. All other forms could be removed as soon as they are not necessary to support freshly poured concrete (provided this will not interfere with proper curing procedures). The inside of the forms shall be free of all debris. When concrete is poured in winter, it shall be enclosed and the air inside the enclosure kept at 50 to 70 degrees.

Reinforcing steel should be kept clean and free of loose rust or mill scale. Any coating of hardened concrete should be removed. Splices of the reinforcing shall not be less than 30 diameters of the reinforcing bars. Reinforcing steel shall have a temperature of at least 50 degrees when the concrete is placed around it.

Where new concrete is placed on top of the old concrete, the surface of the old concrete should be clean, durable, moist and with some agg. exposed to insure a good bond.

When bonding, the surface of the old concrete shall be scrubbed with wire broom and kept wet until the new concrete is placed. The old surface shall be thoroughly coated with a thin coating of 1:1 mortar or neat cement paste thoroughly brushed into the surface.

Segregation in depositing concrete is prevented by providing a vertical drop pipe at the end of the chute. Inclined depositing should be avoided since this method usually results in the agg. being thrown to the far side and the mortar deposited to the near side. The ease of handling and depositing concrete should not govern the consistency of concrete, the opposite should be the rule.

The chutes should be so designed that the concrete will travel fast enough to keep the chute clean, but not so fast that the materials will segregate. A chute that is not flatter than 1 on 3 and not steeper than 1 on 2 is usually acceptable.

Where steep slopes are required, the chutes shall be equipped with baffles or be in short lengths that reverse the direction of flow.

When concrete is handled in buckets, special care should be taken not to shake or jerk the bucket. Buckets are usually trunkated cones, the smaller diameter having a discharge gates. Where buckets are transported by cables, the discharge gate should be mechanically operated. Such a gate reduces chances of a sudden jerk on the cables.

On special jobs, concrete is sometimes pumped through a steel pipe. This has a particular advantage in tunnel construction. Equipment required: a heavy-duty, single acting, horizontal piston type pump; pipe, having outside diameter of 6" to 8" (preferably horizontally laid).

Concrete shall be deposited as nearly as it is practicable in its final position to reduce segretation due to rehandling or flowing. No concrete that has partially set or has been contaminated by foreign material shall be deposited on the work.

On some work, such as sloping wingwalls, the concrete should not be deposited in the tallest section of the form and then forced out to the end. The correct procedure is to remove the top form boards of the sloping face thus providing several access points for depositing the concrete. The concrete should not be allowed to drop more than 3 or 4 feet. Where necessary, as in a case of a wingwall, vertical chutes shall be provided. Concrete should be deposited in 6" to 12" layers for reinforced members and up to 18" for mass concrete. The thickness depends on the width between the forms, the amount of reinforcing and the requirement that each layer be placed before the previous one stiffens. Once a layer is started, it should be continuous throughout the entire length of the forms. "When less than a complete layer is placed in one operation, it should be terminated in a vertical bulkhead."

All layers shall be thoroughly compacted before the next one is started. When, for any reason, placing of concrete is temporarily discontinued, the concrete, after becoming firm enough to retain its form, shall be cleaned of laitance and other objectionable material to a sufficient depth to expose sound concrete so that when placing operation is resumed, the new concrete will have a good bond with the old concrete.

Construction joints shall be placed only where shown on the plans.
In high walls, concrete should be placed to a point about a foot below the top and allowed to settle. Pouring should be resumed with a stiffer concrete and before the set occurs. The form should then be overfilled by several inches and the excess concrete cut off after it stiffens. This will insure sound, free of "water gain" concrete in the most critical portion of the structure - the top.

To avoid cracking, due to settlement, concrete in columns and walls should be allowed to stand for at least two hours before concrete is placed in the slabs, beams or girders they are to support.

The placing of concrete should always start at critical point such as corners, the perimeter of large areas or the ends of the wall and proceed toward the center.

If, for any reason, different types of concrete are used on the same job, care should be taken that these different types are not intermingled within the same panel, section or wall. For the lack of better example, let us take the use of High Early strength and normal cement. In a hypothetical case, a busy intersection might have to be poured and opened to traffic as soon as possible. Naturally, High Early strength concrete is used on the panels of the intersection. Let us further assume that after pouring the intersection, there is a surplus of H.E.S. concrete . For the sake of economy, the inclination is to use this concrete in the panels designed for normal cement. But, since the H.E.S. concrete has a much faster hydration rate, this will result in an objectionable seam, a joint between H.E.S. and normal concrete.

## PLACING CONCRETE UNDER WATER

Whenever possible, concrete should be deposited in the air instead of under water. If this is impossible, a tremie is used. (A tremie is a steel pipe of not less than 10" diameter and long enough to reach from a working platform above water to the lowest point to be concreted). The tremie should have a valve at its depositing end. At the start of the operation, the tremie is filled with concrete as it is lowered into position, then, the foot valve is opened. Once concreting is started, the lower end of the tremie is kept submerged in the fresh concrete to maintain a seal and force the concrete to flow into position by pressure. Placing should be continuous with as little disturbance to the previously placed concrete as possible. The top surface should be kept level.

The under water concrete could be placed by means of a bottom dump bucket. The bucket should have a capacity of not less than ½ c.y.

"The bucket shall be lowered gradually and carefully until it rests upon the concrete already placed. It shall then be raised very slowly during the discharge travel, the intent being to maintain, as nearly as possible, still water at the point of discharge and to avoid agitating the mixtures."

The mixture of under water concrete should be richer than that for placing in the air. The percentage of fines should be higher than for normal concrete, often as much as 45% to 50% of the total aggregate. Coarse agg. should be more than 1 ½ to 2" in size.

## CONSOLIDATING

Consolidating should be done by either spading or puddling.  The spade or puddling sticks should be slender enough to pass between the reinforcing steel and long enough to reach the bottom of the pour.

If consolidation is done with mechanical vibrators, stiffer and harsher mixes can be used.  This results in a better quality concrete.  Vibration of itself does not make concrete stronger, more watertight or more resistant to deteriorating forces.  Far from being a panacea (cure-all), vibration in certain cases can harm the concrete as in a case where concrete, designed for manual consolidation, is mechanically vibrated.  This, almost invariably, results in segregation and water gain at the top.  Sufficient vibration is indicated by the formation of mortar along the forms and the submersion of coarse aggregates.

When mechanical vibrators are used, they should be inserted vertically at about 18" intervals and the vibrated areas overlapping by few inches.

## FINISHING

In structural concrete, all bulges and projections are removed by chipping and tooling and the surface is then rubbed and ground.  The honeycombed and other defective areas must be chipped out to solid concrete.  The edges of such an area are slightly undercut to provide a key at the perimeter of the patch.  Bolt holes should be patched with fairly stiff mortar by ramming it into the holes.

All metal ties and anchorages will be removed to a depth of at least 2" from the face surface.  Where wire ties are permitted, the wire shall be cut at least 1/4" into the concrete.

Screeding is the process of striking of the excess material to bring the top surface to final elevation and grade.  This is a process that is most commonly used in concrete pavement construction.  It is done by a screeding machine that follows the paver.  The template is moved back and forth with sawing motion and advances forward a short distance with each movement.  The screed should always have surplus material against its front face.  This excess concrete will then be forced into low areas as the template passes over.  A tendency for the template to tear the surface is reduced by moving the template forward a shorter distance on each sawing motion.

Floating (also a function of constructing concrete pavement or bridge decks) is done right after screeding.  In this process, the surface is brought to true grade, any high spots are cut down and sufficient mortar is brought to the surface to produce the desired finish.

Troweling should be done after the concrete has hardened enough so that fine materials are not brought to the surface. The tendency is to trowel too soon or to absorb excess water by sprinkling dry cement and then troweling. Both of these practices should be prohibited.

All above mentioned finishing operations should never be started in an area where bleed water is standing. It must be removed or the operation postponed until it evaporates. Water should never be sprinkled on a slab as an aid to finishing.

The surfaces of bridge seats or other bearing surfaces shall be floated and troweled to true grade, or at the option of the engineer, left approximately ½ inch high and then bush hammered or otherwise finished to the exact elevation shown on the plans.

Scoring - A concrete pavement having a very steep grade is sometimes broomed transversely to the direction of the main traffic to produce a scored surface and improve traction during the winter months. Normally, concrete pavement is given a scored surface by longitudinal dragging of moist but not dripping burlap. (In structural concrete) the popularity of rubbed finishes is waning. The same smooth eye pleasing finish can be achieved with form linings. However, where rubbing is required, the first rubbing shall be done with coarse carborandum stones as soon as the concrete is hard enough so that the agg. is not pulled out by the operation.

JOINTS

Where construction joints are made, care should be given to remove all laitance and unsound material from the old concrete. If the concrete to be bonded is a totally cured hardened concrete, a bonding layer of mortar may have to be provided.

When a construction joint is necessitated because it was impossible to complete a structure in one operation, the construction joint should be either vertical or horizontal. The forms for the next pour are secured tightly against the hardened concrete by providing a row of tie rods at least 4" below the construction joint. Where tie rods are not permitted, bolts threaded at both ends, with a nut at the inner end, may be embedded in concrete. When the bolt is removed, the nut remains embedded in the concrete.

Vertical joints are formed by a bulkhead in the forms. Sometimes, keyways are provided to keep the adjoining sections in alignment. Enough horizontal reinforcing steel should pass through the joint.

On water impounding structures, such as tanks, waterstops of copper or galvanized iron strips are used on horizontal joints. The strip is placed in the form so that one half of it extends into the concrete and the other half is left exposed to be imbedded in the next pour.

Expansion and contraction joints - Concrete expands slightly when the temperature rises and contracts when the temperature falls. Also, it will shrink upon drying and expand upon subsequent wetting. The termal expansion is assumed to be 0.0000055 in/per 1 degree F., or 0.66 in. per 100' per 100 degrees F. The shrinkage from saturation to a completely dry state is the same as effect by a change of 100 degrees in temperature. In practice, this is somewhat less since concrete never completely dries out.

Expansion and contraction joints may be built-in strips of metal, bitumen treated felt or other material and dowels or keyways. In some cases, open joints between sections are provided and in other cases, an opening is made which is later filled with an elastic material. Where dowels are used, they should be properly aligned. Particular attention must be given to the sliding part so that it will be free to move and will not become wedged.

## COMPUTATIONS FOR ABSOLUTE VOLUME AND YIELD

The mix of cement and aggregate is always given in the following sequence: cement, sand and coarse aggregate.

When a mix is said to be 1:2:4, it means that it contains 1 bag or 1 cubic foot of cement, 2 c. f. of sand and 4 c. f. of coarse aggregate as measured by volume and as taken directly from the stockpile. Let us assume that a certain batch has 3 c.f. (282 lbs.) of cement. To maintain the proportioning of 1:2:4, 6 c.f. of sand and 12 c.f. of coarse aggregate is added.

The need for computing the yield arises from the fact that the drum of the mixer can only hold a certain volume. Let us assume that a drum is of 34 c.f. capacity. With this given capacity of the drum, it has to be known how much cement, sand, agg. and water is to be used to produce 34 c.f. of plastic concrete. Adding the proportion of the mix will not give the volume of concrete produced since this is the loose volume having many voids.

The fact that a c.f. (or any other volume) of coarse agg. has many empty spaces can be proven by just a visual inspection. Although not as easily proven, the fact also holds true for fine agg. as well as cement (no matter how small they are, the particles do not form a solid mass). On the average, coarse agg. has 45% of voids by volume, sand - 35% cement - 50%. If these three ingredients are mixed, “shaken together” (as in fact they are during the process of mixing) sand will “seep” into the voids of coarse agg. while cement, in turn, will “seep” into the voids of fine agg. and remaining minute voids will be taken up by water. This will result in a solid mass of plastic concrete. From the above, it could be seen that if the solid masses (absolute volumes) of all the ingredients are added, the resultant sum will represent the absolute volume of plastic concrete.

To find the absolute volume of 1 c.f. of any material the weight of 1 c.f. of material with voids is divided by the weight of 1 c.f. of the same material without voids. To find the weight of 1 c.f. of material without voids its S.G. is multiplied by the weight of 1 c.f. of water or 62.4 lbs.

Let's assume that a c.f. of loose sand weighs 110 lbs. and the specific gravity of this sand is 2.65. Then the absolute volume of 1 c.f. of loose sand is: $\frac{110}{62.4 \times 2.65} = \frac{110}{165.36} = .665$ c.f.

COMPUTATIONS FOR YIELD

GIVEN:

1 sack of cement = 1 c.f. and weighs 94 lbs.

Water cement ratio = 6 gallons per sack

Specific gravity of cement = 3.0

Specific gravity of sand = 2.6

Specific gravity of stone = 2.7

1 c.f. of sand weighs = 110 lbs.

1 c.f. of crushed stone weighs = 100 lbs.

Sand is stocked with 3% moisture

Mix is to be of 1:2:4 proportion

Again, cement, sand and stone is measured by loose volume as taken from stockpiles.

Absolute volume of 1 c.f. of cement: The absolute volume of 2 c.f. of sand:

$\frac{94}{3 \times 62.5} = 0.5$ c.f.

$\frac{110 \times 2}{2.6 \times 62.5} = 1.354$ c.f.

Abs. Vol. of 4 c.f. of stone:

$\frac{100 \times 4}{2.7 \times 62.5} = 2.132$ c.f.

Abs. Vol. of water:

7 ½ gal. in 1 c.f. Therefore,
6 gal. would be 6/7.5 = 0.8 c.f.

And concrete produced per 1 sack of cement used:

0.5 + 1.354 + 2.132 + 0.8 = 4.786 c.f.

And 1 barrel of cement will yield

$\frac{27.00}{4.7886}$ = f (Bags/c.y.) = 5.64 bags/c.y.

5.64 x 4 = 1.41 Bbls/c.y.

4.786 x 4 = 19.144 c.f. or 19.144/27 = 0.709 c.y.

The cement factor or barrels per 1 cubic yard is:

1/0.709 = 1.41 bbls./c.y.

To determine the weights of material to be used in a batch per sack of cement:

Cement 1 sack - 94 lbs. Sand 110 x 2 = 220 lbs.
Stone 4 x 100 - 400

In the case where water is present in the agg., this amount will have to be subtracted from the water to be added.

Sand has 3% of water

220 x 3 = 6.6 lbs. One gallon of water weighs 8.33 lbs.

6.6/8.33 = 08 gal.

Gallons to be added into the mixer:

6 - 0.8 = 5.2 gal.

If air entrainment is used, a certain percent of air will be present in the plastic concrete. This percentage will have to be added to the absolute volume of concrete produced.

A mix used on an average job is 1:2:3 with 6 ½ gallons of water for each 94 lbs. of cement. Mix made of these proportions should produce a concrete with an ultimate compressive stress of 3000 psi at the end of 28 days curing.

The most common proportioning for the concrete pavements is 1 : 1 3/4 : 3 ½

Dummy joints are used to control cracking. That is: to make the plain (unreinforced) concrete crack in predetermined places where cracks will do the least amount of damage. When uncontrolled, cracks could appear in a zig-zag pattern forming a small corner or piece of concrete that is separated from the rest of the panel by the formation of such cracks. (Sidewalks, driveways, etc.) Dummy joints must be 1/4 to 1/3 the thickness of the member.

## CURING AND PROTECTION

Fresh concrete has more than enough water for complete hydration of the cement but if precautionary measures are not taken (under most job conditions) most of this water will be lost before the concrete is cured.

One way of curing is to retain the forms even though the concrete has set and they (forms) are not necessary for support. Wooden forms tend to dry out and extract water out of the concrete. To prevent this, specs. prescribe sprinkling of the forms when outside temp. is 70 degrees or higher.

If forms are removed before a proper curing time has elapsed, the exposed surface of the concrete is protected by curing blankets or curing membrane for at least a period of 7 days. This is the type of curing that is used in concrete pavement construction. The membrane should be applied immediately after the concrete has been finished or else it will have to be kept moist by other means until such time when the membrane can be applied.

Sometimes, curing is effected by ponding. A small peripheral dam of earth or other water-retaining material is built, and the enclosed area flooded. Ponding gives a more constant condition than sprinkling.

Temperatures - In hot weather, precautions should be taken to avoid high temperatures in the fresh concrete. In cold weather, it is often necessary to heat the materials and to cover the fresh concrete to provide a heated enclosure.

The air surrounding the fresh concrete shall be kept at the temperature above 50 degrees F., but not over 80 degrees F for a period of 7 days after the concrete is placed. At the end of this 7 day period, the heat shall be gradually reduced, no faster than 1 degree per hour until it equals the surrounding temperature.

The most beneficial temperature for curing depends on the type of structure. That is: on the heat that the hydration of concrete is produced. In large masses of concrete (where hydration itself provides enough heat) such as dams the concrete at the time of placing should be at not less than 40 degrees F. Ordinary reinforced concrete should have a temperature of 70 degrees at the time of placing. Higher temperatures of the concrete being placed result in lower strength. All reinforcing steel and the old concrete against which new concrete is placed should have a temperature of 50 degrees.

In relatively mild weather, with temperatures ranging from 40 to 45 degrees and only short periods below that, only the mix water need be heated. Water is the most convenient of the materials to be heated. A certain amount of heat will raise the temperature of 1 lb. of water by 1 degree F., while the same amount of heat will effect a 1 degree raise in temperature in only .22 lbs. of solid material. To estimate the temperature of fresh concrete, the following formula is used:

$$X = \frac{Wt. + .22\, W't'}{W + .22W'}$$

'W' - weight of solids (cement and aggs)
W - weight of water
t - temperature of water
't' - temperature of solids
X - temperature of mixed concrete

For example, assume a mix with 94 lb. of cement, 210 lb. of sand, 320 lb. of crushed stone, 50 lb. (6 gal) total water, 10 lb. of which is introduced with the sand; temperature of solid materials 45 degrees and of water, 170 degrees.

$$X - \frac{(40 \times 170) + (10 \times 45) + .22\,(94 + 210 + 320)\, 45}{50 + (.22 \times 624)} = 72 \text{ degrees}$$

Aggregates must be heated if they are below 45 degrees F. "When either mixing water or aggregates are heated in excess of 100 degrees F., the aggregates and mixing water shall be premixed in the mixer drum until the heat of these components has been balanced and is below 100 degrees F.; before the cement and the admixtures shall be added to the mix.

## INSPECTION FACILITIES

1. Each concrete plant shall have a building or room available for use as office & lab. equipment required.

1. Power driven C.A. shaker, min. sieve area of 324 in. $^2$, automatic timer, dust cover.
2. Power driven F.A. shaker, independent of C.A. shaker, for 8" min. diameter sieves, with automatic timer.
3. Adjustable agg. sample splitter from ½ to 2".
4. Scale, 50# min. cap., max. 0.02# grads.
5. Scale, 1000 gm. cap., max. 0.5 gm. grads.
6. Stove or hotplate.
7. 2 drawer, locking file cabinet.
8. Necessary test equipment, including sieves.

Building to be ventilated, lighted & heated & cooled. Temp. 70 degrees ± 5 degrees. Tables, benches, shelves, running water. Telephone and toilet available.