FOUNDATIONS
SITEWORK

Almost any exterior job will involve some level of sitework, be it simple grading or a complete reworking of a building lot's contours. Understanding soils, drainage, and subsurface materials is key.

SITE PREPARATION

Excavation must not begin until the locations of underground wires, cables, and pipes have been marked, or until you have verification from utility companies that the area is clear.

Caution: Look for existing utilities before any excavation begins. Any digging within 24 in. of utility locations must be done by hand.

Clearing the Site

Clear the site at least 20- to 25-ft. from the foundation. This involves more than cutting down the trees and pushing them into a pile with a bulldozer:

- Cut up trees and haul them way
- Chip the brush
- Remove the stumps and haul them away

Saving Topsoil

Retain as much topsoil as possible to preserve the environmental quality of a site. Topsoil helps maintain vegetation that will preserve the soil and limit erosion (see **Practical Erosion Controls**, below). When topsoil will be preserved, till the soil first, and then remove to a safe location with a front-end loader. On wooded sites, however, saving topsoil is often more difficult than it's worth because of the number of roots.

EXCAVATING SLAB FOUNDATIONS

Foundation excavations should be as level as possible, particularly for structural slabs. Set an elevation benchmark prior to excavation. Place the benchmark somewhere convenient and make sure everybody on the site knows where it is during excavation.

Plan all utility layouts that will run beneath slabs prior to digging (see Site Layout for Structural Slabs).

EXCAVATING FOUNDATION HOLES

Plan foundation drainage before excavating to identify the locations of cleanouts and daylight drains (see Perimeter Foundation Drains).

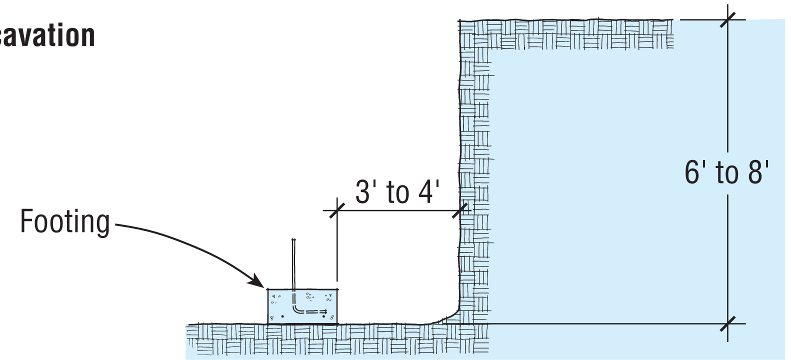
Overdig foundation holes to give plenty of room for a well-draining backfill (see Soil Drainage), and to provide room to work.

- If the depth of the excavation is 6 ft. or less, overdig by 3- to 4-ft.
- If the excavation is deeper than 7 ft., the sides must be sloped outwards at a 45-degree angle above 4 ft. (**Figure A**), or install shoring (**Figure B**).

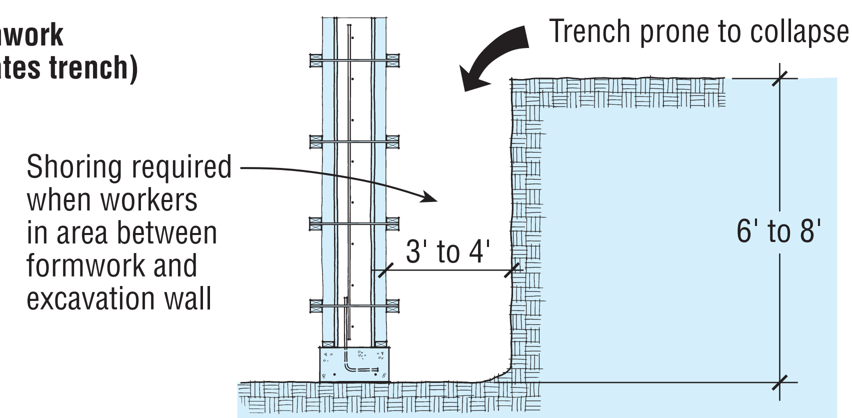
Excavating Foundation Holes

FIGURE A: OPEN EXCAVATIONS

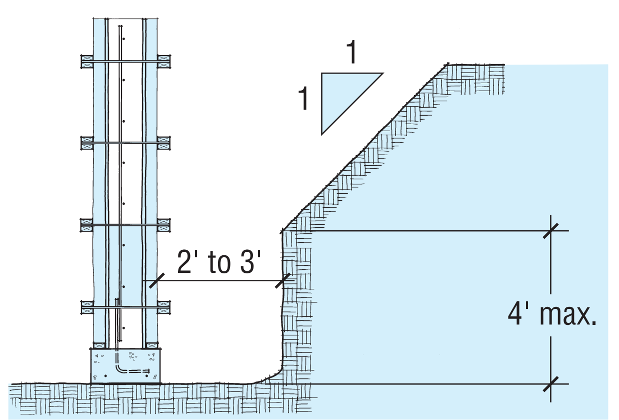
1. Open excavation



2. Formwork (creates trench)



3. Sloped bank at 45Υangle; no further shoring needed

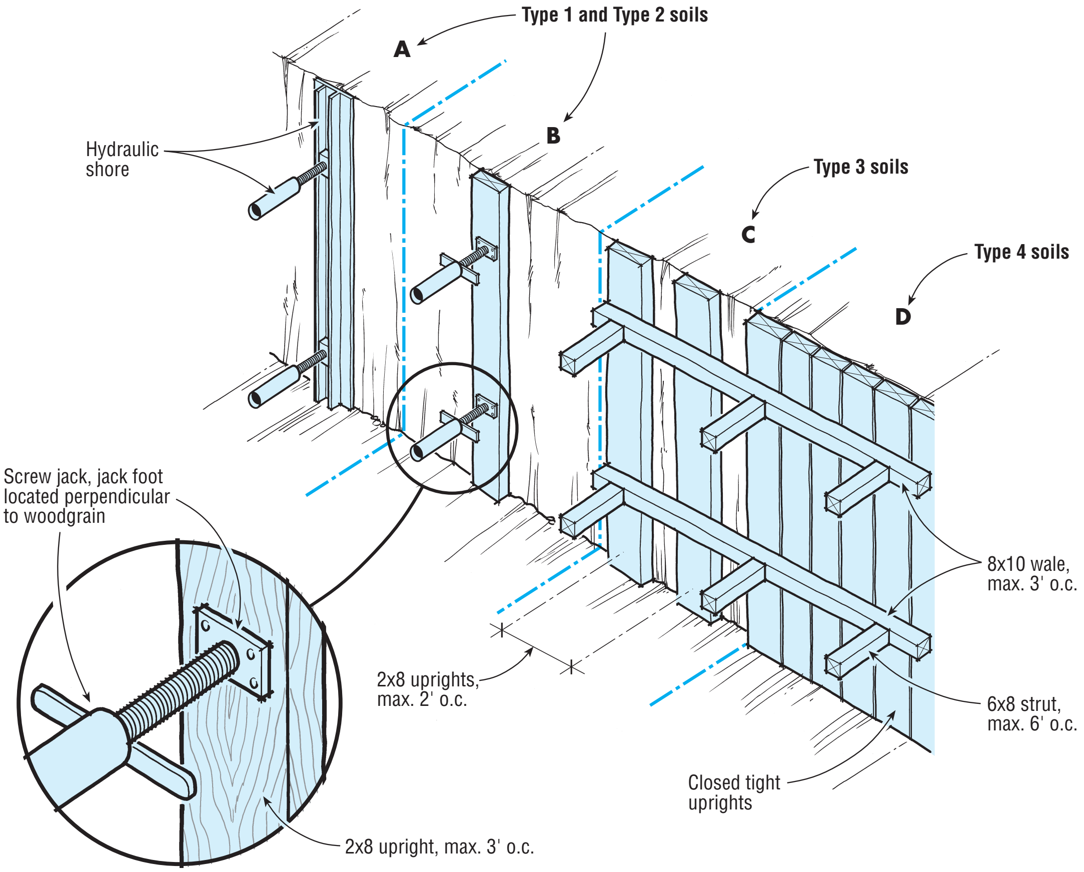


If the sides of an open excavation are higher than 7 ft., slope the sides back at an angle, or install shoring to protect workers who will be setting and stripping forms, applying dampproofing to the foundation, or laying foundation drainage.

Excavating Foundation Holes

Excavating Hillsides

FIGURE B: TRENCH SHORING



For wood shoring components, use No. 2 grade or better lumber. Dimensions shown are suitable for trenches up to 60 in. wide.

EXCAVATING HILLSIDES

One of the problems with excavating steep sites is that as you dig into a hillside, you remove material that holds the hill together, creating an unstable and potentially dangerous situation.

Angle of Repose

Excavate the hill back to an angle of repose — the angle at which the slope is stable. Each type of soil has a natural angle of repose. For most soils it is usually safe to excavate back to a 2:1 slope. This is the easiest and least expensive way to stabilize a hillside, but it's often not practical on a single-family lot because there simply is not enough room.

Vertical Cuts vs. Shoring

An unshored vertical cut should not exceed 5 ft. on a sloped site (**Figure C**). Be sure to reduce the danger of collapse by removing mounded dirt and rubble that can add a surcharge to the area above the cut. Install a series of steps or terraces — as required — to meet minimum height restrictions and reduce erosion (**Figure D**).

Often, shoring is the only safe alternative and will eliminate worry about how delays, change orders, or bad weather will affect the hillside (see Shoring).

Excavating Hillsides

FIGURE C: HILLSIDE CUTS

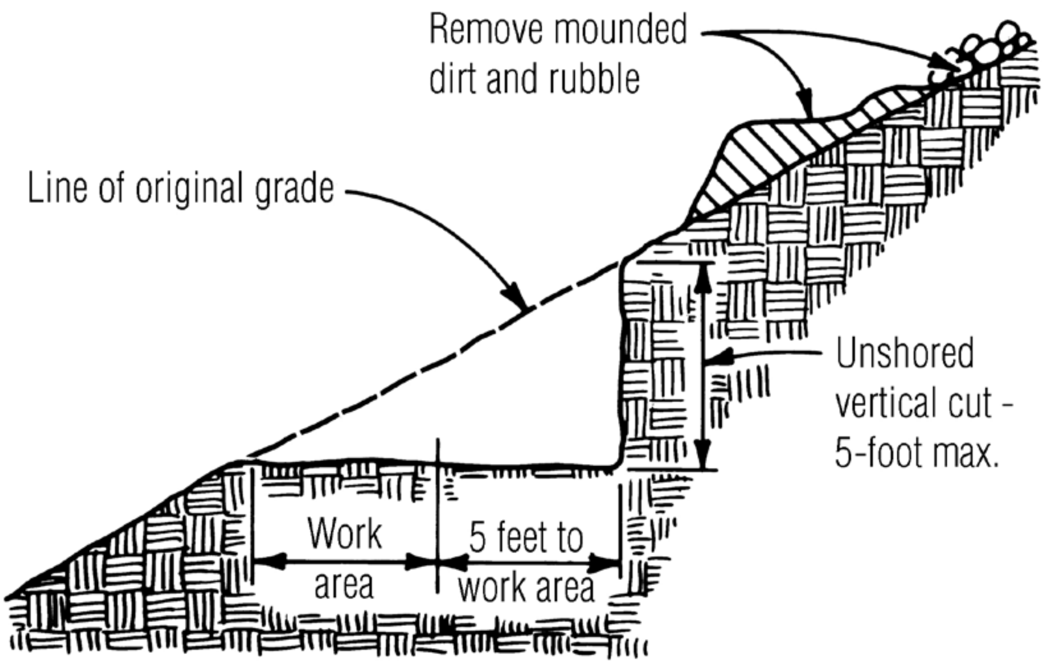
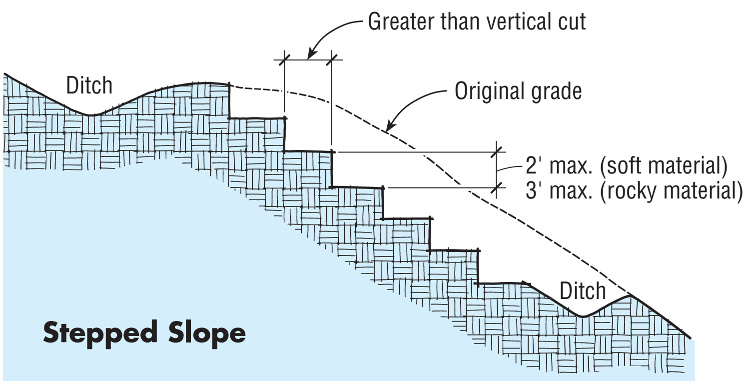
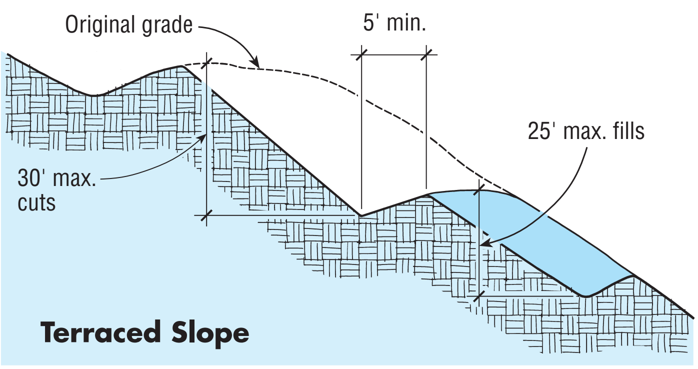


FIGURE D: STEPPED AND TERRACED SLOPES





Excavating Hillsides

Excavation Safety

Pressure Grouting

In porous soils, which are very much at risk of collapse, you may need to drill a pattern of small-diameter holes in the hillside and inject them with concrete. This kind of *pressure grouting* is expensive and is best left to an experienced specialty subcontractor.

EXCAVATION SAFETY

An excavation collapse poses an extreme danger to workers. Soil is heavy — typically weighing more than 100 pounds per cu. ft. This means that a 3x3x3-ft. hole will contain 27 cu. ft. of soil that can weigh almost 11/2 tons — as much as a car. If the soil is damp, wet, or filled with rock, it will weigh even more.

Excavation Failure

Keep an eye out for these signs of distress in and around trenches and open excavations:

- Cracks in the soil parallel to or in the face of an excavation
- Subsidence of the edge or bulging of the side of the excavation (this may be hard to see)
- Heaving or boiling of the bottom of the excavation, which is an indication of imminent failure
- Spalling or raveling of the face of the excavation (this probably indicates lack of proper sheeting and the lack of, or failure to, classify the soil)
- Water running into the excavation from the surface or face (do not allow workers in excavations with standing or running water)
- Bending, buckling, or groaning of any support member (if any movement of a support member can be seen or heard, an extremely dangerous situation exists)

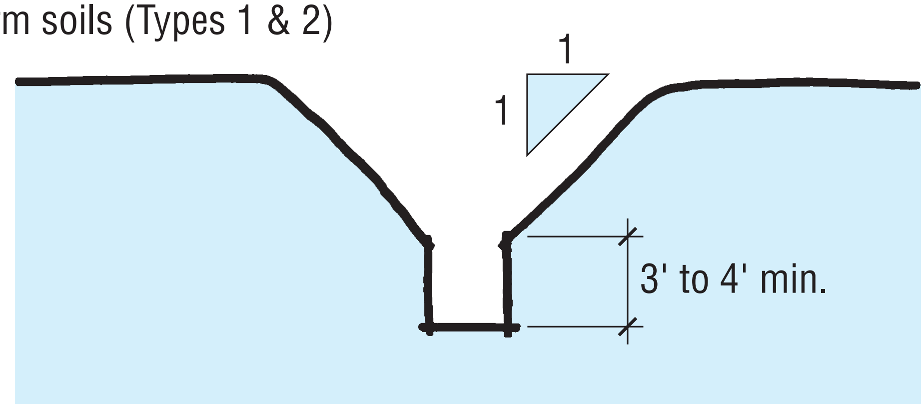
Trench Safety Checklist

- The sides of trenches may need to be sloped back, depending on soil type and trench depth (**Figure E**).
- Place excavated soil at least 2 ft. from the top edge of the trench, or position it behind a stable barrier.
- Trenches more than 4 ft. deep should contain an exit ladder which extends at least 3 ft. above ground level and is located within 10 ft. of a worker at all times.
- Cross-braces and trench jacks should be level and spaced vertically in order to prevent wall material from moving into the trench (**Figure B**).
- Trench boxes or safety cages can provide alternate -protection methods.

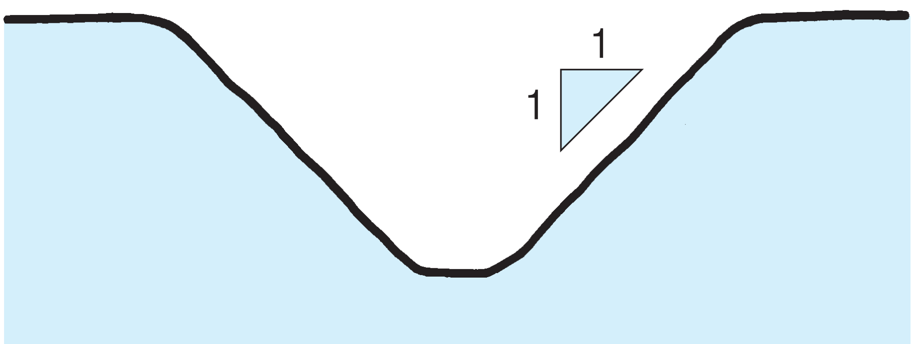
FIGURE E: TRENCHING CUTS

Excavation Safety

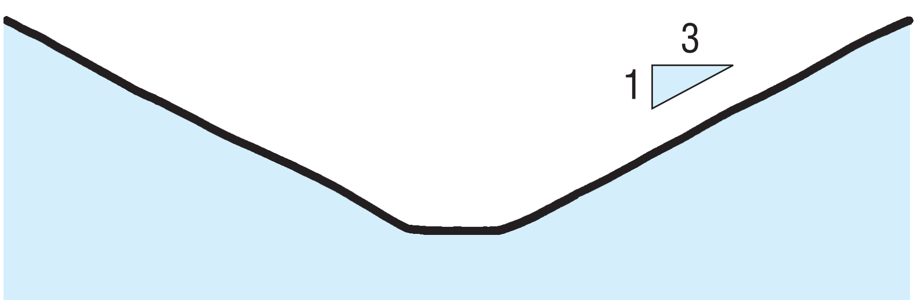
Stiff and firm soils (Types 1 & 2)



Soils likely to crack and crumble (Type 3)



Soft and loose soils (Type 4)



Stiff and firm soils: For trenches deeper than 6 ft., slope sides back at a minimum 45-degree angle above 4 ft. **Soils likely to crack or crumble:** Slope entire height of trench side at a minimum 45-degree angle. **Soft and loose soils:** In sand, gravel, silt, organic soil, soft and wet clay, and loose fill, cut trench sides at a minimum 3:1 slope.

SHORING

In areas where vibrations or unstable conditions are likely, such as near a highway, railroad, or a backfilled trench, plan for very complete shoring.

Provide shoring in an open excavation (foundation hole) deeper than 7 ft. and in trenches deeper than 6 ft., unless the sides have been cut at a slope. On hillside sites, restrict unshored, vertical cuts to 5 ft. (see Excavating Hillsides.)

Installing Shoring

- When installing shoring, place the bucket of the excavation machine in the trench directly in front of the shoring being installed.
- When installing shoring struts or jacks, work from the top down, and remove struts working from the bottom up. Using this method, the worker is protected by the shoring already installed.
- Do not try to remove a jack under pressure or it may cause a sudden collapse. Backfill up to the bottom jack before it is removed; then up to the next jack and so forth.

Shoring Alternative

If shoring is not used, slope the walls of the excavations at a grade of 1:1 (45 degrees) or shallower (**Figure A**). Foundation excavations should be sloped back anyway to provide room enough for a well-draining backfill.

PRACTICAL EROSION CONTROLS

Cleared and excavated sites are prone to erosion from runoff that will carry silt and sand, which can pollute streams and wetlands or damage nearby properties. Fuel, pesticides, and other chemicals also may be carried into the environment by runoff. To avoid liability and reduce landscaping costs, take these practical steps to minimize erosion and pollution:

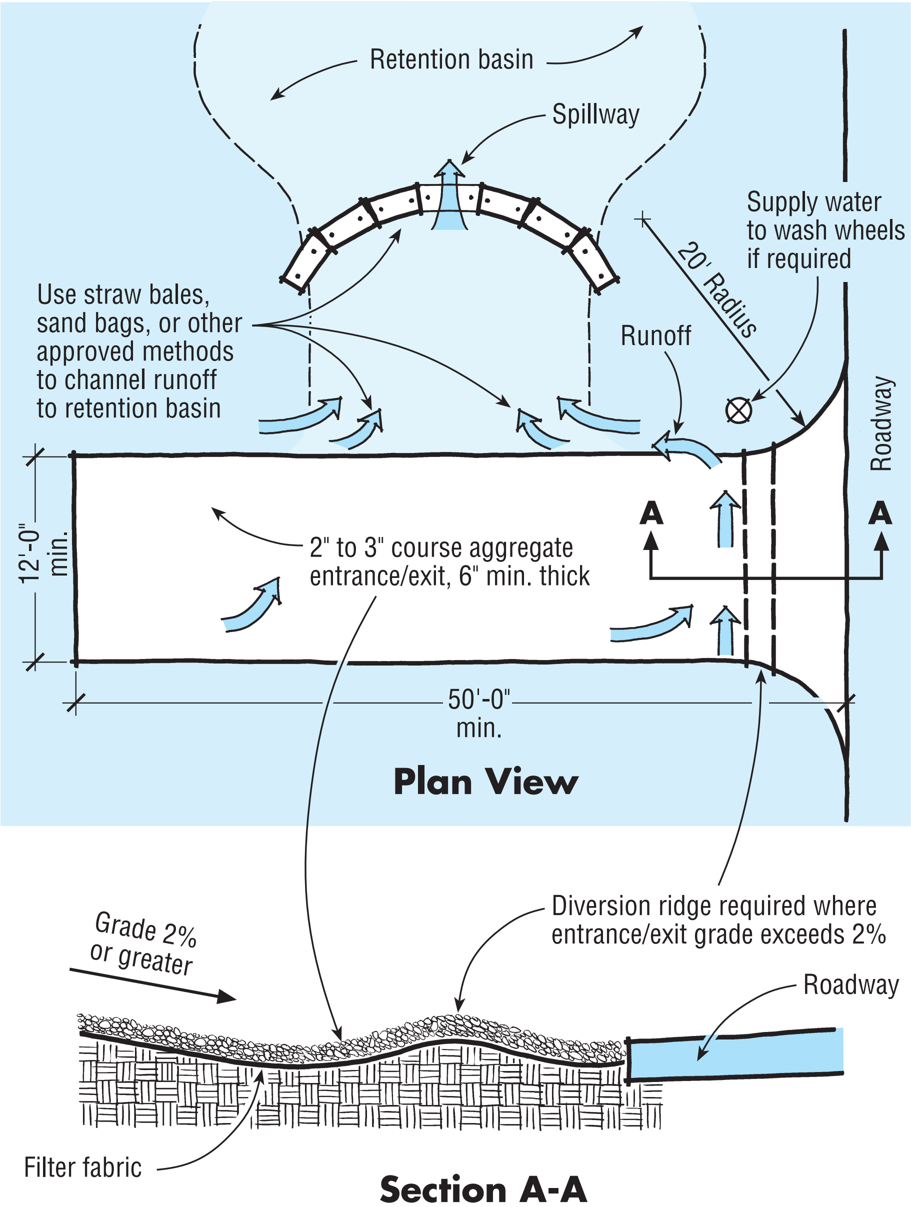
Preserve vegetation: Protect grass, trees, and other plants wherever possible. Maintain strips of grass or other growth across cleared slopes to catch water and soil runoff.

Schedule work in stages: Do not clear or excavate large areas too far in advance of construction; disturb vegetation only as needed, then reseed or replant as soon as is practical.

Control vehicle traffic: Limit equipment traffic in and out of the job site — do not drive over uncleared areas. Protect uncleared areas with snow fencing or other barriers. Place barriers around the drip-line of trees to prevent injury to root systems. If a permanent drive cannot be installed before construction begins, a temporary gravel driveway should be installed where vehicles enter the job site (**Figure F**).

Practical Erosion Controls

FIGURE F: TEMPORARY CONSTRUCTION ENTRANCE



Drives should be installed before construction begins. If the schedule does not allow for this, use 2- to 3-in. of coarse gravel for a temporary roadbed, and use silt fences or straw-bales to trap silt and prevent erosion.

Channel runoff: Divert runoff around cleared areas by mounding earth berms and digging swales. Where -concentrated runoff encounters a cleared slope, create a lined channel or install a drain pipe at the bottom of a swale and cover with gravel. Make drain channels as long and gently sloped as practical. Seed low-volume, shallow swales with grass. Use fabric or rock to protect higher-volume channels.

Install silt barriers: Erect silt fences or staked hay-bale -barriers on the downhill edge of disturbed earth slopes (**Figure G**). Straw bales placed on slope contours should be tightly butted and staked to prevent erosion or flow between and under bales (**Figure H**).

FIGURE G: SILT FENCE

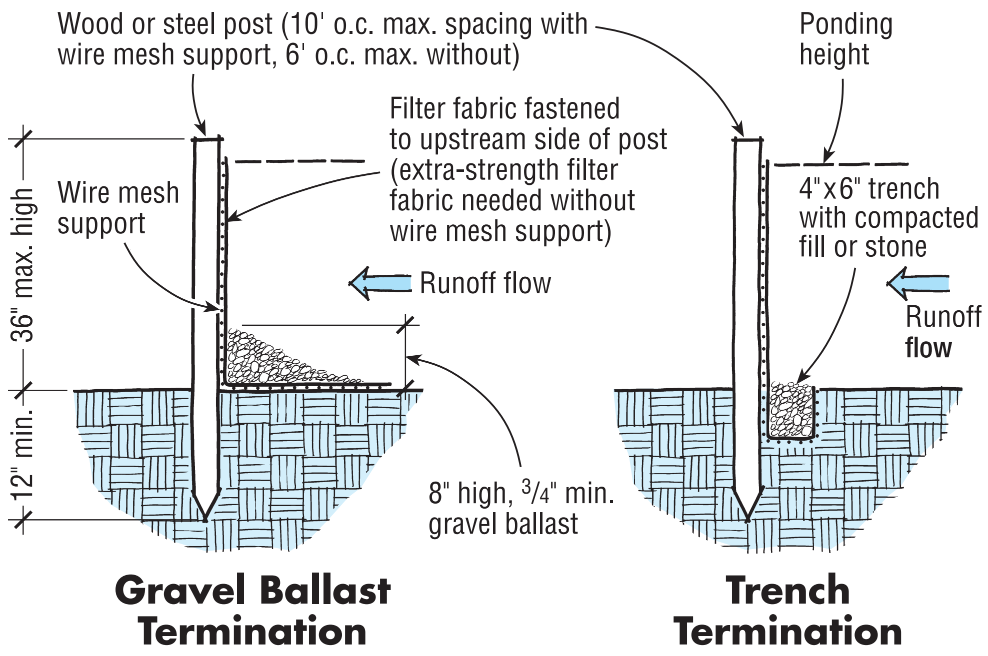
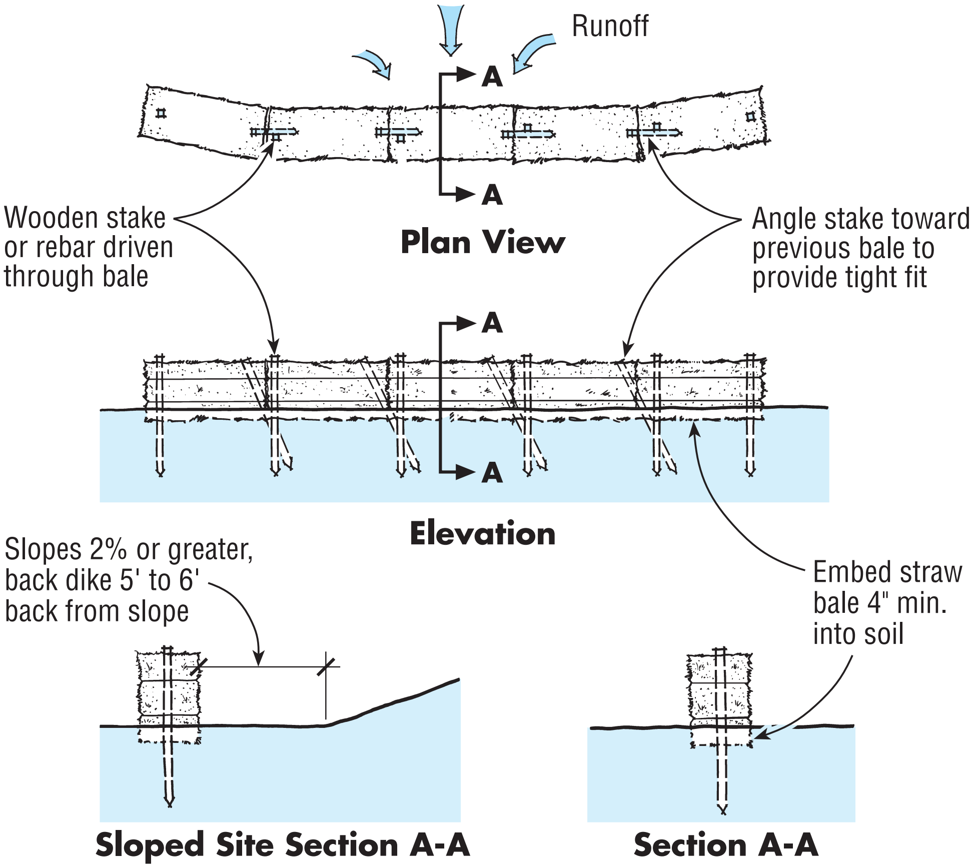


FIGURE H: STRAW-BALE DIKE



Practical Erosion Controls

Estimating Sitework

Protect drains and watercourses: Set up silt fences or staked hay-bale barriers around any stream, drainage channel, or drain opening. Surround storm drains with straw-bale dikes to detain water so silt can settle out. If plans include new, permanent stormwater drainage, install the system as soon as possible, then protect inlets during construction.

Build sediment traps: Use sandbag and gravel structures or silt fencing to pond and detain runoff water, allowing sediment to settle out. Inspect sediment traps and excavate sediment as needed. Place excavated sediment in flat upland areas and seed immediately.

Preserve topsoil: Topsoil is necessary for reseeded plants to thrive (**Saving Topsoil** in Site Preparation). If the existing topsoil will not support vegetation, import good soil. Topsoil is not suitable for use as backfill or subgrade.

Cover exposed soil: Reseed cleared areas as soon as possible. Seed soil (or excavated soil stockpiles) immediately if they will remain on the site for a period of time. If slopes or earth stockpiles cannot be reseeded immediately, cover with plastic sheeting (short-term only), mulch (heavy layer of wood chips or straw), or erosion-control fabric (mesh, netting, or geoblanket).

ESTIMATING SITEWORK

Costs of sitework depend on particular soil and site conditions (see Evaluating Soils on Site). Unseen soil conditions below grade can drastically increase sitework costs and change design requirements.

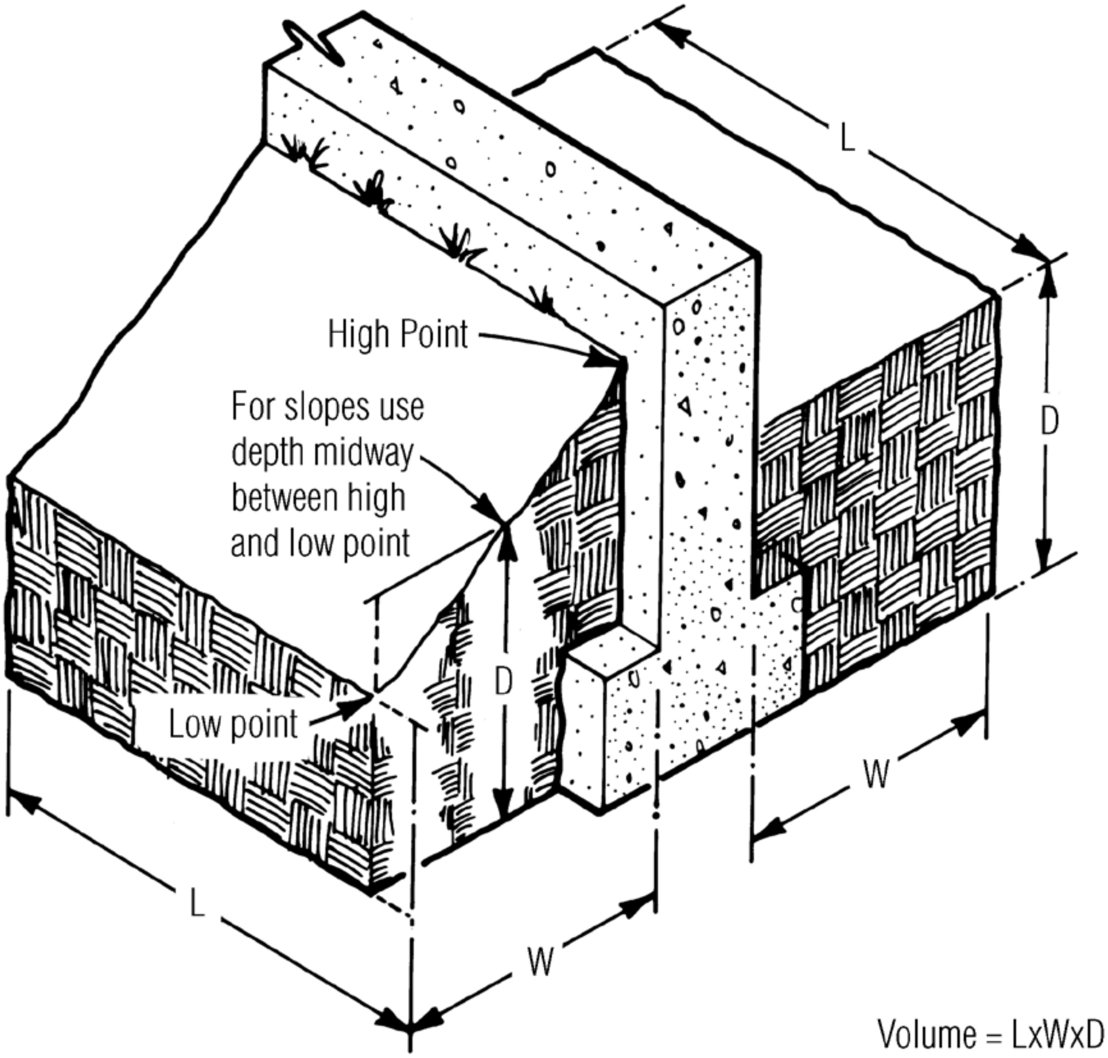
Estimating Earth Removal

When calculating earth removal volumes, the volume of dirt is always much larger than expected. Dirt becomes entrained with air as you dig and swells in volume; double the volume of *embankment earth* to find the volume of *loose yardage*. Calculate sloped embankments as shown in **Figure I**.

Estimating Sitework

Estimating Concrete

FIGURE I: ESTIMATING EARTHWORK



When calculating the volume of sloped earth, measure the depth of the cut midway between the high point and the low point of the slope.

When pricing excavation and fill, include these factors:

- **Hauling Charges:** Hauling is often the biggest cost of fill materials, and travel time can also boost excavators' and other operators' fees.
- **Disposal Charges:** Costs of disposal for removed earth and rock vary by locale.

ESTIMATING CONCRETE

Concrete subcontractors often charge a unit rate per yard of concrete, especially for flatwork. Use **Figure J** to calculate total yards of concrete.

Use a 5% to 10% waste factor to cover subgrade irregularities or spillage. If pouring trenched footings, overdigging in the trench cannot be filled with soil, so allow for extra concrete.

Estimating Concrete

FIGURE J: COVERAGE OF ONE CU. YD. CONCRETE

Wall Area (Sq. Ft.) = Wall Ht. x Wall Length
Slab Area (Sq. Ft.) = Slab Length x Slab Width
Yds. of Concrete = Area ÷ Coverage

Thickness of Wall or Slab (in.)	Coverage (sq. ft./yd.)
12	27
11	29.5
10	32.4
9	36
8	40.5
7	46.3
6	54
5	64.8
4	81
3.5	92.6
3	108
2.5	129.6
2	162

To calculate the concrete yardage required for a foundation wall or slab, first calculate the wall or slab area, then divide by the coverage factor (column 2 for each given thickness).

Estimating Concrete for Piers

Figure the amount of concrete needed to fill a sonotube by multiplying the height of the tube in feet by the concrete amount per pier, as shown in **Figure K**.

FIGURE K: CONCRETE AMOUNTS FOR PIERS AND PIER FOOTINGS

Round Pier Footing Diameter	Concrete Amt. per Pier	80-lb. Bags Concrete Mix
8-in.	.013 cu. yd.	0.6 bags per ft.
10-in.	.02 cu. yd.	0.9 bags per ft.
12-in.	.029 cu. yd.	1.3 bags per ft.

Rectangular Pier Footing Dimensions	Concrete Amt. per Footing Unit	80-lb. Bags Concrete Mix
8x16x16-in.	.044 cu. yd.	2 bags
10x20x20-in.	.086 cu. yd.	3.8 bags
12x24x24-in.	.15 cu. yd.	6.75 bags

ESTIMATING BLOCK

To estimate standard 8x16-in. block:
1 Square Ft. of Wall = 1.125 Block
Wall Area (Sq. Ft.) x 1.125 = Total Block Needed

(Note: When using 8-in. block, convert all wall and opening heights and lengths to multiples of 8 in.)

ESTIMATING MORTAR

When mixing mortar, allow one bag of masonry cement for every 28 block:
Total Block Needed ÷ 28 = Bags Cement Needed

Allow one ton of sand for each 8 bags of masonry cement:
Total Bags of Masonry Cement Needed ÷ 8 = Tons of Sand Needed

Mortar Batches

When setting block, expect to use about one batch of mortar per 100 block. When using mortar to set and parge, allow one batch per 60 block.

SOIL TYPES

Good natural soils can support almost any residential foundation. However, problem soils can contribute to moisture problems, settlement, building movement, or foundation failure. Soil problems can turn up after construction has begun. When work starts, stay alert to soil conditions that may affect schedules or could cause damage to work in progress — especially subsidence, erosion, frost action, or drainage problems.

Different soil types are classified mostly by the size of the soil particles (**Figure L**).

FIGURE L: SOIL TYPES

Soil Type	Particle Size(fractions of in.)
Gravel	Larger than 1/5
Coarse Sand	1/5 to 8/100
Fine-Medium Sand	3/1,000 to 8/100
Silt	3/1,000 to 4/10,000
Clay	Smaller than 4/10,000

Different soil classification systems use different particle sizes to define soil types. Approximate values shown here are drawn from the Unified Soil Classification System. To determine particle sizes, samples are sifted through a series of screens

Most soils are blends of different particle sizes, and so they have combined names such as “silty sand” or “clayey -gravel.”

Characteristics of Soil Types

Different soils have different characteristics that make them more or less suitable as a support for a foundation or as a well-draining backfill. Refer to **Figure M**.

Soil Types

FIGURE M: PROPERTIES OF SOILS ACCORDING TO THE UNIFIED SOIL CLASSIFICATION SYSTEM

Soil Group	Unified Soil Classified System Symbol	Soil Description	Drainage Character-istics	Frost Heave Potential	Volume Change Potential (Expansion)
Group I	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Good	Low	Low
	GP	Poorly graded gravels or gravel-sand mixture, little or no fines	Good	Low	Low
	SW	Well-graded sands, gravelly sands, little or no fines	Good	Low	Low
	SP	Poorly graded sands or gravelly sands, little or no fines	Good	Low	Low
	GM	Silty gravels, gravel-sand mixtures	Good	Medium	Low
	SM	Silty sand, sand-silt mixtures	Good	Medium	Low
Group II	GC	Clayey gravels, gravel-sand-clay mixtures	Medium	Medium	Low
	SC	Clayey sands, sand-clay mixtures	Medium	Medium	Low
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium	High	Low
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Medium	Medium to Low
Group III	CH	Inorganic clays of high plasticity, fat clays	Poor	Medium	High
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	High	High
Group IV	OL	Organic silts and organic silty clays of low plasticity	Poor	Medium	Medium
	OH	Organic clays of medium to high plasticity, organic silts	Unsatisfactory	Medium	High
	PT	Peat and other highly organic soils	Unsatisfactory	Medium	High

Note: The percolation rate for good drainage is over 4 in. per hour; medium drainage is 2- to 4-in. per hour; and poor drainage is less than 2 in. per hour. The table above shows the two-letter designations for the soil types defined in the Unified Soil Classification System, which is widely used for construction engineering. A soil engineering report will usually use this scheme to identify soils on a site. In general, sands and gravels have good characteristics for bearing strength and drainage, while soils that contain more fine silt or clay are weaker and drain more slowly. Soils that contain large amounts of decaying plant material (the peats and organic clays) are no good for building and have to be removed.

BEARING CAPACITY OF SOILS

Bearing Capactiy of Soils

If the native soil type is known, codes allow builders to assume a bearing strength based on soil type (**Figure N**). Footings must be placed on undisturbed original soil to use these assumed values. Soil testing may establish higher bearing strengths, in which case footing size sometimes can be reduced.

FIGURE N: SOIL BEARING CAPACITIES

Material	Loadbearing Value (pounds per sq. ft.)
Chrystalline bedrock	12,000 psf
Sedimentary rock	4,000 psf
Sandy gravel or gravel	3,000 psf
Sandy, silty sand, clayey sand, silty gravel, and clayey gravel	2,000 psf
Clay, sandy clay, silty clay, and clayey silty	1,5000 psf

Loadbearing values indicate the amount of force that undisturbed, native soils can support. Refer to Figure: Minimum Width of Concrete or Masonry Footings (in.) in Footings for sizing concrete and masonry footings.

To support foundation loads, the width of the footing depends on the loadbearing value of the soil. See Footings.

Problem Soils

Organic soils. Soils containing decaying plant or animal matter, like topsoil or peat, are a special type called *organic soils*. Organic soils will not support a building and should be removed, or the building must be relocated.

Expansive clay. Certain clays that are highly attractive to water tend to expand with force when wet and shrink when dry; this is a special class of soil called *expansive clay*. Expansive soil swells when it gets wet and shrinks when it dries, leaving large cracks that channel water down into the hillside. The swelling action of expansive soil can be powerful enough to lift a house, and expansive soil used for perimeter fill can cause windows and doors to stick, and stucco, siding, drywall, and even the foundation to crack. A site with expansive soil may require specialized pier and grade beam foundations with extensive drainage, deeper piers and footings, and more heavily reinforced concrete slabs (see Pier Foundations). In many cases, the expansive soil must be removed and replaced with non-expansive fill.

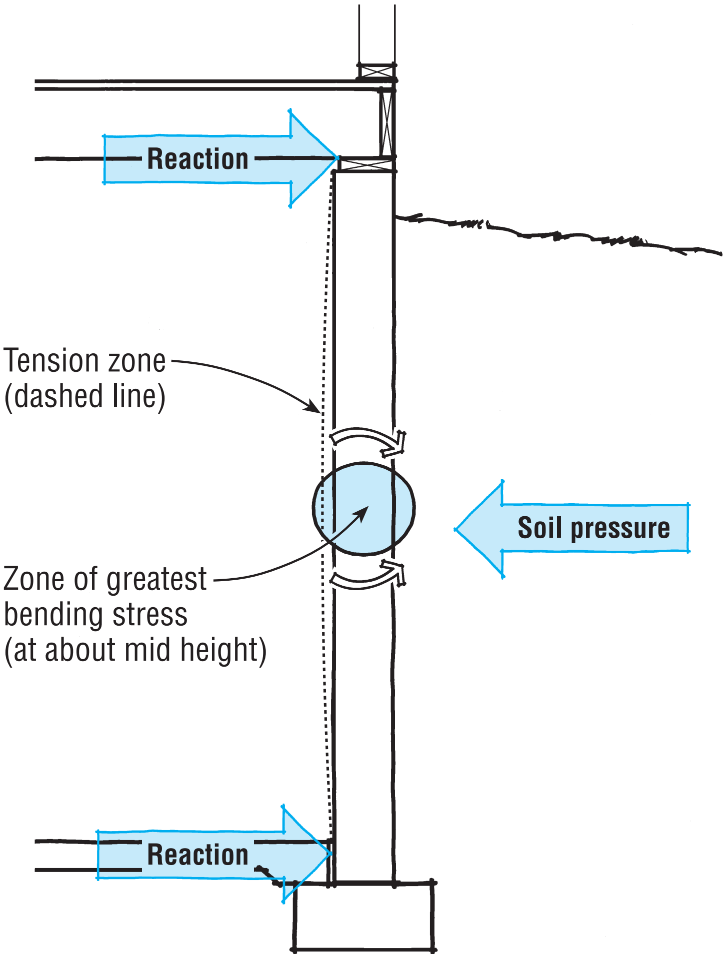
Natural fill vs. engineered fill. Soils that have been moved or brought in from outside, called *fill*, are not a soil type as such, but may be any type of soil that's been moved to a new location. Fill often contains junk, debris, or wood and tree stumps. Because it subsides, compresses, and washes out, fill is generally unsafe to build on. The only exception is *engineered fill*, or soil material that has been carefully placed and compacted under an engineer's supervision.

Soil Pressures on Foundations

SOIL PRESSURES ON FOUNDATIONS

Pressure exerted by soil on the sides of foundation and basement walls is a major concern in the design and construction of foundation walls (**Figure O**) and retaining walls. This is known as *lateral pressure*, and is defined in terms of *equivalent fluid pressure*. Similar to the way water pressure increases at increased depth, lateral soil pressure increases with depth of soil (or height of fill).

FIGURE O: LATERAL PRESSURE ON FOUNDATIONS



In all but the sandiest soils, the pressure of the earth can bow and crack a concrete foundation wall. Well-draining backfill reduces lateral pressure, while rebar strengthens the concrete and prevents cracks from appearing on the inside face.

Water in soil tends to increase lateral pressure:

- Silts and clays (especially clays) become more fluid-like as they become wet or saturated, exerting greater lateral pressure than they do when dry.
- Sands and gravels tend to be less influenced by water content.

Equivalent Fluid Pressure

Soil pressures are usually the greatest loads on a foundation. Code rules of thumb can be used when building on sites with natural sand or gravel soils. Engineered design is recommended when natural soils are clay or silt.

Soil Pressures on Foundations

As a rule of thumb, code assumes a lateral fluid pressure of 30 psf for block or concrete foundations, which is typical for a well-drained sand or gravel soil. But fine, cohesive soils can exert higher pressures. **Figure P** shows typical fluid pressures associated with various soil types in different foundation cases.

Look for foundation soils that exert low pressures in the active and at-rest cases, and exert high resistance in the passive case. Sand and gravel meet these requirements. By contrast, soft clays — which exert high pressures in the active and at rest cases and are relatively weak in the passive case — are not good foundation soils. Foundation and retaining wall failure is a much greater threat when the structure is built on clay.

FIGURE P: SOIL FLUID PRESSURES

Soil Classification	Friction Angle (degrees)	Density or Consistency	Unit Soil Weight (pcf)	Equivalent Fluid Pressure (psf/ft. of depth)		
				Active	At Rest	Passive
Coarse sand or sand and gravel	45	compact	140	24	41	820
	38	firm	120	29	46	510
	32	loose	90	28	42	290
Medium sand	40	compact	130	28	46	600
	34	firm	110	31	48	390
	30	loose	90	30	45	270
Fine sand	34	compact	130	37	57	460
	30	firm	100	33	50	300
	28	loose	85	31	41	280
Fine, silty sand or sandy silt	32	compact	130	40	61	420
	30	firm	100	33	50	300
	28	loose	85	31	45	280
Fine, uniform sand	30	compact	135	45	68	400
	28	firm	110	38	58	300
	26	loose	85	33	48	220
Clay silt	20	medium	120	59	79	245
	20	soft	90	44	59	183
Silty clay	15	medium	120	84	99	170
	15	soft	90	53	67	153
Clay	10-0	medium	120	84-120	99-120	170-120
	10-0	soft	90	63-90	74-90	153-90

This chart shows estimated pressures exerted by various types of soils under three conditions. The **active** case refers to situations where the structure can give somewhat to relieve the pressure, such as a foundation restrained by a wood frame floor. The **at rest** case applies if the structure cannot flex at all, as when a foundation wall is pinned in place by a concrete slab. The **passive** case applies when the structure wants to move but the soil is resisting that force.

SOIL DRAINAGE

Coarse soils drain better than fine soils. The ability to drain is measured by a *permeability coefficient* (**Figure Q**). The higher the coefficient, the better a soil can drain.

FIGURE Q: PERMEABILITY RATES IN SOILS

Soil	Permeability Coefficient
Fine to coarse, clean gravel	23 ft./min.
Uniform, fine gravel	11 ft./min.
Uniform, very coarse, clean sand	6.9 ft./min.
Uniform, coarse sand	1.0 ft./min.
Uniform, medium sand	14 ft./hr.
Clean, well-graded sand and gravel	1.4 ft./hr.
Uniform, fine sand	13 ft./day
Well-graded, silty sand and gravel	1.3 ft./day
Silty sand	9.8 ft./month
Sandy clay	5 ft./month
Silty clay	1.2 in./month
Clay	1.2 in./month

Soils with high permeability coefficients drain faster, and therefore exert less pressure against the foundation.

EVALUATING SOILS ON SITE

It is hard to identify soils precisely in the field. If you are uncertain about the soil type, consult a soil engineer. A preliminary soil investigation may give enough information to go on, but sometimes an engineering soils report will be required.

Soil Identification

Some rough information about soils can be learned from simple on-site tests:

- **Dirt-ball test:** To assess soil cohesiveness, take a moist double handful of soil and squeeze it into a ball, then drop it from a height of about 1 foot. If the soil will not form a ball or if the ball readily fragments when dropped, the soil is relatively non-cohesive and granular, with a low proportion of fine clay. However, if the soil forms a ball that holds together when dropped, it is more likely to contain a high percentage of cohesive clay.
- **Water suspension test:** Drop a scoop of soil into a large jar of water. Gravel and sand will settle to the bottom of the jar almost immediately. Finer silt particles will take fifteen minutes to an hour to settle. Clay particles will remain suspended in water for a day or longer. So if the water remains very cloudy for a long time, the soil probably contains a high percentage of clay.
- **Noodle test:** Roll a small quantity of soil into a thin noodle or string shape between your palms. If the soil can be rolled as thin as 1 in. without breaking apart, it is probably a cohesive soil with a substantial percentage of clay.

Evaluating Soils on Site

Compacting Soil

Caution: These casual tests are not a substitute for a soils laboratory report. Visual identification of soils is unreliable. For example, soils containing both clay and gravel may look like gravel but behave as clay. Soils containing 20% clay have the bearing strengths and drainage characteristics of a clay soil, and soils containing 30% clay are defined as clays even though large amounts of gravel may be present.

Soil Borings

The building department may require soil borings taken by a qualified geotechnical engineering firm. Even if not required, an engineer's report is useful to establish the type of soil, the bearing strength of the soil, lateral soil pressures, drainage characteristics of the site, and the presence of rock below the surface.

- Soil borings, or "test pits," are recommended on low-lying sites near water, on sites that are suspected of having been filled in the past, or whenever soft, unstable, or expansive soils are encountered during excavation.
- Sample borings are especially important where piers are involved, because they help determine both the presence of water and the anticipated depth of the piers.
- A sample boring analysis can determine whether on-site soils will be useful as engineered fill.

Number of Borings

- On flat, well-drained sites, at least two test pits should be bored, at opposite corners of the proposed foundation. Intermediate borings may be required if the test holes are far apart. It is the site engineer's responsibility to determine if this is required.
- On hillsides or potentially wet sites, at least four or five borings should be taken, preferably on both the uphill and downhill sides of the proposed building.

Depth of Borings

- On flat, well-drained sites, borings should be made to a depth 5 to 8 ft. below the proposed footing depth.
- On hillsides, deep borings — 25 ft. deep or deeper — are essential. A deep boring can better define "bedrock" and help locate subterranean water moving horizontally through the hillside. A deep boring may also identify ancient landslides and waterways, which can affect the stability of the ground above.

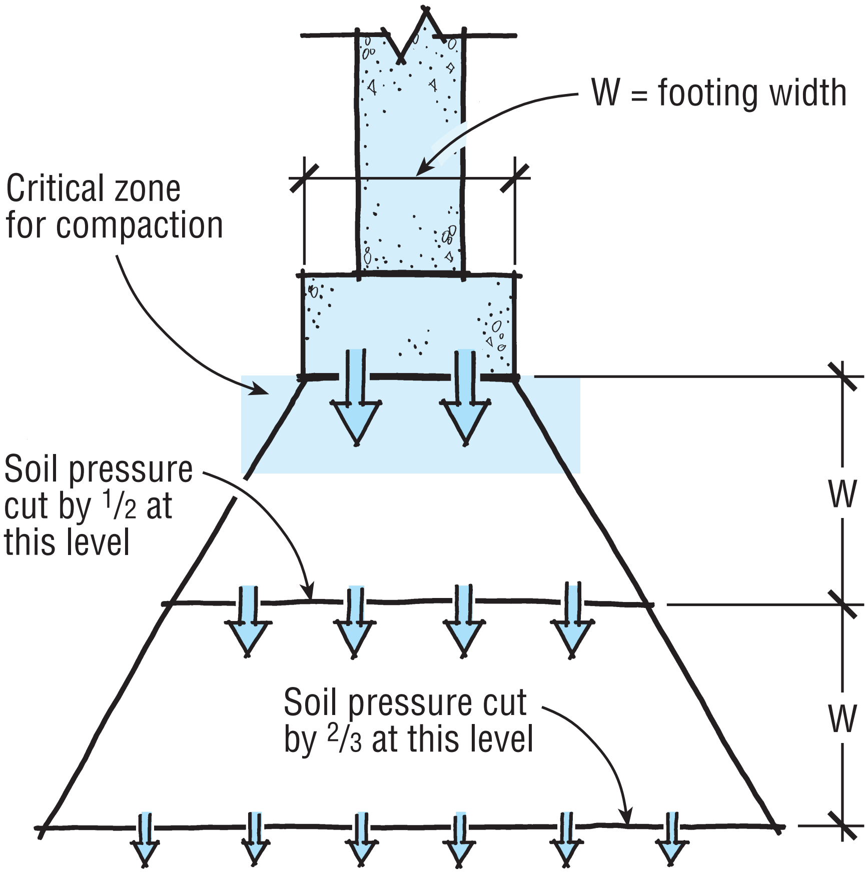
COMPACTING SOIL

Any fill that is placed during or after construction, and any soil that is disturbed during excavation, must be compacted to prevent future settlement.

- Compact footing trenches and slab sub-bases before pouring footings or adding a gravel base (**Figure R**).
- Compact backfill in utility trenches to prevent settlement.
- Compact backfill around foundation walls.
- It is best to use a gravel or sandy gravel for fill, because the compaction of silts and clays is too hard to control.

Compacting Soil

FIGURE R: SOIL PRESSURE BETHEATH FOOTINGS



As the load under a footing spreads out, pressure on the soil diminishes. Soil directly under a footing takes the greatest load. To ensure against settlement, footing trenches should be thoroughly compacted.

Compacting Different Soil Types

Some soils are easier to compact than others (**Figure S**). In general, gravel sub-bases can be quickly compacted with a vibrating plate compactor. Gravel used for backfill will settle very little, even if not compacted. By contrast, clays typically require engineering and may not be practical to compact at all.

FIGURE S: SOIL COMPACTING CHARACTERISTICS

Type of Soil	Compacting Characteristics and Equipment
Gravel	Compacts readily with vibrating plate
Sand	Compacts well with vibrating plate
Silt	Can be compacted with difficulty; impact compactors work best
Clay	Difficult or impractical to compact (consult engineer)
Organic soil	Not compactible (do not use for building site)

Each type of soil responds best to a given type of compaction equipment. Any organic soil, such as topsoil or peat, cannot be compacted and should not be used.

Compacting Equipment
For gravels and sands, use a vibrating plate compactor or vibrating smooth roller. For silts, use a vibrating compactor or an impact compactor (jumping jack). For clays, use an impact compactor.

Compact Soil in Lifts
Place and compact soil in lifts no higher than 6 in.

Effect of Moisture on Compaction
Different soils compact best at different moisture contents. Moisture in a granular soil lubricates the grains and helps them slide into a more tightly packed arrangement. In cohesive soils, moisture makes the soil somewhat mold-able. However, too much moisture in a soil will hold particles apart and prevent full compaction. On site, properly moistened soils will hold together in a ball when squeezed, but will not release water. To accurately specify and monitor optimum soil moisture, however, engineering services are required.

Compaction Engineering
Jobs with soil engineering specifications usually call for a minimum soil compaction as measured by the *Proctor test*. This lab test determines the optimum moisture content of a specific type of compacted soil. An engineer can then measure field compaction with a density meter; 90% of the lab value is considered sufficient.

DRIVEWAY LAYOUT
Evaluate the drainage strategy for any drive at the layout stage (see Subgrade, below).

Driveway Width
Plan for a 12- to 14-ft.-wide roadbed. With a paved roadbed, you could get away with 11 ft., but some drivers might feel a little restricted on such a narrow drive, especially if it's long.

If you have two or three houses at the end of the driveway, with two-way traffic likely, you'll need to go with a 22-ft.-wide road.

Turnarounds
On a long driveway, plan for parking and a turnaround so residents don't have to back out. Don't skimp on space in a turnaround; the minimum turning radius should be 24 ft. to allow room for larger cars or pickup trucks.

SUBGRADE
- All driveway beds should be cut in stable native soils.
- Cut out soil or place fill to create the proper drainage grade.
- Plan the cut so the finished driveway is at least 1 in. higher than the surrounding soil.
- Clear the roadbed of roots, twigs, bushes, grass, and topsoil that will decay and might cause the drive surface to sink or break up.

Unsuitable Soils
Peat and expansive clays should be excavated and replaced with compacted granular fill. Unpaved drives built on soils with high clay content must be stabilized with lime (see **Subgrade Stabilization** in Unpaved Drives)

Subgrade

Drainage

Existing Fill

On existing home sites, probe the soil with a steel rod. If resistance below the top 6 in. is less than resistance at the surface, deep fill may have been placed and compacted only at the surface, leaving an unreliable subgrade. Uncompacted fill should be excavated down to native soil and replaced with proper fill.

DRAINAGE

A subsurface drainage system consists of trenches, drainpipe, stone or gravel aggregate, and geotextiles (**Figure T**). A complete system is crucial to keeping unpaved drives from turning to mud, and for extending the life of more expensive paved toppings.

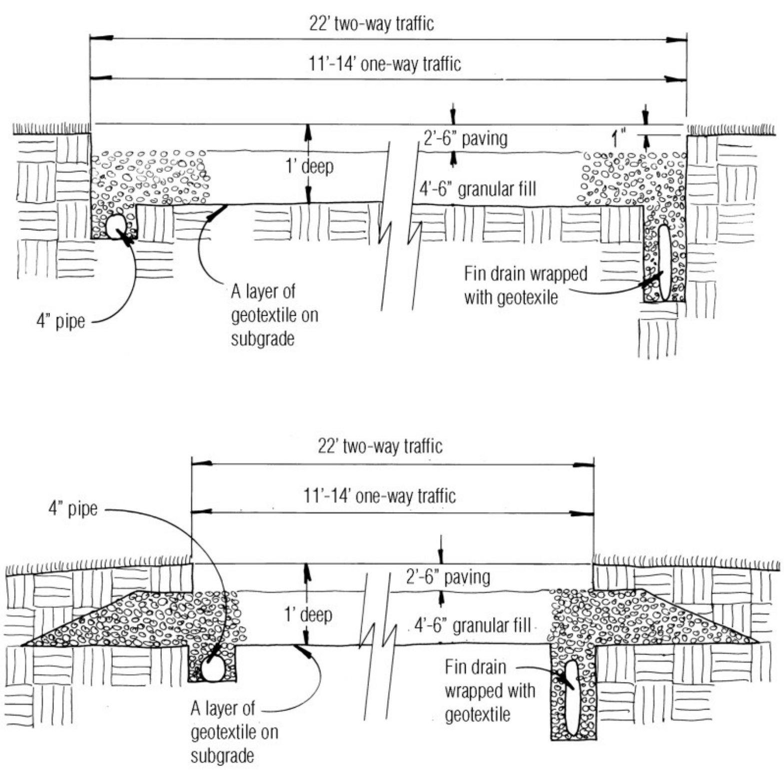
Drainage Patterns

Grade the subsurface so it slopes away from the building site, if possible, to allow water from rain or snow-melt to drain away from the house.

Drainage for Downhill Drives

If the building site is at the bottom of a slope, build a swale to collect water, or use a slot drain in front of the garage door and wherever else the water might flow toward the building. Connect slot drains to a collection drain large enough to carry the water away from the building. If the drainage design might not completely handle all the water, plan on a step-up and ramp into the garage.

FIGURE T: ROADBED CONSTRUCTION



A roadbed must have a drainable aggregate base and good subsurface. Use either a 4-in. pipe drain or a fin drain to collect the water. To protect edges from becoming rutted, extend the base at least 18 in. from the surface edges (at bottom).

Drainage for Uphill Drives
On uphill driveways, route subsurface drainage to a storm sewer or ditch at the edge of the main road. On rural sites, the driveway usually passes over an entrance culvert where it intersects the main highway. Bring the drain pipe from your drain system to this collection point, so the ditch will carry away the run-off. Put a rodent screen over the drain pipe because field mice will damage polymeric materials.

Drainage Trenching
After grading the roadbed, excavate drainage trenches on both sides of the road. A small, 6-in.-wide chain trencher works best. The trenches should be at least as deep as the drain pipe or fin drain, but deeper is better.

Geotextiles
After grading subgrade, lay down a good "road fabric" — a minimum 20-mil woven polypropylene. Geotextile fabric actually provides tension support across the bottom of the base materials, allowing the road to carry greater loads. Without road fabric, wheel action will eventually push the granular base materials into the mud, creating potholes in paved surfaces and corrugations in unpaved surfaces.

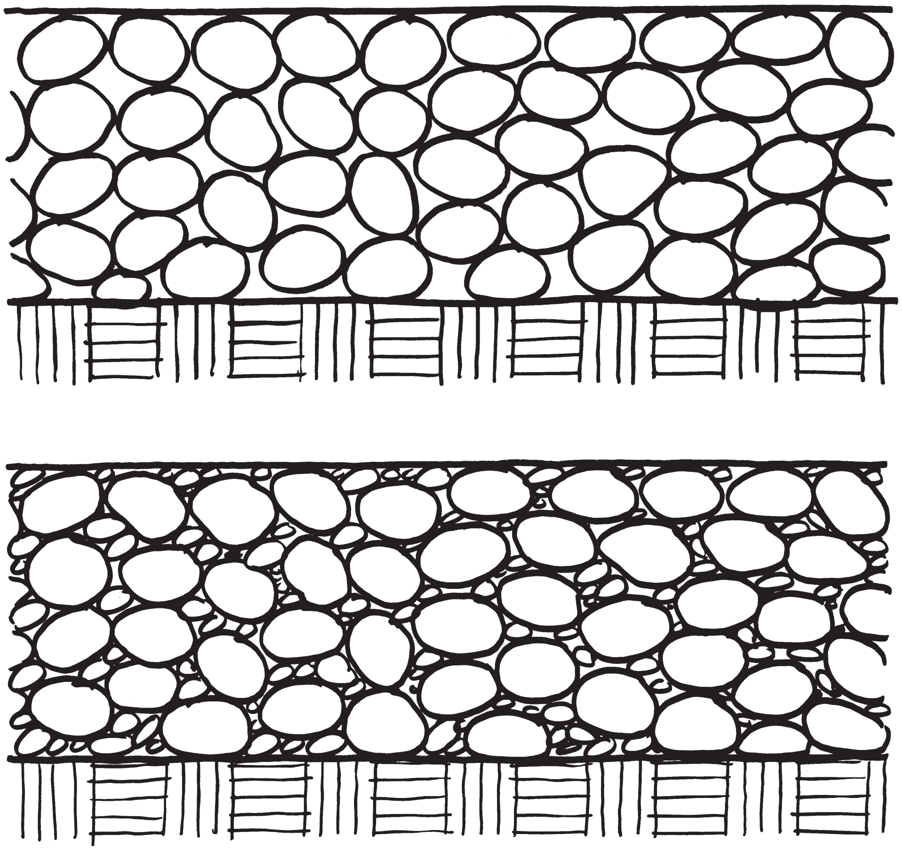
Drainage Pipe
Lay the geotextile across the subgrade and drainage trenches, then lay in drainage pipe — a standard 4-in. corrugated drain tubing or fin drains. (Fin drains can carry more water; see Drainage). Wrap geotextile around the drain.

Driveway Shoulders
On many driveways, the owners will want to landscape right up to the edge of the paving. The best way to handle this is to extend the road base 18- to 24-in. beyond the road surface, then haul in topsoil, spreading it over the shoulders of the base and right to the edges of the finish surface (**Figure T**). This method will help stabilize the edges of the surface lift.

Driveway Base Materials
Good road base requires a mix of aggregate sizes (**Figure U**). Avoid using pea gravel and other natural gravels from river deposits. These aggregates are too round and smooth, and will not compact well, so they are likely to shift under traffic.

Drainage

FIGURE U: ROAD MIX



A roadbed made from stones of equal size (at top) will shift under the weight of vehicles. A dense mix of stones of different-sized aggregate (at bottom) will compact under load.

Placing Base Materials

Firm compaction of base fill is crucial for any areas that will carry vehicle traffic. Place up to 12 in. of fill in at least two, 6-in. lifts. Compact each lift with the wheels of a trac-tor or with construction trucks, or compact with a small crawler (roller) from a rental yard. If the schedule allows, let the driveway sit for several months to allow-- settlement before placing a final 3- to 4-in. lift of surface fill (gravel drives) or paving with asphalt or concrete.

Wet-Site Roadbeds

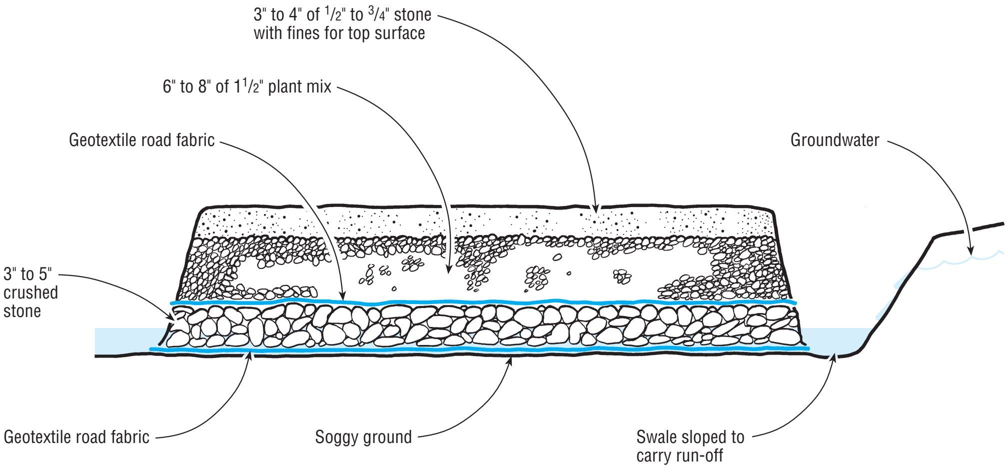
When building a road over wetlands, do not cut and fill. Not only is digging messy and expensive, but it may be difficult to get permits. Land planners frown on any roadbed with deep gravel fill that might create a dam and block wetlands from flowing.

Lay road fabric over the ground, and place a layer of 3- to 5-in. stone on top of the road fabric to help spread out traffic loads on the soggy land (**Figure V**). Over this stone, spread another layer of geotextile, and place 6- to 8-in. of mixed gravel base material, topped by a 3- to 4-in. layer of gravel surface mix.

Drainage

Unpaved Drives

FIGURE V: DRIVEWAY CONSTRUCTION FOR WET SITES



On wet sites, place road fabric directly on top of soggy ground and cover with a heavy stone base. Next, install a second layer of fabric over the stone before placing the gravel base and surface layers.

Base Materials for Unpaved Drives

The base material used for an unpaved drive is different than it is for paved roads, but good base and subgrade drainage material are important for both.

- **Road pack:** A mix of gravel or crushed stone, road pack contains a high percentage of fine aggregate (called "fines"), and is the least expensive material used for unpaved drives. While road pack compacts well and is reasonably stable when dry, it has very poor internal drainage and gets soft and spongy when wet. Do not use in wet, low-lying areas. A road bed made of this material should be graded several times a year to keep it from getting rough and to keep it free of potholes.
- **Open-graded aggregate:** This is a gravel mix with particles ranging from about 1/4- to 1-in. in diameter (range of sizes in the mix varies according to local supplier), which will drain better than road pack, but is not stable enough to use as the surface course of a driveway.
- **Crushed stone:** The best base material for a gravel drive is crushed stone, which is angular and compacts well, but doesn't clog as easily as road pack. The more angular the material, the less regrading will be required. Crushed stone mixes vary by region, and every region has its own numbering system for specifying aggregate.

UNPAVED DRIVES

Unpaved roads typically have the same surface and base materials (see "Base Materials for Unpaved Drives," above). Proper subgrade preparation, good subsurface drainage, and the use of geotextiles are critical for maintaining a drivable surface over time.

Subgrade Stabilization

Subgrade soil stabilization will help make an unpaved driveway less muddy and will help prevent potholes and corrugation. Use hydrated lime, distributed from open bags off the tailgate of a pickup truck. Add 3% to 5% by weight of the soil. Mix in the lime to a depth of 4- to 6-in. with a garden tiller or a disk; then recompact the subgrade.

Surface Mix for Unpaved Roads

After the house is finished and the last load of topsoil has been hauled onto the job site, top the road with a surface mix. This can be the same material used for the base, but good practice calls for 2- to 4-in. of a “three-quarter-minus” mix — 3/4-in. stones, fine stones, and a small amount of clay or organic topsoil for a binder. Alter-natively, use 4 in. of 1/2-in. stone “plant mix,” which has a complete mix of aggregate to create a smooth surface.

Place the surface mix in thin, 2-in. lifts, and compact each lift with a crawler. The driveway surface should finish out to be at least 1 in. higher than the surrounding soil.

ASPHALT DRIVES

An asphalt, or “blacktop,” drive is the best system to use when you have a long approach to a home. Blacktop is a bitumenized concrete — a mixture of asphalt and small stones, 1/2 in. or smaller — that should last for 12 to 14 years. Eventually, asphalt will begin to lose its ability to expand and contract with temperature changes, and cracks will form. To prolong the life of the driveway, the owner should be prepared to fill cracks and put on a sealer coat every two years.

For asphalt drives, prepare subgrade and install subsurface drainage, as described above.

Base Materials for Asphalt Drives

The aggregate mix used for a paved road is slightly different from that used for an unpaved road. Because blacktop will spread loads better than a gravel surface, the base does not need to be as tightly packed. Larger chunks of aggregate will drain better, since there is plenty of room for water to percolate through and travel to the drains at the sides of the road.

Use 3/4- to 1-in. gravel as a base for asphalt. Compact the base materials with a plate compactor or vibratory roller. This material is harder to spread and compact than dense-grade base mix, such as road pack. If it will be left for a few months before paving, add some smaller aggregate — a mix of 1/8- to 3/8-in. angular aggregate — at the surface.

Base Thickness for an Asphalt Drive

Place a minimum of 6- to 8-in. of aggregate base material over the roadbed, as well as the drain system. A base thickness of 8- to 12-in. of gravel will extend the life of the blacktop; it’s cheaper to put in more base material and less asphalt.

Asphalt Mix

Asphalt hot mix should have an asphalt/cement ratio of 4.5 to 6% by weight for the first lift (the tack course) and 5% to 7% for the *wearing course*.

Do not use cold-mix asphalt. This is used only for patching.

Placing Asphalt Paving

- Before applying blacktop, roll the base to ensure even compaction. If soft spots are detected, add fill and compact. Crown the base course slightly to the center of the driveway width (1- to 2-in. over 12 ft.). This ensures that when the topping is applied, the surface will drain and there will be no low spots where puddles can form.
- Some asphalt mixes may require a primer.
- Place asphalt on a warm day. Asphalt that cools too fast won’t compact well. Do not place on frozen base materials.
- On a residential drive, asphalt can be placed in a single lift. However, it is better to apply it in two

Asphalt Drives
Concrete Drives

thin lifts, rolling between the tack course and the wearing course.

• With a 10- to 12-in. base, the total asphalt thickness can be as thin as 11/2 in. For a 6- to 8-in. base, increase the topping thickness to about 21/2 in.

• Apply the top, wearing course at one time so there are no seams in it. Roll it out until all roll marks disappear.

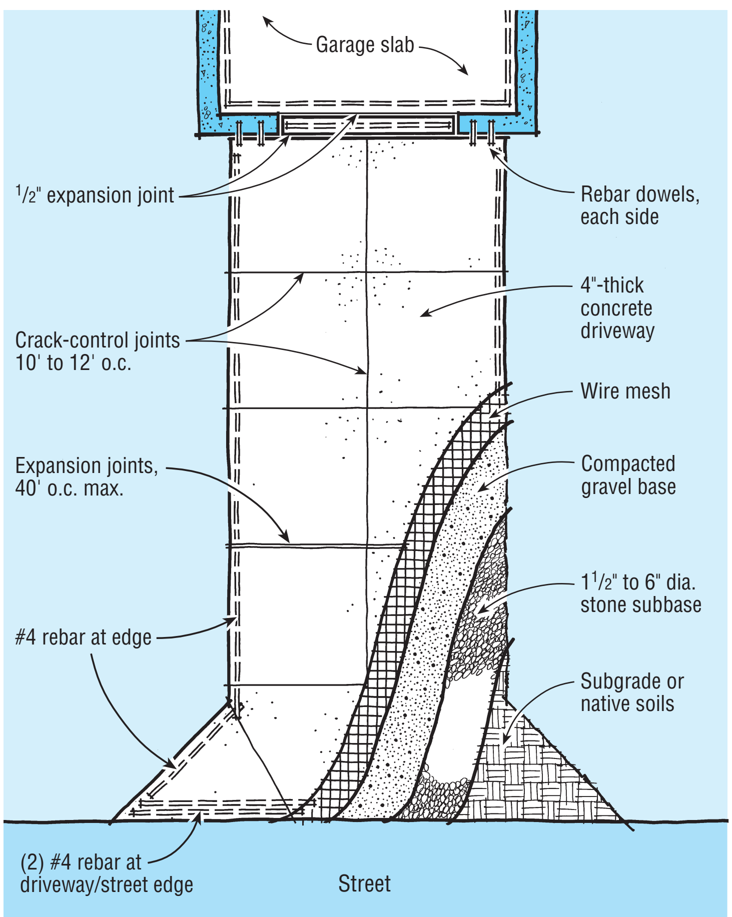
Asphalt Edges

Edge reinforcing is typically not required, but you must compact soil well along the edges, or else the outer few inches will chip off (see **Driveway Shoulders** in Drainage). Cover the gravel base at the edge with geotextile, then sod or topsoil.

CONCRETE DRIVES

Like other durable roadbeds, a concrete drive is built up in layers: A subgrade of native soil (if suitable) or compacted fill, a subbase of compacted stone, a base of compacted gravel, then a 4-in. concrete slab (**Figure W**).

FIGURE W: CONCRETE DRIVEWAY CONSTRUCTION



Plan View

To prevent settling and cracking, a concrete driveway must be built on a well-compacted base and subbase. Use rebar to reinforce slab edges and control joints to limit surface cracking.

Concrete Drives

Subgrade and Subbase

Concrete is brittle and requires more support than a gravel or asphalt topping. If the native soils are free-draining sand or gravel, they can be compacted to serve as a subbase. Otherwise, 11/2-in. (maximum) stone should be brought in and compacted for the subbase.

Base Materials for Concrete Drives

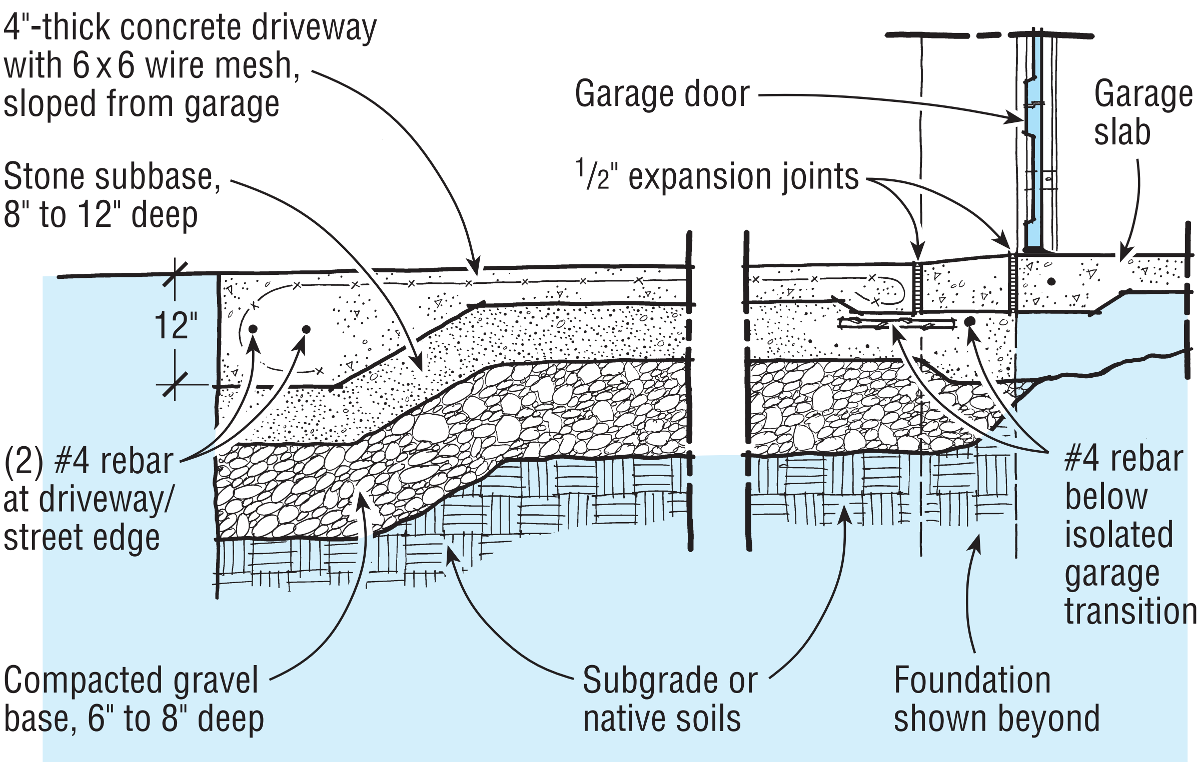
Use a 3/4- to 1-in. gravel as a base for concrete, placed and compacted as described for other roadbeds (see **Placing Base Materials** in Drainage).

Preparing Slab Edges

Because concrete is so brittle, slab edges can chip or break if they are thin or unsupported. Before pouring concrete, scrape the outermost corners of the form to clear build-up of loose soil so that the slab is full thickness (or thicker) and supported on a well-compacted subgrade.

Where the driveway joins the street, thicken the concrete to 12 in. and reinforce with double rebar (**Figure X**).

FIGURE X: CONCRETE DRIVEWAY SUBBASE



Concrete requires a subbase of compacted stone fill. The subbase adds support and serves as a capillary break for preventing frost heaves from cracking the brittle surface.

Concrete for Driveways

Driveway surfaces may not see heavy truck traffic, but they may take a lot of abuse from freeze-thaw cycles and road salt. Use a minimum 3,500-psi concrete mix with a maximum 4-in. slump (see Concrete).

Isolation Joints

Concrete expands and contracts with temperature. To prevent damage to the driveway or other structures, place expansion joints where the driveway meets the street and the house, and within the driveway every 40 ft. or less (see Control Joints for Concrete Walls).

Garage Transition

Where the driveway meets the garage, the driveway slab should be free to move up but not down. Even a piece of garage door trim that restrains the slab from heaving upward may crack the concrete. Expansion joints must also be placed on each side of a garage transition to isolate the driveway from the garage (**Figure W**).

To support the slab edge and to keep it from sinking near the garage transition, drive rebar dowels into drilled holes in the foundation wall (#4 bar, 12-in.-long, driven minimum 2 in. into wall, 4 ft. o.c.).

Expansion joints in exterior slabs should be sealed with caulk to prevent water from infiltrating the joint (see figure, **Finished Expansion Joint** in Structural Slabs).

Crack Control Joints

All concrete will crack from shrinkage as elements cool after placement and water evaporates. Control joints are provided to induce cracking to occur at the intended location. In driveways, place control joints in a roughly square grid with squares 10- to 12-ft. on a side. When cracks occur, seal the cracks with caulk. Advise homeowners that caulk must be renewed every few years to prevent water intrusion below the slab.

Crack Control Reinforcement

Support from the base, not from steel in the slab, gives the slab the strength to carry vehicle loads. Steel should be included to limit the size of shrinkage cracks. Use #3 or #4 rebar around the slab perimeter, 3 in. from the edge and 2 in. down from the top surface. In the field, use 6x6-in. welded wire mesh, 2 in. down from the top surface (**Figure X**).