CHAPTER 7
ENGINEERED GRANULAR MIXES
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7.1 OVERVIEW

Engineered granular mixes have been developed by the NYSDOT for specific engineering applications. Gradation affects many properties of an aggregate such as density, physical stability and permeability. Therefore, the grain size distribution of a material can be important in understanding its physical properties. Gradation describes the distribution of the different size groups within a soil sample. A soil may be well- or poorly-graded. Each of these materials may be desirable in different engineering applications.

- **Well-Graded**: soils containing a good range of all representative particle sizes between the largest and the smallest. All sizes must be represented, and no one size should be either overabundant or missing.
- **Poorly-Graded**: soils which either contain a narrow range of particle sizes or have some intermediate sizes lacking.
  - Uniformly-Graded: soils with a limited range of particle sizes.
  - Gap-Graded, Step-Graded, or Skip-Graded: soils that have some intermediate size or sizes not well represented or missing.

In addition to grain size distribution, plasticity has a significant effect on the engineering properties of a material. The plasticity index (PI) is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (see NYSDOT GDM Chapter 6). As the PI of an inorganic soil increases, so does the amount of clay. As the PI lessens towards zero, the amount of clay and silt are likewise diminished to insignificant amounts.

This chapter addresses the principles and methods used in developing designs for the following applications:
- Subbase Course
- Select Granular Subgrade
- Underdrain Filter Material
- Select Granular and Select Structural Fill
- Stone Fill and Rip Rap

In addition to developing designs of specific requirements for natural material that apply to the above engineering applications, the NYSDOT has also investigated and designed specific requirements for allowable substitutions of recycled materials.

This chapter also addresses the NYSDOT Quality Assurance testing program instituted to ensure the receipt and use of quality granular materials on Departmental projects.
7.1.1 Recycled Material

The policy for the use of recycled materials in engineered granular mixes is set by the Geotechnical Engineering Bureau. It is an important topic, both politically and economically. The NYSDOT strives to meet the demand to use recycled materials, but has to temper that effort with consideration of performance and operational concerns.

The basic categories of recycled materials are:

1. Products containing recycled materials (i.e. snow plow blades made of recycled rubber, noise barriers consisting of recycled plastic, etc.)

2. Construction materials consisting wholly or in part of recycled materials. This category may be broken down further into two sub-categories:
   a. Recycled materials generated from past work performed in accordance with NYSDOT specifications, and incorporated into new NYSDOT work. Examples include reclaimed asphalt pavement (RAP) from asphalt millings, and aggregate made from crushed concrete pavement, known as recycled Portland cement concrete aggregate (RCA).
   b. Recycled materials generated outside NYSDOT, but proposed for incorporation into work done by or managed by NYSDOT. Examples include dredge spoils, fly ash, crushed glass, municipal solid waste (MSW) combustor ash, and shredded or chipped tires.

The public, responding to reports of the devastation of the rain forest, the growing hole in the ozone layer, and other assaults on the environment, is more educated and environmentally conscious than ever. On a local level, people fight (and win) battles to close existing landfills and prevent new ones from being opened. On a national level, more stringent solid waste regulations are forcing the closing of existing landfills. Political leadership at the national and state levels are very much aware of these issues and are increasingly bringing pressures to bear on any organization or group that has any possibility of incinerating, burying, or inappropriately disposing these materials.

The NYSDOT has a policy in place that permits the evaluation and use of these waste materials in a controlled manner. The use must not compromise the basic function and longevity of the infrastructure, and be able to be implemented without incurring additional costs or hardship on the taxpayers. It is important to realize that although the NYSDOT uses millions of tons of material in its projects annually, it is not feasible to totally replace natural materials with recycled materials.

To be considered suitable for highway use, a waste material must exhibit the proper engineering characteristics, consistently satisfy specification requirements, provide an acceptable level of performance, be available in sufficient quantity to make the effort worthwhile, and be economically competitive with available construction materials without harming the environment.
• The NYSDOT is open to the evaluation of waste material for use on NYSDOT projects. The Department will approach each evaluation objectively, and will perform the evaluation in accordance with the objectives and intent stated in the Policy statement.

• Waste or recycled materials used by the NYSDOT should be “sound” engineering materials and, when used alone or in conjunction with other materials, should provide durable, predictable performance results. These materials must satisfy specification requirements, exhibit proper engineering characteristics, provide an acceptable level of performance, and be economically competitive with naturally occurring construction materials.

• The continued successful use of any recycled material must be profit-driven. It will not be the NYSDOT’s general policy to fund the utilization of recycled materials, except in the special case of a pilot or demonstration project.

• The proper evaluation and eventual acceptance of the use of any material is a gradual process. Eventual and continued acceptance will be based on evaluation of long-term performance of the facility in which the material is used.

• Proposed and actual use of waste or recycled materials must meet FHWA, EPA and NYSDEC regulations. For some materials, this means getting a Beneficial Use Determination (BUD) from the DEC.

• The use of recycled materials should be “environmentally clean”, and may not pose an additional hazard to the taxpayers. It is possible that such use may potentially pose a hazard or danger to workers and/or equipment during construction. The eventual approval of each specific use will depend on the successful implementation of safety procedures that minimize additional hazards to health, safety, and equipment.

• Evaluation and acceptance of each use of recycled materials will be based on existing quality and performance standards. However, evaluation techniques may and should be adjusted on a case-by-case basis when appropriate. Current standards are written for natural materials that are appropriate for a wide range of applications. In order to properly and fairly evaluate recycled materials, a change in thinking is necessary. Occasionally, a recycled material will perform in a similar or even superior manner to its naturally occurring counterpart, but in a more limited number of applications.

• Life cycle costs should be equivalent or less than those from the use of standard construction materials. Cost analyses should take into account first instance costs, maintenance costs, expected service life, and quantifiable performance characteristics.

• It is not acceptable to blend in even minor amounts of unsound or deleterious materials in products, pavements, or structures when such practice may adversely affect performance or lower current quality standards.
• Suitable quality control/quality assurance (QC/QA) procedures should be included in all specifications using recycled materials.

7.2 SUBBASE COURSE

Subbase Course is the layer of aggregate material of the pavement structure placed on the subgrade. Subbase is often the main load-bearing layer of the pavement structure. Its role is to spread the load evenly over the subgrade. This material is typically unbound granular material and is very important for the useful life of the road.

• Unbound – an unbound granular material does not need additional admixtures for proper performance as a base course. The materials functionality is a result of its quality, designed gradation, thickness, and method of placement.

• Bound – a bound granular material utilizes a binding agent to address deficiencies in the native granular material in order to properly perform as a base course. Common binding agents include asphalt emulsion or Portland cement.

The subbase layer is typically 12 in. thick. The subbase course is used to provide support for PCC slabs and as a structural component for HMA pavements. The ideal subbase is strong, uniform, stable, frost-resistant, and free-draining. Strength is derived from the gradation of the material and its placement. Uniformity is provided by stockpiling subbase material (i.e. stockpiled material is obtained from the same source and the stockpile testing requirements are intended to ensure that the performance of the product in its final position is consistent, predictable, and meets expectations over the lifetime of the installation).

The free-draining characteristic depends on the percentage of fine particles (fines). Unfortunately, a granular material derives more of its strength by packing the voids with fines. Because of the allowance of up to 10% fines and the concerted compaction effort, the subbase is considered a low-permeable layer, not free draining.

Gradation of subbase material, particularly of the component passing the No. 200 sieve, is a compromise of competing needs, complicated by the availability of material statewide. Material designed to be free draining (i.e. open-graded) have lesser amounts of material passing the No. 200 sieve. However, such material can develop unstable areas and can rut during paving operations. Also, such material is not available in some areas of the state, leading to increased costs due to transport or additional processing. Subbase stability benefits from some material passing the No. 200 sieve, but too much leads to frost problems. NYSDOT’s requirement of a maximum of 10% passing the No. 200 sieve, as stated in the Standard Specifications, represents a reasonable compromise that provides good stability, adequate frost resistance and sufficient drainage. Materials meeting this requirement are readily available statewide.
7.2.1 Design Development

The gradations of subbase course types have been designed to be:

• Readily compactable in unconfined layer (i.e. well-graded, stable, etc.),
• Non-frost-susceptible, and
• Pump-resistant under Portland cement concrete pavement.

The NYSDOT Standard Specification was developed to accept any kind of material that will meet all of the above requirements, eliminate various special specifications, and provide the Contractor options regarding the kind of material, gradation band, and placement as one or two courses.

7.2.1.1 Stability

A stable base is one which is trafficable under the loads of heavy construction equipment and readily compactable with modest efforts.

Advantages of having adequate stability:

• Subbase course better able to support construction equipment because it can physically act as a layer to a greater degree.
• More easily compacted and trimmed to grade.
• Higher subgrade resilient modulus, \( M_r \), in service under pavements (see NYSDOT GDM Section 7.3.1.1 Pavement Design Development).
• Because of a better granular-interlocked structure within the layer which can better resist displacement under traffic loads when saturated. Fines cannot go into suspension and move, causing differential loss of support for pavement.
• Based on previous statement, normal frost heaving will have little residual effect.

7.2.1.2 Durability

7.2.1.2.1 Frost Susceptibility

Repeated freeze-thaw cycles can weaken and, over time, break-down the pavement structure if attention is not paid to the construction materials. “Spring break-up” is the direct result of detrimental frost action in the subgrade soil immediately underlying the pavement of a highway. Frost action may be divided into two phases: freezing of the soil water, and thawing of the soil water. Practically all surface soils of New York State undergo some frost action, the magnitude of which is dependent upon the locally prevailing climate and rainfall.

From a highway engineering standpoint, frost action becomes detrimental when either or both of the following effects result:

1. The freezing phase is accompanied by a noticeable heaving of the road surface, or
2. The thawing phase is accompanied by a noticeable softening of the road surface.
In the freezing phase, there are three conditions (all of which must exist) before “frost heaving” can occur:

1. A sufficiently cold climate to allow freezing temperature to penetrate below the road surface into the base and subgrade.
2. A supply of water into the freezing zone.
3. A material which is frost-susceptible and lying within the freezing zone.

In the thawing phase, “loss of support” occurs when the bearing capacity of some layer beneath the road surface, upon thawing, is so reduced below its normal summer value that it no longer able to properly support the overlying layers, and, consequently, displaces when a wheel load is applied to the road surface.

If any one of these conditions is completely eliminated, there will be no noticeable heave.

New York State is subjected to a cold climate, which obviously cannot be altered. Therefore, Condition #1 cannot be eliminated.

Condition #2 can be reduced by adequate and proper drainage in the form of ditches, culverts, and underdrains. Since all bases and subgrades normally contain some moisture or water in their voids, and because this water cannot be entirely eliminated by adequate drainage facilities, particularly when such facilities are frozen and blocked with snow and ice, Condition #2 can never be entirely eliminated in our relatively humid climate. However, it is not the normal soil water which causes the spectacular and noticeable frost heaves on our highway, because water only expands 9% in volume when freezing and this water comprises only a low percentage of the soil mass. Since the normal volume of water is small, a 9% increase in such volume cannot account for the tremendous increase in volume caused by the formation of large lenses of ice in the freezing zone and as evidenced by a very noticeable heaving of the surface. Water must be supplied, usually from below and the sides, to enable these ice lenses to form. The supply of much of this water can be cut off from the freezing zone by adequate highway drainage. The importance of adequate and proper drainage facilities in reducing or minimizing frost heave cannot be overemphasized.

Condition #3 mentions frost-susceptible soil within the zone of freezing. A frost-susceptible soil is one that:

a. Because of the size of its particles, or gradation, i.e. the coarseness or fineness of its structure, permits and encourages the flow of water through it by capillary action, and consequently, supplies the water necessary to promote the formation of ice lenses in the freezing zone, and/or

b. Because of its structural characteristics, loses a large percentage of its summer bearing capacity when the water within the soil thaws after being frozen during the winter. Actually, it is possible for some New York State soils to thus suffer a considerable reduction in summer bearing capacity, without the addition of any water, as a consequence of shifting from the freezing phase to their normal moisture content.
Soils may be divided into two groups: non-frost-susceptible and frost-susceptible.

- The only soils that can be considered non-frost-susceptible are very clean mixtures of open graded crushed stone. These materials drain readily by gravity to low moisture contents and, even when saturated, the freezing of the water in the voids only causes negligible expansion, and this expansion only causes a negligible decrease in bearing capacity and internal stability when the pore water thaws.

- The remainder of the soils of New York State are frost-susceptible to varying degrees, depending upon many factors. Frost-susceptible soils may range from those only moderately frost-susceptible, such as some glacial tills and dirty sands and gravels, to those highly frost-susceptible, such as fine sands, silts and rock flour. It is obvious that practically all of New York State has frost-susceptible soils.

If frost-susceptible soil within the freezing zone were removed and replaced with a non-frost-susceptible, clean sand and gravel to the full depth of frost penetration, no heave would occur, regardless of the degree of drainage. This would be one method of preventing frost heave. However, since frost penetration ranges to a depth of 5 ft. in some areas of the State, replacing frost-susceptible soils can be very expensive. See NYSDOT GDM Section 7.3 Select Granular Subgrade.

Not all frost heave is detrimental to a highway pavement. If the pavement is raised uniformly, over considerable distances by frost action, no bumps or rolls are evident and the riding qualities of the pavement are not affected. In fact, the heave is apparent to no one unless levels are taken in the summer and winter. Heaving, if uniform, is not generally destructive to the pavement, nor does it present a hazard to traffic. Heave is only destructive and troublesome when it is differential or sharply varying, during the freezing or frozen phase.

Differential or local heaving is most apparent and occurs at locations such as:

a. At transitions from cut to fill.
b. In earth cuts where the ditches are inadequate or non-existent.
c. In cuts through laminated, broken and folded rock formations.
d. Over culvert pipes.
e. Adjacent to driveways damming highway ditches, because the driveway culvert is blocked or non-existent.
f. Wherever there is an abrupt and drastic change in subgrade material, subbase thickness, and drainage conditions.

To address these potential problem areas, the NYSDOT utilizes acceptable and proven standard design and construction methods.
7.2.1.2.2 Strength

In turning the focus from frost heave to loss of support, there are two conditions or requirements, both of which are necessary for loss of support to occur:

1. The thawing zone located within the depth of frost penetration of a frost-susceptible material. Melt water cannot drain due to the still frozen bottom layers and the soil becomes saturated and loses most of its bearing capacity (or supporting strength) such that it cannot satisfactorily support the stress of a wheel load applied to the road surface.
2. Detrimental traffic loads.

If either of these conditions is eliminated, loss of support will not occur.

Condition #1 can be addressed by designing and constructing any highway such that the surface will satisfactorily support, during the spring thaw, the probable traffic distribution, a certain percentage of which may impose maximum legal wheel loads.

Pavements, bases and subgrades of the roads in New York State must be designed and constructed for the most critical time of the year, the spring thaw. If a road serves satisfactorily during the spring thaw each year, it will be more than adequate the rest of the year. Any method of pavement and base thickness design or determination that does not take into account frost action is not adaptable to New York State roads.

In general,

I. For highways on frost-susceptible soils, which includes virtually all of New York State, no pavement section; i.e. wearing course, base and subbase, should be less than 15 in. thick. This minimum thickness should only be used under optimum soil conditions, and where the anticipated traffic is very light and where no heavy truck traffic is anticipated (less than 2 million 18,000 lb. equivalent single axial load (ESAL’s) over the design life). As the soil conditions become less favorable, and as the anticipated wheel loads and traffic-density increase, heavier pavement thicknesses, approaching 24 in. will be required. Highly frost-susceptible soils may require a pavement thickness as much as 36 in.

II. After subtracting the thickness of the wearing course, no pavement section should have less than 12 in. of clean non-frost-susceptible granular material. The remainder of the section below this may be composed of moderately frost-susceptible granular material.

III. The drainage facilities of any highway should be adequate. Generally speaking, the grade line should not be less than 48 in. above the bottom of the adjacent ditches, if feasible. If 48 in. is not feasible, 24 in. should be the minimum.

IV. The design and construction of any highway should include those features necessary to eliminate abrupt changes in subgrade material and drainage conditions in order to minimize local frost heaves, bumps, and rolls.
In regard to the above suggestions, the specifications for the non-frost-susceptible material should require a natural or processed clean sound sand and gravel, having from 30% – 65% passing the ¼ in. sieve and absolutely not more than 10% passing the No. 200 sieve. The upper portion of the non-frost-susceptible material layer may consist of broken stone, but the bottom portion should be a well-graded material to prevent migration of the fines from the subbase or subgrade into the broken stone.

The specifications for the moderately frost-susceptible granular material should require that not more than 70% pass the No. 40 sieve and not more than 15% pass the No. 200 sieve.

Condition #2, detrimental traffic loads, can be addressed by limiting the wheel loads allowed on any road, during the spring thaw, to that value which experience has shown to be the maximum the road will satisfactorily support. This may be an option on Local roads where moneys available in the town budget, for highway purposes, are insufficient to provide for the construction of highways having the pavement thickness and drainage facilities necessary to minimize spring break-up under unrestricted, but legal, wheel loads. Counties may resort to posting certain vulnerable roads, in order to prevent their destruction during the spring thaw. As with any other law, the effectiveness of the various sections of the Vehicle and Traffic Law is only as good as enforcement and the cooperation of the public. Posting certain roads, and thereby excluding from these roads vehicles imposing wheel loads that would be detrimental to them during the spring thaw, has been successful in certain areas.

### 7.2.1.3 Resistance to Pumping

Pumping under Portland cement concrete pavement with intact joints should not occur with any acceptable gradation under the specifications because the stability requirements are more severe than the requirements to avoid pumping.

### 7.2.2 Material Requirements

The NYSDOT Standard Specifications provide the material requirements for subbase course. The old, and still commonly used, term “Item 4” was discontinued in 1973. There are four different subbase types based on materials, processing, and/or placement location. For Types 1, 3 and 4, the materials consist of approved Blast Furnace Slag, Stone, Sand, and Gravel, or blends of these materials. For Type 2, the materials consist of approved Blast Furnace Slag or of Stone which is the product of crushing or blasting ledge rock, or a blend of Blast Furnace Slag and of Stone.
### Table 7-1 Subbase Gradation for Various Types

<table>
<thead>
<tr>
<th>Sieve Size Designation</th>
<th>Type 1</th>
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<tr>
<td>4 in.</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>3 in.</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2 in.</td>
<td>90-100</td>
<td>100</td>
<td>-</td>
<td>100</td>
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<td>¼ in.</td>
<td>30-65</td>
<td>25-60</td>
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<tr>
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#### 7.2.2.1 Blast Furnace Slag

Blast furnace slag is formed when iron ore or iron pellets, coke and a flux (either limestone or dolomite) are melted together in a blast furnace. ASTM C125 *Definition of Terms Relating to Concrete and Concrete Materials* defines blast furnace slag as “the non-metallic product consisting essentially of silicates and alumino silicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.” During the period of cooling and hardening from its molten state, different forms of slag products are produced such as air-cooled blast furnace slag (ACBFS), expanded or foamed slag, pelletized slag, and granulated blast furnace slag.

Both ACBFS and expanded blast furnace slag can be used as a conventional aggregate in embankment fill and subbase. This material requires minimal processing to satisfy conventional soil and aggregate engineering requirements. However, the history of the use of blast furnace slag in New York State includes only minimal implementation, solely in Region 5, and is now seldom used due to limited availability.

Blast furnace slag is considered an exempt hazardous waste under 6 NYCRR Part 371 - *Identification and Listing of Hazardous Wastes*, §371.1 (e) (2) (iv).

#### 7.2.2.2 Substitution Allowances

The following materials are an acceptable replacement for Types 1, 3 and 4. Only one alternate shall be selected for use per stockpile.

- **Alternate A**: Recycled Portland Cement Concrete Aggregate (RCA) where the material is at least 95%, by weight, of RCA and is free from organic and other deleterious material. This material may contain up to 5% by weight asphalt pavement and/or brick.
- **Alternate B**: Recycled Portland Cement Concrete Aggregate (RCA) where the material is a mixture of RCA with stone, sand, gravel or blast furnace slag. This material may contain up to 5% by weight asphalt pavement and/or brick.
Alternate C: Reclaimed Asphalt Pavement (RAP) having a maximum top size of 2 in. at the time of placement.
Alternate D: Blends of Blast Furnace Slag, Stone, Sand, and Gravel, with not more than 30% by weight of glass. Glass shall be crushed to a maximum particle size of ⅜ in.
Alternate E: Blend of Alternate A with not more than 5% by weight of Corian® having a maximum top size of 2 in.
Alternate F: Blend of Alternate B with not more than 5% by weight of Corian® having a maximum top size of 2 in.

7.2.2.2.1 Recycled Portland Cement Concrete Aggregate (RCA)

Crushed Portland cement concrete from highway reconstruction projects or construction demolition sites is trucked to an aggregate supplier equipped with crushers, and processed into recycled Portland cement concrete aggregate (RCA). After processing, the recycled material is very similar to granular material obtained from naturally occurring sources.

Since the early 1990’s, the growth in the use of RCA as subbase material indicates that it is an economical resource in its own right. Contractors pay Producers to accept Portland cement concrete debris, and later purchase RCA from Producers at a lower cost than for other granular materials.

In 1988 New York State passed the Solid Waste Management Act, regulating the use of RCA. This law could have considered the placement of this material to be construed as creating a landfill, subjecting its use to a permitting process with a lengthy checklist for control procedures. However, because this material had been successfully used since 1982, the NYSDEC considers RCA to be essentially free from contaminants. RCA (and RAP and glass in subbase) are considered to be pre-determined BUDs in regulation 6 NYCRR 360-1.15(b)(5) and (b)(11). Producers only need to obtain a license and can then file for a beneficial use exemption for the permitting process.

7.2.2.2.2 Reclaimed Asphalt Pavement (RAP)

The NYSDOT makes economical use of reclaimed asphalt pavement (RAP), the asphalt-cement concrete removed by milling machines during pavement rehabilitation. These millings, with the consistency and appearance of a stabilized granular material, are usually of sufficient quality and meet performance requirements.

This material can be used as an unbound subbase material, but is more common as an aggregate in Hot Mix Asphalt (HMA) or Cold Mix Asphalt (CMA). RAP has proven to be a valuable component to these mixes. RAP (and RCA and glass in subbase) are considered to be pre-determined BUDs in regulation 6 NYCRR 360-1.15(b)(5) and (b)(11).
7.2.2.2.3 Glass Aggregate

Glass aggregate and blends thereof are strong, safe, and economical. The main source of crushed glass utilized in the construction industry is via glass cullet. Glass cullet is comprised of the mixed colored glass fragments resulting from the breakage of colored glass containers, typically collected at Municipal Recovery Facilities (MRFs). Glass cullet, if properly sized and processed, can exhibit characteristics similar to that of gravel or sand.

In 1991, Executive Order #142 directed all State Agencies to make maximum use of recycled materials. In 1994, the NYSDOT issued an Engineering Bulletin (EB 94-039) allowing crushed glass to be recycled on construction projects as a substitute for natural aggregates as part of a blended product. Subbase material may be a blend of Blast Furnace Slag, Stone, Sand, and Gravel, with not more than 30% by weight of glass. In addition, glass may be incorporated into embankments if it is thoroughly mixed with other suitable material so that glass constitutes no more than 30% by volume anywhere in the embankment. Glass additions in subbase (and RCA and RAP) is considered to be pre-determined BUD in regulation 6 NYCRR 360-1.15(b)(5).

7.2.2.2.4 Corian®

Corian® sheet and shape production lines produce many colors throughout the day and week. Each time a line is started up, shut down, or transitions between colors a quantity of liquid mix (80 – 200 lbs.) is diverted from the casting machine to a container where it cures. When the new color has purged the old color from the filling hose the flow is returned to the casting machine. This material is collected in “purge drums” where it solidifies and is landfilled. The composition of the material is identical to Corian® sheets and shapes (tested for BUD No. 924-9-15).

- Shape drums: always solid, white or off white. These drums are loaded directly into a roll-off container and landfilled.

- Sheet drums: many different colors. Sometimes they expand (look like head on a draft beer) during cure based on temperature.

The sheet purge drums are currently taken to a facility where they are broken with a hydraulic hammer to ensure no drums have soft centers. The material is then loaded into a roll-off container and taken to a landfill.

The shape purge drums are transported to a facility in roll-off containers for grinding and recycling under BUD No. 924-9-15. Prior to grinding, all material is downsized with a hydraulic hammer on a steel plate adjacent to the Corian® collection area. The material is downsized to facilitate grinding in the horizontal impact crusher. This material is ground, screened and used per the BUD.
7.2.3 Open-Graded Subbase

As stated previously, because of the allowance of up to 10% fines, subbase is considered a low-permeable layer and is not free-draining. To address situations where this attribute will be detrimental to the pavement structure (e.g. natural occurring springs or very shallow watertable), the NYSDOT has developed requirements for an open-graded subbase course.

A special specification provides the material requirements for the open-graded subbase course.

<table>
<thead>
<tr>
<th>Sieve Size Designation</th>
<th>Percentage Passing by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½ in.</td>
<td>100</td>
</tr>
<tr>
<td>½ in.</td>
<td>25-60</td>
</tr>
<tr>
<td>¼ in.</td>
<td>10-35</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-7</td>
</tr>
</tbody>
</table>

Table 7-2 Open-Graded Subbase Gradation

Some permeability testing has been performed on samples taken from construction projects. Permeability test results provide an approximate value of 100 ft./day as compared to the NYSDOT Standard Specification which averages approximately 2 ft./day or less as computed in Figure 7-1.

Utilizing the permeability of 2 ft./day, it would take a drop of water 11 days to travel from the centerline of a normal-crowned pavement to the outside of a 10 ft. shoulder versus approximately 5 ⅓ hours using a permeability of 100 ft./day.

This material has some inherent disadvantages which should be reviewed prior to specifying its use:

- Material becomes unstable if utilized unprotected in the direct support of traffic loads in a work zone traffic control pattern, particularly where starting and stopping of vehicles occur.
- Supply is limited, particularly where there are no quarries nearby.
- Suppliers can find it challenging to make the material because it requires a change in their “normal” operation.
- Use in certain conditions such as pavement widening results in a non-uniform pavement section. This could result in differential frost heaves, particularly in the northern portion of New York State.
Figure 7-1 Nomograph for Estimating Coefficient of Permeability of Granular Drainage and Filter Materials
(NCHRP Synthesis #96: Pavement Subsurface Drainage Systems)
7.2.4 Natural Base Course Stabilization

The NYSDOT has investigated the use of bound native aggregates as a cost-effective means for rehabilitating low to medium traffic volume highways. When the native aggregate is not of satisfactory gradation for compliance with the subbase specification, it may be blended with an additive in order to stabilize the mix. Note that although the Standard Specifications contain requirements for natural base course stabilization, these methods have not been used by the NYSDOT since the early 1980’s.

7.2.4.1 Bituminous Stabilized Course

The NYSDOT Standard Specifications contain the requirements for mixing and placing this stabilized material. Bituminous stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing granular material to form a stable base. Bitumen increases the cohesion and load-bearing capacity of the granular soil.

Each stockpile of granular material used for a stabilized course must be evaluated by the Geotechnical Engineering Bureau to determine an appropriate application rate. Geotechnical Control Procedure GCP-16 establishes the State-wide procedure for the recommended application rate of additive(s) and for inspection and calibration of soil stabilization plants.

This process has not been used by the Department since the 1980’s.

7.2.4.2 Soil Cement Course

The NYSDOT Standard Specifications contain the requirements for mixing and placing this stabilized material. Soil cement, a.k.a. cement-modified soil or cement-treated aggregate base, is a dense, highly compacted mixture of aggregate, Portland cement, and water. The stiffness of the soil cement course acts to distribute loads over a wider area, reducing subgrade stresses and allows the base to maintain its original grade.

This process has not been used by the Department since the 1980’s.

7.3 SELECT GRANULAR SUBGRADE

The subgrade is the foundation for the pavement structure. In cut situations, the subgrade is comprised of the subgrade surface. In fill situations, the subgrade is comprised of not only the subgrade surface but also the subgrade area. Figure 7-2 provides a road section, segmented into a cut and fill situation, identifying the subgrade surfaces and subgrade area respectively. Controls are imposed on the materials placed within the subgrade area.
Figure 7-2 Road Section Depicting Subgrade Surface and Subgrade Area

- Subgrade Surface: the surface of the road section upon which the select materials and/or subbase are placed.

- Subgrade Area: that portion of an embankment situated above either of the following:
  A. A line located 2 ft. below the subgrade surface and extended to the intersection with the embankment side slopes or,
  B. The embankment foundation, whichever is higher.

- Embankment Foundation: the surface upon which an embankment is constructed after all of the following preparation work is completed:
  A. Clearing and grubbing,
  B. Removal of structures and obstructions,
  C. Sod and topsoil removal (if required),
  D. Unsuitable material removal (if required),
  E. Construction lift (working platform, if required), and
  F. Benches.

The purpose of the subgrade area is to provide a uniform, stable platform on which to place the pavement structure and to minimize differential frost heaves. Methods to improve the subgrade area are as follows:

1. Reduce the amount of water in the subgrade area. Improve drainage by creating roadside ditches to a depth of 4 ft., measured from the pavement edge to the ditch flow line. Underdrains and crushed stone trenches may be used to lower the water table in cut sections. Also note when modifying a ditch cross section, that it is important to consider the traversability of the section relative to the design clear zone.

2. Minimize differential frost heaves or increase load-bearing capacity. The most common method is to remove (undercut) unstable (saturated) materials and replace them with select granular subgrade material.
Subbase material alone or in combination with a geotextile may also replace removed material. Rock in the subgrade area is either removed or is fragmented and drained (called Rock Subgrade Fragmentation). Transition sections at culverts and in boulder removal areas are also used to provide uniformity.

3. Stabilize subgrade. Stabilize the subgrade with rollers that are 30 to 50 ton proof-roller type compactors. Mix in-situ material to break up stratified layers into more uniform material. Clayey soils can be stabilized by adding lime.

If subgrade improvement appears warranted, the Designer should always contact the Regional Geotechnical Engineer for subgrade improvement recommendations.

7.3.1 Pavement Design Development

7.3.1.1 Subgrade Resilient Modulus, $M_r$

The subgrade resilient modulus, $M_r$, is a measure of the stiffness of the subbase and subgrade soils. It is a necessary component for determining the pavement thicknesses of HMA pavements. The higher the $M_r$, the stronger the subgrade soil, and the better support it will provide to the pavement.

The Designer should contact the Regional Geotechnical Engineer to obtain a value for the subgrade resilient modulus, $M_r$. For reconstruction projects, $M_r$ values can be determined by either taking soil samples (by comparing blow counts with visual descriptions) or Falling Weight Deflectometer (FWD) testing along the proposed project route. FWD testing is conducted by the Highway Data Services Bureau of the Office of Technical Services. For new projects or widenings, $M_r$ values can be found by taking soil samples.

As indicated in Table 7-3, $M_r$ values below 4,000 psi may signify a fine-grained soil. Poorly drained soils will also have lower $M_r$ values. $M_r$ values below 3,000 psi indicate soft soil, probably with poor drainage, and offers weak subgrade support. $M_r$ values from 5,000 to 7,000 psi are characteristic of fine to medium-grained soil and are typical values for most NYS roadway subgrades.
### Table 7-3 Resilient Modulus, $M_r$, for Various Soil Types

#### 7.3.2 Material Requirements

The NYSDOT Standard Specifications provide the material requirements for select granular subgrade. The material consists of rock, stone, slag, cobbles, or gravel, substantially free of shale or other soft, poor durability particles. Well-graded rock may be used for this item with particles not exceeding 12 in. in its greatest dimension nor $\frac{2}{3}$ of the loose lift thickness, whichever is less.

All materials, other than well-graded rock, furnished under this item have no particles greater than a 6 in. maximum dimension. For the portion passing the 4 in. square sieve, the material meets the gradation provided in Table 7-4.
7.3.2.1 Substitution Allowances

The following materials are an acceptable replacement for natural material:

- **Alternate A**: Recycled Portland Cement Concrete Aggregate (RCA) where the material is at least 95%, by weight, of RCA and is free from organic and other deleterious material. This material may contain up to 5% by weight asphalt pavement and/or brick.

- **Alternate B**: Recycled Portland Cement Concrete Aggregate (RCA) where the material is a mixture of RCA with stone, sand, gravel or blast furnace slag. This material may contain up to 5% by weight asphalt pavement and/or brick.

- **Alternate C**: Reclaimed Asphalt Pavement (RAP) having a maximum top size of 2 in. at the time of placement.

RCA is described in NYSDOT GDM Section 7.2.2.2.1 *Recycled Portland Cement Concrete Aggregate (RCA)* and RAP is described in NYSDOT GDM Section 7.2.2.2.2 *Reclaimed Asphalt Pavement (RAP)*.

7.3.3 Subgrade Stabilization

7.3.3.1 Hydrated Lime Stabilized Subgrade

The NYSDOT Standard Specifications contain the requirements for the in-place mixing of hydrated lime with the existing subgrade material to produce a stabilized pavement foundation course. The introduction of lime can have positive short-term and long-term effects on certain types of soils. Short-term effects include soil modification of plasticity and swell reduction and a drying effect. Long-term effects include soil stabilization resulting from a prolonged pozzolanic reaction generating a strength gain.

The area to be stabilized is graded and shaped and then scarified and pulverized to accept the lime. If the depth of lime stabilization exceeds 6 in., the subgrade soil in excess of the 6 in. depth is removed, placed in windrows and processed as an additional lift. The hydrated lime is applied to the pulverized material by the approved method and rate. The spreading equipment is to uniformly distribute the lime without excess loss. The primary mixing operation is completed within four hours after application of the lime. The hydrated lime is to be uniformly incorporated into the subgrade to the full depth of treatment in such a manner that the result is a homogeneous, friable mixture of subgrade soil and lime, free from clods or lumps.

Immediately after the primary mixing operations are completed for the full depth of treatment, the surface of the subgrade is shaped and lightly sealed with a pneumatic-tired or smooth steel wheel roller. The surface is crowned so as to properly shed water if rain occurs.
Following primary mixing operations, the stabilized course is allowed to cure to allow the lime to properly react with the subgrade soil. During the curing period, the surface of the material is kept moist to prevent drying and cracking, and maintained in a properly sealed and crowned condition.

Immediately after the completion of the curing period, the stabilized course is completely mixed and pulverized to the full depth of stabilization. Secondary mixing continues until the material is properly mixed and blended. Once complete, the surface of the treated subgrade is kept continuously moist until the subbase course material is to be placed and compacted.

This process has not been used by the Department since the 1980’s.

**7.4 UNDERDRAIN FILTER MATERIAL**

Underdrains are narrow trenches filled with clean aggregate material that is both pervious to water and capable of protecting the trench from infiltration by the surrounding soil. See GDM Chapter 20 for more information on groundwater depletion drains.

**7.4.1 Design Development**

A filter pack is an envelope of sand or gravel, which is designed and placed to separate surrounding material from entering a particular subsurface zone while permitting the free-flow of groundwater.

Filter pack design is based on filter criteria originally proposed by Terzaghi (US Army Corps of Engineers, 1941 – see Johnson, 1963). The design process involves the following:

- **Permeability Criterion:** The particle diameter of the 15 percent size of the filter material ($d_{15f}$) should be at least four times as large as the diameter of the 15 percent size of the soil material ($d_{15s}$) – see NYSDOT GDM Chapter 20:

  \[ d_{15f} \geq 4d_{15s} \]

  This requirement would make the filter material roughly more than ten times as permeable as the soil.

- **Retention or Stability Criterion:** The 15 percent size of the filter material ($d_{15f}$) should not be more than four times as large as the 85 percent size of the soil material ($d_{85s}$) – see NYSDOT GDM Chapter 20:
Equation 7-2

\[ d_{15f} \leq 4d_{85s} \]

This requirement would prevent the fine soil particles from washing through the filter material.

The gradations of the underdrain filter materials have been designed to adequately filter the varying New York State subgrade materials (subsoils). The following is a list of applicable underdrain materials:

- Underdrain Filter Material, Type 1 – used to filter existing subsoils of a well-graded mixture, predominately consisting of Sandy GRAVEL or Gravelly SAND.
- Underdrain Filter Material, Type 2 - used to filter existing subsoils of a well-graded mixture, predominately consisting of Silty FINE SAND or a Sandy SILT.
- Underdrain Filter Material, Type 3 - used to filter existing subsoils of a well-graded mixture, predominately consisting of SILT or CLAY.

### 7.4.2 Material Requirements

The NYSDOT Standard Specifications provide the material requirements for underdrain filter material. There are three different underdrain filter material types whose applications are based on the existing subsurface soils to be drained. The underdrain filter material consists of crushed stone, sand, gravel, or screened gravel meeting the gradations provided in Table 7-5.

<table>
<thead>
<tr>
<th>Sieve Size Designation</th>
<th>Percentage Passing by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>1 in.</td>
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<tr>
<td>½ in.</td>
<td>30-100</td>
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<td>⅜ in.</td>
<td>0-30</td>
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<tr>
<td>No. 4</td>
<td></td>
</tr>
<tr>
<td>No. 8</td>
<td></td>
</tr>
<tr>
<td>No. 10</td>
<td>0-10</td>
</tr>
<tr>
<td>No. 16</td>
<td></td>
</tr>
<tr>
<td>No. 20</td>
<td>0-5</td>
</tr>
<tr>
<td>No. 30</td>
<td></td>
</tr>
<tr>
<td>No. 50</td>
<td></td>
</tr>
<tr>
<td>No. 100</td>
<td></td>
</tr>
<tr>
<td>No. 200 (wet)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7-5 Underdrain Filter Material Gradation**
7.4.2.1 Substitution Allowances

The following material is an acceptable replacement for Types 1 or 2.

- Alternate A: Crushed glass backfill meeting the gradation requirements of Table 7-6.

<table>
<thead>
<tr>
<th>Sieve Size Designation</th>
<th>Percentage Passing by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ in.</td>
<td>100</td>
</tr>
<tr>
<td>⅜ in.</td>
<td>90 – 100</td>
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<td>0 - 5</td>
</tr>
</tbody>
</table>

Table 7-6 Underdrain Filter Material, Glass Substitution Gradation

Glass aggregate is described in NYSDOT GDM Section 7.2.2.2.3 Glass Aggregate.

- Alternate B: Corian® backfill meeting the gradation requirements of Underdrain Filter Material, Types 1 or 2 (see Table 7-5).

Corian® is described in NYSDOT GDM Section 7.2.2.2.4 Corian®.

7.5 SELECT GRANULAR FILL AND SELECT STRUCTURAL FILL

Select granular fill is typically used as pipe backfill. The design of a buried pipe assumes a certain response to loads from a pipe/soil composite structure. Proper controls of the trench excavation, pipe laying, pipe joining and backfill compaction are essential to the success of the installation. The type of backfill material and its proper compaction are likely to dominate the structural performance of both pipe and soil. The desired constant pressure around the pipe and uniform support of the pipe in the longitudinal direction are the major objectives of a successful installation.

Select structural fill is typically used as abutment or retaining wall backfill. The design of an abutment or retaining wall is developed to resist anticipated loads based primarily on the material properties of the backfill soil. The material placed behind an abutment or retaining wall must be a select, free-draining, granular material. Retaining walls are commonly designed to resist the active earth pressure development by the select structural fill on the wall.

Select granular fill and select structural fill have the same material requirements. The need for two separate item numbers is a derivation of Engineering Shares – a grouping of items that relate to one another in some way (e.g. items that are all associated with a highway, bridge, specific work site location or items to be paid for with specified funds such as Federal Aid or a utility). Highway work is typically designed, detailed and estimated by a Design Squad, whereas Bridge work is typically designed, detailed, and estimated by a Structures Squad. The highway work typically includes pipe installations, which require appropriate backfill material. The bridge work...
typically includes abutment construction, which requires appropriate backfill material. Although the “appropriate backfill material” is the same for both applications, the quantities (and the two shares) are kept separate to eliminate any miscommunications regarding how items are being paid for in the final contract document.

7.5.1 Design Development

7.5.1.1 Select Granular Fill as Pipe Backfill

The performance of pipe installations depends largely on the quality of the compacted fill in the embedment zone. The denser the fill, the more likely surcharge and live wheel loads will be distributed away from the pipe by the adjacent soil. In addition, the denser the fill, the less likely pipe deformation will occur.

Select granular fill used as pipe backfill material is identified in Figure 7-3 as the pipe “Embedment”. This area encompasses the pipe and defines the pipe/soil composite structure.

![Figure 7-3 Pipe Terms](Corrugated Polyethylene Pipe Design Manual & Installation Guide, Plastic Pipe Institute®)
Using the terms identified in Figure 7-3 for the Embedment material:

- **Bedding:** Bedding material is required to establish line and grade and to provide firm pipe support. Uniformity of the underlying soil that forms the trench bottom avoids stress concentrations and irregular pipe deformations that non-uniformity may cause. Differential settlements may compromise the structural integrity of a buried pipe. A proper foundation is the starting point for eliminating that possibility.

To ensure uniformity, the trench bottom is over-excavated and replaced with a layer of properly compacted bedding material for the full width of the trench. This also eliminates the potential of large protruding boulders exerting point loads on the pipe.

The bedding control line (BCL) is a horizontal line located below the invert which represents the bottom elevation for bedding material placement and top elevation of undercut backfill, where required. The location of the BCL and the actual bedding thickness vary with pipe size and wall thickness. See Standard Sheet 203-04 Installation Details for Reinforced Concrete Pipes and Standard Sheet 203-05 Installation Details for Corrugated and Structural Plate Pipe and Pipe Arches.

- **Haunch:** The haunching area of the pipe/soil composite structure provides the majority of the resistance against soil and traffic loadings. The backfill in the haunch area should be “shoveled” and hand-tamped with a haunch tamping tool to ensure that no voids remain.

![Figure 7-4 Haunch Support](image)

- **Initial Backfill:** Initial backfill materials must provide adequate pipe support and protect the pipe from stones or cobbles in the final backfill. The extent of the initial backfill material depends on the location of the subgrade surface. The embedment’s select granular fill is extended 12 in. above the top of pipe, or to the subgrade surface, whichever is less.
• Final Backfill: If the top of the pipe embedment is lower than the subgrade surface, then final backfill material is placed above the pipe embedment material to meet the subgrade surface. The material used for final backfill material is suitable excavated material from the trench excavation.

Select granular fill has been developed to be an integral part of the pipe/soil composite structure given the variety of performance requirements it must meet while addressing the various types of pipes available for use.

### 7.5.1.2 Select Structural Fill

Satisfactory performance of fill type retaining walls is a result of accurately predicting load configurations for the site-specific design analysis and obtaining and installing construction materials corresponding to the design analysis assumptions. Load vectors and weight counterbalances for fill type retaining walls are largely dependent on the soil properties of the compacted fill placed directly behind (and on top of the heel, if appropriate) the wall.

![Figure 7-5 Forces on an Earth Retaining System](Earth Retaining Systems, GEC No. 2)
The process of slow, continuous deformation or yielding of a soil mass under constant stress is defined as soil creep. It is known that nearly all soil structures undergo a certain amount of creep. The rate of soil creep depends on factors such as the gradient, water absorption and content, type of material, etc. To address these factors, backfill material for fill type retaining walls ideally consists of relatively free-draining sands and gravels (i.e. cohesionless soils). These soils drain rapidly, are not susceptible to excessive frost action, nor creep movements, and are easily placed and compacted in confined areas. A certain amount of water offers cohesion to the sand, which binds the sand particles together. However, the presence of too much water fills the voids between the grains creating a slip plane between the particles. As mentioned above, this is addressed by utilizing a free-draining backfill material and providing a positive drainage outlet.

In contrast, cohesive backfills are difficult to compact. Additionally, in order to design a wall with cohesive backfill, extreme caution is necessary in selecting pressures between the active and at-rest cases (to assume the most unfavorable condition). Cohesive backfills designed for active earth pressures will continue to move gradually (creep) throughout the structures lifespan as it is exposed to water, either through rainwater percolation or rising groundwater elevation. The creep of the cohesive backfill is caused by the expansion of materials when they are exposed to water. Clay expands when wet, then contracts after drying. The expansion portion exerts pressure while the contraction results in consolidation at the new offset (hence movement).

Select structural fill has been developed to be an integral part of the fill type retaining wall system by providing predictable soil parameters for use in the design of the various types of structures, e.g. concrete cantilever (cast-in-place or precast), gravity, or prefabricated wall systems.

### 7.5.2 Material Requirements

The NYSDOT Standard Specifications provide the material requirements for select granular and select structural fill. There are two different types of select granular fill whose applications are based on the type of pipe the material will be supporting. In addition, some pipe material requires a complete substitution from select granular fill (e.g. plastic water main installations utilize Sand Backfill as depicted on Standard Sheet 663-01 Water Main Pipe Installation Details). Select granular and select structural fill material meet the gradation requirements of Table 7-7 and consist of rock, stone, slag, cobbles, or gravel, and are substantially free of shale or other soft, poor-durability particles. Sand Backfill material gradation has also been included in Table 7-7.
### CHAPTER 7

**Engineered Granular Mixes**

<table>
<thead>
<tr>
<th>Sieve Size Designation</th>
<th>Typical – Select Granular Fill or Select Structural Fill</th>
<th>Select Granular Fill used as Backfill for Corrugated Aluminum Pipe</th>
<th>Sand Backfill used as Backfill for Plastic Water Main</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage Passing by Weight</td>
<td>Percentage Passing by Weight</td>
<td>Percentage Passing by Weight</td>
</tr>
<tr>
<td>4 in.</td>
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</tr>
<tr>
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</tr>
<tr>
<td>½ in.</td>
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<td></td>
</tr>
<tr>
<td>¼ in.</td>
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</tr>
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<td>0-15</td>
<td>0-15</td>
<td>0-5</td>
</tr>
</tbody>
</table>

**Table 7-7 Select Granular Fill, Select Structural Fill, and Sand Backfill Material Gradation**

### 7.5.2.1 Substitution Allowances

The following materials are an acceptable replacement for natural material:

- Alternate A: Recycled Portland Cement Concrete Aggregate (RCA) where the material is at least 95%, by weight, RCA and is free from organic and other deleterious material. This material may contain up to 5% by weight asphalt pavement and/or brick.
- Alternate B: Recycled Portland Cement Concrete Aggregate (RCA) where the material is a mixture of RCA with stone, sand, gravel or blast furnace slag. This material may contain up to 5%, by weight asphalt pavement and/or brick.

RCA is described in NYSDOT GDM Section 7.2.2.2.1 *Recycled Portland Cement Concrete Aggregate (RCA).*

### 7.6 STONE FILLING AND RIP RAP

Bank and Channel Protection design addresses the construction of blankets and walls of erosion-resistant materials to prevent undesirable erosion of earth exposed to flowing water. Unchecked erosion can damage and destroy highways, bridges, culverts and other facilities. Therefore, it is important to construct the protective works such that they will fulfill their mission.

In preparing the design of a highway project, the Designer usually has to design channels to carry water. Such channels range from small roadside drainage ditches or gutters to major river relocations. In addition, highway embankments and structures often have to be located in or adjacent to existing rivers, streams, lakes, reservoirs or other bodies of water.
A newly constructed channel or a natural channel modified by man will generally experience accelerated erosion of the banks and scour of the bottom at some locations, while sediments will be deposited at others. A channel may be modified by changing its width or alignment, or by construction in or adjacent to the channel which will alter the natural flow boundaries at any flow stage. Failure to consider in design the erosive power of water may have the following adverse consequences:

- Damage to, or destruction of, the facility.
- Damage to adjacent property.
- Pollution of surface waters by eroded soils.

Stone fill lining is a cluster of stone satisfying rather tight dimensional limits, positioned into a lining either by dumping or individually placing the stones in such a manner that the stones resting on the foundation soil or bedding layer, support other stones. As a result, the lining consists of more than a single layer of stones, and the underlying material is not exposed if downslope creep takes place or individual stones are displaced by ice action. An additional advantage of stone lining, under certain conditions, is its coarse surface texture which dissipates the energy of water flowing over it, thus reducing its velocity. The erosion resistance of stone linings depends on the average size of the stone, gradation, surface roughness and on channel geometry.

Rip rap is individual stones placed in a single layer on the surface to be protected. Rip rap is placed to prevent scour or erosion of the bed, banks, shoreline of streams or rivers or near structures such as bridge abutments or piers. It is positioned in a well-knit, compact, uniform layer to achieve suitable hydraulic performance and maintain stability against hydraulic loading. Rip rap is intended to absorb and deflect the hydraulic energy before it reaches the defended structure.

### 7.6.1 Design Development

Geotechnical Design Procedure (GDP-10) *Bank and Channel Protective Lining Design Procedures* provides the designer with guidelines for erosion-resistant design.

The gradations of stone filling have been designed to be able to resist a range of forces exerted by the water while also preventing the washing out of underlying materials through the openings between particles. The flow velocity for a given stone size depends also on the flow conditions (uniform, gradually varying or rapidly varying) which are determined by the curvature of the channel alignment and the presence of obstructions in the channel.

The gradation of stone filling (fine), stone filling (light), and bedding material are obtainable from rock cuts or stone quarries with a minimum of processing. Stone filling is an especially economical material if it can be obtained within the limits of the project (on site). The suitability of the excavated rock for stone filling items should be evaluated during design by the Departmental Geotechnical Engineer or a Departmental Engineering Geologist.
There is a benefit in having a well-graded stone fill as lining material, with individual stones ranging from a size equal to the thickness of the lining down to 1 in. spalls. This type of material forms its own filter that prevents the underlying finer materials from washing out through the lining and thoroughly chinks the stone together. Experiments referred to in NCHRP Report 108, *Tentative Design Procedure for Rip-Rap-Lined Channels*, HRB, 1970, indicate that a well-graded dumped stone lining can be considerably thinner than a uniformly graded dumped stone lining and will still provide equivalent protection against washing out of the underlying material.

### 7.6.2 Material Requirements

The NYSDOT Standard Specifications provide the material requirements for stone fill and rip rap. Stone fill and rip rap material is obtained from an approved source and inspected by an Engineering Geologist. Geotechnical Control Procedure (*GCP-14* Procedure for Control of Stone Filling and Rip Rap Items) provides the procedures to be followed for the control of the gradation and soundness requirements of these items.

Particles sizes and gradations for stone filling are identified in Tables 7-8 and 7-9.

<table>
<thead>
<tr>
<th>Stone Filling Item</th>
<th>Stone Size</th>
<th>Percent of Total by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>Smaller than 8 in.</td>
<td>90-100</td>
</tr>
<tr>
<td></td>
<td>Larger than 3 in.</td>
<td>50-100</td>
</tr>
<tr>
<td></td>
<td>Smaller than No. 10 sieve</td>
<td>0-10</td>
</tr>
<tr>
<td>Light</td>
<td>Lighter than 100 lbs.</td>
<td>90-100</td>
</tr>
<tr>
<td></td>
<td>Larger than 6 in.</td>
<td>50-100</td>
</tr>
<tr>
<td></td>
<td>Smaller than ½ in.</td>
<td>0-10</td>
</tr>
<tr>
<td>Medium</td>
<td>Heavier than 100 lbs.</td>
<td>50-100</td>
</tr>
<tr>
<td></td>
<td>Smaller than 4 in.</td>
<td>0-10</td>
</tr>
<tr>
<td>Heavy</td>
<td>Heavier than 600 lbs.</td>
<td>50-100</td>
</tr>
<tr>
<td></td>
<td>Smaller than 6 in.</td>
<td>0-10</td>
</tr>
</tbody>
</table>

Table 7-8 Stone Filling Gradation
Table 7-9 Stone Filling – Approximate Shape to Weight Correlations

Particle sizes and gradations for rip rap (identified in Table 7-10) are more particular to address placement, interlocking and development of a specific overall surface. The material is to consist of stones shaped as nearly as practicable in the form of right rectangular prisms. One dimension of each of the stones furnished is to be at least equal to the thickness of the rip-rap identified by the Designer.

<table>
<thead>
<tr>
<th>Specified Weights and Sizes</th>
<th>d=18 in.</th>
<th>d=23 in.</th>
<th>d=15 in.</th>
<th>d=23 in.</th>
<th>d=27 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 lbs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 lbs.</td>
<td>d=15 in.</td>
<td>d=18 in.</td>
<td>d=12 in.</td>
<td>d=18 in.</td>
<td>d=21 in.</td>
</tr>
<tr>
<td>150 lbs.</td>
<td>d=12 in.</td>
<td>d=15 in.</td>
<td>d=9 in.</td>
<td>d=15 in.</td>
<td>d=17 in.</td>
</tr>
<tr>
<td>100 lbs.</td>
<td>d=10 in.</td>
<td>d=13 in.</td>
<td>d=8 in.</td>
<td>d=13 in.</td>
<td>d=15 in.</td>
</tr>
<tr>
<td>100 lbs.</td>
<td>d=8 in.</td>
<td>50 lbs.</td>
<td>25 lbs.</td>
<td>100 lbs.</td>
<td>25 lbs.</td>
</tr>
<tr>
<td>25 lbs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16 lbs.</td>
</tr>
<tr>
<td>50 lbs.</td>
<td>10 lbs.</td>
<td></td>
<td></td>
<td>40 lbs.</td>
<td></td>
</tr>
<tr>
<td>10 lbs.</td>
<td></td>
<td>20 lbs.</td>
<td></td>
<td>10 lbs.</td>
<td>7 lbs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stone Weight</th>
<th>Gradation Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavier than 300 lbs.</td>
<td>50-100 percent of total by weight</td>
</tr>
<tr>
<td>100 lbs. – 300 lbs.</td>
<td>Remainder of stones</td>
</tr>
</tbody>
</table>

Table 7-10 Rip Rap Gradation

7.6.2.1 Substitution Allowances

The following materials are an acceptable replacement for fine stone fill and light stone fill:

- Air-cooled blast furnace slag, cobbles or gravel having at least one fractured face per particle are acceptable substitutes for stone under these items, provided that the soundness and gradation requirements are met.

7.7 MATERIAL ACCEPTANCE

The purpose for sampling and testing construction materials is to determine the physical properties. For engineered granular mixes, the Contractor shall furnish the Engineer, at the preconstruction meeting, the sources of supply, types and contract pay item(s) of materials which it proposes to use in the work in order to ensure that the materials are obtained from approved sources or that required inspection or approval will be completed in a timely manner.
All materials used in the work are to meet the quality requirements described in Standard Specification Section 733 Earthwork Materials. Materials are inspected, sampled, and tested by the procedural directives issued by the Department, specifically Geotechnical Control Procedure (GCP-17) Procedure for the Control and Quality Assurance of Granular Materials. The initial acceptance of a material in no way precludes further examination and testing of the material at any time the Engineer suspects that the material is no longer properly represented by the accepted sample. The acceptance at any time of any materials will not bar its future rejection if it is subsequently found to be defective in quality or uniformity.

Ideally, the engineered granular mix is controlled during its manufacturing and/or processing by a quality control (QC) program. The purpose of the Supplier’s QC program is to provide data on the physical properties of the material and to allow adjustments to their operations to comply with the specification requirements. However, the Department’s level of confidence in the supplied engineered granular mix is low if there is no exchange of information regarding operations, no ability to control and/or monitor sampling intervals, or no guarantee in delivery of the specifically processed engineered granular mix to the specific project location.

Additional steps are required to boost the level of confidence. Quality Assurance (QA) is defined by the American Association of State Highway and Transportation Officials (AASHTO) as all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service.

### 7.7.1 Quality Assurance (QA)

Quality assurance (QA) refers to the overall system for ensuring project quality. The core elements of a QA program consist of:

- Contractor/Supplier QC
- Personnel Qualification/Certification
- Laboratory Accreditation/Qualification
- Independent Assurance
- Agency/Owner Acceptance
- Dispute Resolution

The NYSDOT has established a QA Program in accordance with 23 CFR 637 to ensure the materials and workmanship incorporated into each Department project are in conformity with the approved plans and specifications. The controls for the various construction materials are specific to the type and application. The material types are sensitive to permeability, segregation and contamination and the requirements are intended to ensure that performance of the product in its final position is consistent, predictable, and meets expectations over the lifetime of the installation. For example, subbase material must have similar drainage and stability characteristics both longitudinally and between the roadbed limits so that the pavement structure is adequately and uniformly drained and supported. Similarly, backfill for Mechanically Stabilized Earth Structures (MSES) must have consistent physical, and, for systems utilizing metal reinforcing straps or mesh, electro-chemical properties to ensure that the overall structure is constructable, and meets predicted, long-term performance requirements.
As mentioned in NYSDOT GDM Section 7.7 Material Acceptance, a Supplier assumes full responsibility for all quality control (QC) activities for the production of the material. QC activities include ensuring the material meets the specification requirements for which it is manufactured, as well as a plan to manage the inventory. QC is defined as “all Contractor/Vendor operational techniques and activities that are performed or conducted to fulfill contract requirements.” Independent Assurance (IA) is the auditing of the project deliverables quality and is an added phase in the process that not only ensures the Department that the specifications were met, but also supports the effectiveness of the QC program administered by the Contractor’s Supplier.

IA of engineered granular mixes involves collecting samples and performing testing at various points in the process. Depending on the Item, this can include some or all of the following:

- Source evaluation
- Stockpile sampling and testing
- Sampling and testing material on the contract site. This may be from on the grade or from behind a structure after placement by the Contractor, or at any other location where the material is being stored or used.

Failure of material to meet specification requirements at any point in the QA process will result in rejection of that material.

Stockpiled material must be free from organic and other deleterious material (which includes, but is not limited to, wallboard, wood, plastic and metal). Recycled Concrete Aggregate (RCA) likewise must be free of deleterious material but may contain up to 5%, by weight, of recognizable pieces of brick and/or asphalt pavement.

Stockpiled material may be rejected without testing for failure to meet all requirements listed in Geotechnical Control Procedure (GCP-17) Procedure for the Quality Control of Stockpiled Granular Material. Material may be rejected based on visual inspection by a Departmental Geotechnical Engineer, or his/her Representative. Samples will not be collected. Written documentation will be provided to the Engineer (for contract specific stockpiles) or the Contractor/Supplier (for non-contract specific stockpiles) describing the reason for the rejection. Photographs and/or other evidence can also be provided to support a decision to reject a material.

In June, 1951, a pavement performance study was conducted by the Geotechnical Engineering Bureau (formerly Soil Mechanics Bureau) on a section of the New York State Thruway. The existing Portland cement concrete pavement, which was placed in the late 1940’s, showed extensive signs of distress. The study concluded that the foundation course gravel was the primary cause for the premature failure of the pavement. The gravel used was basically fine with a high plasticity index and a significant portion passing the No. 200 sieve. As a result, the NYSDOT’s IA program was developed out of necessity to address failures and continues to be assessed and revised. The responsibility for the testing and approval of granular material was given to the Geotechnical Engineering Bureau on August 1, 1951 by General Instruction No. 465.
The same General Instruction gave the responsibility for the investigation and sampling of the granular sources to the Regional Offices.

In April, 1967, a pavement evaluation was conducted on a project in Region 7 and the cause for the premature failure was attributed to the subbase course not meeting the specification requirements. As a result, a statewide uniform sampling procedure for subbase material was established by the Geotechnical Engineering Bureau. The earliest version of Geotechnical Control Procedure (GCP-17) Procedure for the Quality Control of Stockpiled Granular Material was published in April, 1969. The manual developed by the State for documenting compliance with the specification requirements involves sampling and testing of granular materials in lots. The intent of the manual is to accept the lot if 95% of the material meets the specification requirements (i.e. all the material has to meet the specification requirements with a 95% confidence level).

After publication, the results obtained from the FHWA-sponsored record sampling program over a number of years indicated a failure rate for gradation of 5% ±. This indicates that the State’s assurance procedure substantially meets the objectives of 95% compliance with the material specification requirements. In addition, an early review of the Granular Material Evaluation and Documentation records of 1500± stone and gravel stockpiles sampled identified that 17% ± failed. An observation from the above data is that the QC at the Contractor and /or Supplier level is not adequate to ensure meeting specification requirements, whereas the State’s QA procedure is within its designed limits.

The Geotechnical Engineering Bureau continues to assess and revise the IA program as needed.

**7.7.1.1 Stockpile Approval**

To ensure quality, engineered granular mixes are either stockpiled to be inspected, sampled, and tested or the source of the material is evaluated. The procedural directives issued by the Department, specifically Geotechnical Control Procedure (GCP-17) Procedure for the Control and Quality Assurance of Granular Materials outlines the procedures.

The purpose of stockpiling material is to allow the Department to effectively evaluate engineered granular mixes, in a timely manner, to ensure that it meets specification requirements. Stockpiling is required for applications where the quality of the material is critical for the long-term performance of the structure (e.g. subbase under pavement, underdrain, and MSES backfill).

Off-site manufacturing in the construction industry is described as an Off-site Construction Technique (OSCT). Construction, in this case the processing of engineered granular mixes, takes place at a different location than the location of use. OSCT processing occurs in a gravel pit or quarry specifically equipped for this type of processing. Individual stockpiles of granular mixes are processed and evaluated at the source and then transported to the site for placement.
Since manufacturing takes place off-site, the Supplier is in full control of the material, processing equipment and methods of stockpile construction, which should lead to a high quality, predictable product. OSCT reduces project construction time as the engineered granular mixes are processed either ahead of time or concurrently with site preparation. In addition, the amount of site disruption is decreased as less work is performed on-site.

During the OSCT processing, the Engineer inspects the construction of stockpiles and then requests approval of the stockpile from the Regional Geotechnical Engineer. Inspection of the construction of stockpiles may also be performed by the Regional Geotechnical Engineer. The Regional Geotechnical Engineer supervises the sampling and arranges for the testing of the stockpiles.

Note that other controls, in addition to the sampling requirements, are necessary in order for the NYSDOT to be confident that the engineered granular mixes placed in the work meets specification requirements. These include:

- **“Chain of Custody”** – This describes the documentation process by which the NYSDOT ensures that the material being placed in the work is from a given approved stockpile. This process is the responsibility of the Contractor and Supplier, and it may include the employment of Contractor staff at the stockpile source, and the use of delivery tickets.
- **The effects of handling on the material** – It is the responsibility of the Contractor/Supplier to make sure that the methods used for delivering and handling the material do not result in a significant change in the material’s properties, such that the material goes “out of spec” due to segregation of particles. The NYSDOT may employ QA procedures, such as sampling material placed on the grade, to ensure that the material placed still meets specification requirements.

### 7.7.1.1 Statistical Analysis of Sampling Procedure

The defined sampling procedure described in Geotechnical Control Procedure (GCP-17) *Procedure for the Control and Quality Assurance of Granular Materials* has been developed and analyzed by the NYSDOT to ensure the non-biased, uniform actions exercised by a Sampler result in a representative sampling of the overall stockpiled material.

As stated in the *Development of Granular Materials Assurance Program*, Soil Mechanics Bureau Technical Report #42, November, 1988, the statewide uniform sampling procedure was developed by analyzing the test results of samples obtained from extensively sampling two stockpiles. “There were numerous random samples obtained from each pile and statistical routines were performed to determine the number of samples that would be required to statistically predict the natural variability of the material in the stockpile. The analysis indicated that a level of confidence of 95% could be obtained with 4 samples.”

Additionally, the Geotechnical Engineering Bureau (formerly Soil Mechanics Bureau) requested the Engineering Research and Development Bureau to statistically analyze four sampling methods used on a single stockpile. As stated in the *Statistical Analysis of Stone Subbase*
Sampling Methods, Engineering Research and Development Bureau, Client Report 17, June, 1987, “The statistical tests performed in this investigation indicate that overall the four stone subbase sampling methods produce similar results. In addition, the location in the stockpile did not have a strong influence on the outcome of the sieve analysis.”

7.7.1.2 Source Approval

To assure quality, engineered granular mixes are either stockpiled to be inspected, sampled, and tested, or the source of the material is evaluated. The procedural directives issued by the Department, specifically Geotechnical Control Procedure (GCP-17) Procedure for the Control and Quality Assurance of Granular Materials outlines the procedures.

The purpose of evaluating a source is to allow the Department to effectively determine characteristics of the engineered granular mix, in a timely manner, to ensure that it meets specification requirements. As mentioned in NYSDOT GDM Section 7.7.1.1 Stockpile Approval, Off-site manufacturing in the construction industry is described as an Off-site Construction Technique (OSCT). OSCT evaluation occurs in a gravel pit or quarry specifically equipped for processing granular mixes. Each year, a list of granular material sources, which are anticipated to be used for upcoming NYSDOT contracts, is submitted by the Regional Geotechnical Engineer to the Geotechnical Engineering Bureau. The Geotechnical Engineering Bureau responds with the required number of samples to be collected and forwarded for testing. Material from each Source will be evaluated for Magnesium Sulfate Soundness and Plasticity Index before it is allowed to supply non-stockpiled material to NYSDOT contracts. This evaluation is valid for a 12-month period.

The evaluation samples are obtained under the direction of the Departmental Geotechnical Engineer. The number and location of samples are dependent upon the topography of the area, stratification of the deposit and quality of the material. Samples are chosen to characterize the quantity of material required.

OSCT evaluation of approved sources allows for reduced project construction times as the engineered granular mixes do not have to be (re)tested for quality. Items which are not stockpiled, but which require conformance to a particular gradation, need only be sieve-tested by project-level earthwork inspection personnel.

7.7.1.3 Visual Disparity of Samples

Approval of a stockpile does not relieve the Contractor of the responsibility to place, in its final position, an engineered granular mix conforming to all the specification requirements for the intended item. If the Engineer observes material being placed on the grade that appears to be outside of the specification requirements, or sees a visual difference in the material, a request to the Regional Geotechnical Engineer may be made to obtain quality assurance (QA) samples at any location.
If test results from QA samples indicate that the engineered granular mix does not meet specification requirements, that material is rejected. Determination of the amount and extent of rejected material depends on the importance of the application (i.e. MSES backfill requirements are more critical than those for backfill around a concrete pipe), as well as on the nature of the deviation from the specifications. Possible consequences could include, but would not be limited to:

- Requiring the Contractor to remove and replace the material placed that day;
- Requiring the Contractor to conduct an investigation to determine the full extent of the unacceptable material, followed by removal and replacement;
- Issuance of a Stop Work order by the Engineer.

### 7.7.1.4 Random Location of Samples

The Department may elect to take samples from the grade at any time as part of the overall QA process. This will not be limited to conditions described in NYSDOT GDM Section 7.7.1.3 Visual Disparity of Samples.

As outlined in the NYSDOT Standard Specifications, all materials furnished are to be in reasonably close conformity with the material requirements, including tolerances. Mid-range specification values are to be considered the design values from which any deviations are allowed. It is the intent of the specifications that the materials and work quality is to be uniform in character and conform as nearly as realistically possible to the prescribed target value or to the middle portion of the tolerance range. The purpose of the tolerance range is to accommodate occasional minor variations from the median zone that are unavoidable for practical reasons. For example, although maximum and minimum values are specified in the MSES backfill requirements, the production and processing of the material and the performance of the work shall be controlled so that material will not predominantly be of borderline quality or dimension.

It is the responsibility of the Contractor/Supplier to make sure that the methods used for delivering and handling the material do not result in a significant change in the material’s properties, such that the material goes “out of spec” due to segregation of particles.

The Department reserves the right to sample and test material on the contract site in order to be confident that the material placed in the work meets specification requirements.

#### 7.7.1.4.1 Method for Random Location Samples for Critical Structures

Because of the critical importance of backfill placed for Mechanically Stabilized Earth System (MSES) applications, the Department will always take additional samples from behind the new structure, during its construction, for additional testing. The frequency and approximate location (station, offset, and elevation) of these additional samples will be determined by the Geotechnical Engineering Bureau’s General Soils Laboratory Supervisor based on a history of the source and the quantity of material being placed.
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Engineered Granular Mixes

Geotechnical Control Procedure (GCP-20) Procedure for Taking Random Samples of Backfill Material for Mechanically Stabilized Earth Systems provides the uniform procedure for taking random samples of backfill material, including how to determine and randomly select sublots to eliminate bias.

7.8 REFERENCES


Fuller, W. B., and Thompson, S. E., The Laws of Proportioning Concrete, Transactions of ASCE, ASCE, Vol. 59, 1907, pp.67-143.


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