ENGINEERING CONCEPTS

Constructors must have a basic understanding of the natural characteristics of materials which are incorporated into the construction process. This information can be obtained from published technical reports and advertising material prepared by suppliers. Some sources of information concerning technical properties of specific materials can be found in these sources.

Sweets Catalog compiles technical construction material advertising literature published by suppliers. It is organized by the Construction Specification Institute’s Master Format which is organized by 16 Divisions. American Society for Testing and Materials (ASTM) is an organization engaged in the standardization of technical specifications and testing methods. American Standards Association (ASA) develops national industrial standards representing manufacturers, technical organizations and government agencies. Underwriters Laboratories (UL) is a nonprofit organization which investigates and tests materials, products, equipment, construction methods and construction systems in its laboratories. A UL-APPROVED seal of approval is recognized as a safeguard against hazards to life and property. Many specifications require UL approvals. Thomas’ Register compiles manufacturers’ information on various manufactured products.

Engineering Material Properties
The Materials most widely used in the construction industry are aggregates, asphalt, Portland cement concrete, masonry, iron, steel and wood. Therefore, a basic understanding of their material properties is reviewed here. The Specifications are developed to provide the contractor with an in-depth description of what materials to use, the characteristics the materials must have, the installation procedures the contractor must follow, the manufacturer’s instructions and the inspection and testing procedures that will be utilized to verify the proper installation and strengths. The properties most often considered when selecting materials are outlined below.

Aggregate Properties
Aggregates are particles of random shape and size. They are found in nature as sand, gravel, or rock that can be crushed into particles. Aggregate sizes vary from several inches to the smallest grains of sand. Particles smaller than the size of a grain of sand are considered impurities. Aggregates are normally used as bases placed on top of the soil to uniformly distribute the load over the soil for a footing or road. The qualities that indicate the usefulness of aggregate for the construction industry are the weight, the strength of the particles to resist repetitive freezing and thawing, the strength of the mass to transmit a compressive force, the strength of the individual particles to resist being crushed the strength of the aggregate particles to resist wear by abrasion, the adhesion of the aggregate particles to a cementing agent such as Portland cement or asphalt and the permeability of the mass. Weight is important for large stone used for riprap. Riprap is placed at the end of culverts or along the edge of a body of water to prevent erosion. The aggregate quality of resisting weathering is called soundness of the aggregate. The aggregate
particles at the surface of asphalt or concrete are subject to abrasion from the vehicle wheels. Also, in an asphalt pavement the aggregate particles throughout the asphalt pavement are subject to abrasion because the pavement is continuously shifting under the weight of the vehicles which causes the particles to rub against each other. Finally, permeability is a measure of the ease with which water will flow through an aggregate’s voids. High permeability is needed if the aggregate is used as a filter or drain.

Aggregate Size and Gradation are important for all construction applications. The most important features are range of sizes and gradation. Gradation is the distribution within the range covered. A set of sieves stacked on top of each other is used to determine size and gradation. A sample of the aggregate to be analyzed is placed in the top sieve which has the largest holes. The Sieve sizes commonly used for aggregates in the construction industry and the actual dimensions, the sizes designated in millimeters and inches or fractions of an inch are shown below. The sieve designations indicate the clear openings between wires which are squares with the given dimensions. When a size is given as a number, such as a No. 40 sieve, it means there are that number of holes in a lineal inch. Therefore, the No. 40 sieve has a total of 40 openings per lineal inch and 1600 openings in a square inch. The openings are not 1/40 of an inch in width because the wires take up much of the space. Therefore, the openings are actually smaller but it is an approximate method for estimating opening sizes in inches.

<table>
<thead>
<tr>
<th>Sieve Designation</th>
<th>Sieve Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>inches</td>
</tr>
<tr>
<td>75 mm</td>
<td>3 inches</td>
</tr>
<tr>
<td>37.5 mm</td>
<td>1-1/2 inches</td>
</tr>
<tr>
<td>19.0 mm</td>
<td>3/4 inch</td>
</tr>
<tr>
<td>12.5</td>
<td>½ inch</td>
</tr>
<tr>
<td>6.3 mm</td>
<td>1/4 inch</td>
</tr>
<tr>
<td>4.76 mm</td>
<td>No. 4</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>No. 8</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>No. 16</td>
</tr>
<tr>
<td>0.6 mm</td>
<td>No. 30</td>
</tr>
<tr>
<td>0.3 mm</td>
<td>No. 50</td>
</tr>
<tr>
<td>0.15 mm</td>
<td>No. 100</td>
</tr>
<tr>
<td>0.074 mm</td>
<td>No. 200</td>
</tr>
</tbody>
</table>
Gradations can be identified on a graph as well graded, uniform, or gap graded. **Well-graded** means sizes of particles within the entire range are in approximately equal amounts. **Uniform** gradation means that a large percentage of the particles are of approximately the same size. **Gap graded** means that most of the particles are of a large size or a small size with very few particles of an intermediate size. The result of a sieve analysis is normally graphed using the percentage retained for each gradation level and plotted on a gradation curve. The shape of the curve provides visual help in identifying the type of gradation. A line nearly vertical indicates that a large quantity of materials is retained on one or possibly two sieves. This is considered a Uniform gradation. A line with a constant slope indicates that approximately the same amount of material is retained on each successive sieve. This is considered a well-graded gradation. A horizontal line or nearly horizontal line indicates that is no change or little change in percentage finer through several successive sieves. This is considered a Gap gradation.

The American Society for Testing Materials ASTM Standard C125 defines various types of aggregates as follows. **Course Aggregate** is defined as aggregate predominately retained on the No. 4 (4.76-mm) sieve. **Fine aggregate** is defined as aggregate passing the 3/8 inch sieve and almost entirely passing the No. 4 sieve and predominately retained on the No. 200 sieve. **Gravel** is a granular material predominately retained on the No. 4 sieve and resulting from natural disintegration of rock. **Sand** is a granular material passing the 3/8 inch sieve and almost entirely passing the No. 4 sieve and predominately retained on the No. 200 sieve. **Bank Gravel** is a gravel found in natural deposits, usually more or less intermixed with fine material, such as sand or clay. Normally referred to as gravelly clay, gravelly sand, clayey gravel, and sandy gravel.

**Concrete Mix Properties**

**Concrete** is composed of 60-80 percent aggregates, Sand and gravel, and 20-40 percent of active ingredients which is water and Portland cement. The commonly used aggregates and Portland cement and water normally produces a concrete mixture which weighs 150 - 154 pounds per cubic foot. There are numerous variables that affect the properties of concrete. The ease with which concrete can be modified by its variables can often work to the disadvantage of the user unless quality control measures are followed precisely. The Portland cement when mixed with the water produces a chemical reaction called hydration and it forms a bond to other cement particles, to the aggregates, and to any reinforcement that it contacts. Portland cement does not need air to harden or set. The chemical reaction will harden as well under water as well as if it is exposed to air. The heat generated when the Portland cement and water chemically react is called the heat of hydration, and can be a critical factor in the use of concrete.

**Portland Cement** for individual use is shipped in 90 pound bags. ASTM identifies five types of Portland cement with are produced for different applications as outlined below. Type 1 Portland cement is reasonably resistant to most forms of chemical attack that might occur naturally. A Type II Portland is used where resistance to moderate sulfate attack is important, as in areas where sulfate concentration in groundwater is higher than normal but not severe.
A Type III Portland cement is called a High-Early-Strength because it achieves its specified strength in 7 days rather than in 28 days, but there is also a corresponding increase in the heat of hydration. A Type IV Portland cement referred to as Low Heat is used where the rate and amount of heat generated must be minimized. It is primarily used in large mass placements of concrete such as deep or thick foundations. A Type V Portland cement has high resistance to sulfate attack and is important. It is primarily used where the soil or ground water contains high sulfate concentrations.

The Water/Cement Ratio determines the strength of Portland cement concrete. This ratio is the most important parameter used to control the compressive strength of concrete. There is a minimum Water/cement ratio required for complete hydration of all the cement molecules. But, an excessive amount of water reduces its strength, hardness, durability and resistance to chemical attack and resistance to freeze-thaw. Thus the construction worker who adds water to the mix to make it more workable is significantly reducing all the desirable characteristics of the finished concrete. All of the desirable properties of the finished concrete, such as durability, hardness, abrasion resistance, etc. are improved as the strength increases.

Air-Entrainment of Portland cements is the process of adding microscopic bubbles of air which are distributed uniformly throughout the mix. Air entrainment provides improved resistance to freeze-thaw and to scaling caused by chemicals and salts used for ice and snow removal.

Concrete Reinforcement

Concrete Reinforcement is used in most structural applications because Portland cement concrete is quite weak in tension. Therefore, it is reinforced for tension with deformed reinforcing bar also known as rebar. In the United States, the Concrete Reinforcing Steel Institute (CRSI) Manual of Standard Practice describes the selection, use and standard placement methods for bar supports and reinforcing bar. The bar supports are commonly known as chairs and bolsters. Reinforcing is manufactured for a variety of yield stresses or grades. The most common reinforcement grades are Grade 40, Grade 50, Grade 60 and Grade 75. For these grades, the yield stress is 40,000, 50,000, 60,000, and 75,000 psi, respectively. Reinforcement is rolled into round bars with deformed surfaces designed to improve the adhesion to the concrete.

There are a few different types of Concrete Reinforcement. The two primary types used in the United States are Welded Wire Fabric (WWF) and Deformed reinforcing. Welded Wire Fabric (WWF) containing of wires arranged in a square or rectangular configuration and welded at their intersection. This designation identifies a Plain wire is denoted by the letter “W” [MW] and deformed wire by the letter “D” [MD’]. The brackets [ ] indicate Metric Units.
The Welded Wire fabric designation of: WWF 6 x 12 - W16 x W8 [152 x 305 - MW103 x MW52]. This is identified as follows. The 6 indicates the Spacing (inches) of the longitudinal wires which is 6 inches [152mm] in this example. The 12 indicates the Spacing (inches) of the traverse wires which is 12 inches [305 mm] in this example. The W16 [MW103] indicates the longitudinal plain wire size and the W8 [MW52] indicates the traverse wire size.

Deformed Reinforcing Bar is specified as a bar number such as a #3 bar or #4 bar. The diameter is determined by taking the bar # and dividing by 8. Therefore, a #3 bar is 3/8 inch in diameter. A #4 bar is 4/8 or ½ inch. The Deformed Rebar table below provides the identifying number on reinforcing and its corresponding Nominal Dimension in inches, the Diameter and the Weight per Foot in Pounds.

<table>
<thead>
<tr>
<th>Bar No.</th>
<th>Bar size in inches</th>
<th>Diameter in inches</th>
<th>Area Sq. in.</th>
<th>Perimeter in inches</th>
<th>Weight-lbs per foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1/4 Rd.</td>
<td>0.250</td>
<td>0.05</td>
<td>0.786</td>
<td>0.167</td>
</tr>
<tr>
<td>3</td>
<td>3/8 rd.</td>
<td>0.375</td>
<td>0.11</td>
<td>1.178</td>
<td>0.376</td>
</tr>
<tr>
<td>4</td>
<td>½ rd.</td>
<td>0.500</td>
<td>0.20</td>
<td>1.571</td>
<td>0.668</td>
</tr>
<tr>
<td>5</td>
<td>5/8 rd.</td>
<td>0.625</td>
<td>0.31</td>
<td>1.963</td>
<td>1.043</td>
</tr>
<tr>
<td>6</td>
<td>3/4 rd.</td>
<td>0.750</td>
<td>0.44</td>
<td>2.356</td>
<td>1.502</td>
</tr>
<tr>
<td>7</td>
<td>7/8 rd.</td>
<td>1.875</td>
<td>0.60</td>
<td>2.749</td>
<td>2.044</td>
</tr>
<tr>
<td>8</td>
<td>1 rd.</td>
<td>1.000</td>
<td>0.79</td>
<td>3.142</td>
<td>2.670</td>
</tr>
<tr>
<td>9</td>
<td>1 sq.</td>
<td>1.128</td>
<td>1000</td>
<td>3.544</td>
<td>3.400</td>
</tr>
<tr>
<td>10</td>
<td>1 1/8 sq.</td>
<td>1.270</td>
<td>1.27</td>
<td>3.990</td>
<td>4.303</td>
</tr>
<tr>
<td>11</td>
<td>1 1/4 sq.</td>
<td>1.410</td>
<td>1.56</td>
<td>4.430</td>
<td>5.313</td>
</tr>
<tr>
<td>14</td>
<td>1 ½ sq.</td>
<td>1.693</td>
<td>2.25</td>
<td>5.320</td>
<td>7.650</td>
</tr>
<tr>
<td>18</td>
<td>2 sq.</td>
<td>2.257</td>
<td>4.00</td>
<td>7.909</td>
<td>13.600</td>
</tr>
</tbody>
</table>

Types of Bar Supports
Bar supports are used to position reinforcing bars in reinforced concrete to ensure a minimum amount of concrete cover over the rebar. The bar supports may be made of steel wire, plastic or precast concrete. Bar supports are not normally shown on the plans and they are not furnished by the reinforcing steel supplier which generally means that the contractor must follow the standard which is incorporated by reference and the reference standard is found in the Technical Specifications. Normally, the Bar Supports are not found on the Contractor’s plans.
Reinforcement Placement

Concrete Reinforcement is placed according to a moment diagram for a beam that is supported by two columns under typical load conditions. The beam will be under tension on the bottom of the section at mid span between the two columns and it will be under tension on the top of the section over the columns. Therefore, you must place the proper size of reinforcing bar, located in the correct position in both regions to sustain these tensile forces.

As a general rule, the minimum standard Concrete Cover over Reinforcement is specified from the outside of the bar to the face of the concrete and they are based on the size of the bar and the location as follows. Three inches at sides where concrete is cast against earth and on bottoms of footings. Two inches for bars larger than a #5 where concrete surfaces would be exposed to the weather and 1-1/2 inches for smaller than #5 bars. 1-1/2 inches over spirals and ties in columns. 1-1/2 inches to nearest bars on the top, bottom and sides of beams and girders. Also, a 3/4 of an inch cover is needed for #11 rebar and smaller bars on top, bottom and sides of joists and on top and bottom of slabs where concrete surfaces are not exposed to the ground or weather. 1-1/2 inches for #14 and #18 bars. Also, 3/4 of an inch cover is required from the faces of all walls not exposed directly to the ground for #11 and smaller bars.

Masonry Properties

Organizations such as the International Masonry Institute (IMA), and the Brick Institute of America (BIA) have established an engineered approach to Masonry Design and Construction. Their efforts continue to provide the latest in engineering data, design guidelines, and construction practices for masonry construction. Masonry wall units are held together with mortar and the quality of the mortar mix effects the wall. Mortar binds the masonry units together into a single permanent structure and it seals the joints against moisture and air penetration. The mortar acts as the bond for the various components of the masonry structure such as reinforcement rebar, metal ties and anchor bolts. Portland cement, lime, sand and water are combined to produce mortars which have good durability and high compressive strengths. But, masonry cement, sand, and water are combined for convenience. The masonry cement is pre-blended by the manufacturer and it will normally include lime, an air-entraining agent, and other ingredients which produce the desired properties. The properties of the individual ingredients are provided below.

Portland cement used in mortars allows Types I, II, and III. Air-entraining Portland cement should be used with extreme caution since the research has shown that there are wide variations in the actual measured air content at the job site. The compressive strength of the mortar depends upon the proportion of Portland cement in the mix.

Hydrated Lime is essential to good quality mortar. It is a key ingredient and it is important to understand its characteristics and effects on mortar. The lime component improves workability, elasticity and water retention. Water retention in a mortar prevents rapid loss of water from
mortar in contact with the masonry units. Lime also improves its bond strength and improves the mortar’s plasticity and flexibility. Lime undergoes the least amount of change in volume which means it shrinks the least after hardening. Mortar is resistant to weather and should be able to resist strong winds, freezing temperatures, and alternate wet and dry weather. These cycles are beneficial to lime-based mortar, and they increase the overall strength of the mortar as it ages.

*Sand* acts as a filler in mortar which contributes to the strength of the mix. Natural sand is used in most mortars. Sand decreases the shrinkage of mortar which occurs in setting and drying, therefore, minimizing cracking. It is important to use a good grade of sand. *Water* used in mortar should be clean and free from alkalis, salts, acids, and organic matter. *Retempering* is the addition of water to mortar mixes that have lost water while sitting on the mortar board. The practice of retempering will reduce the compressive strength, but it increases the bond strength of the mortar mix. Many times, the CSI Division 04 Masonry, the technical specifications limit the number of times that retempering is permitted and establishes a time limit for the use of a mortar.

Types of Masonry Cement
As mentioned before, *Masonry Cement* is a pre-blended by the manufacturer and used for convenience at the job site. The American Society for Testing Materials (ASTM) recognizes five types of mortars for masonry. They are types M, S, N, O, and K. Type M is the strongest. Types O and K are the weakest. Until recently, the masonry codes recognized all five mortar types, but, the latest masonry codes focus primarily on the use of Type S and Type N.

*Type N mortar* is a medium-strength mortar recommended for use in exposed masonry above grade. Typically it is used for exposed exterior building walls, interior load-bearing walls and interior non load-bearing walls or partitions, chimneys, and parapet walls. *Type S mortar* is a medium-high strength mortar which is used where high bond strength and lateral strength are important. Type S mortar is recommended for use in foundations, basements, exterior walls, interior load-bearing walls, reinforced walls and non-reinforced masonry where maximum flexural strength is required.

Types of Masonry Walls and Their Components
Masonry Walls are formed from various types of masonry units and their backing can be block, brick, wood or concrete. The descriptions below describe the most common types of masonry walls. The *concrete block wall* consists of masonry units bonded together with mortar to form load bearing or non-load bearing walls above or below grade. The concrete masonry block units come in various sizes and wall thicknesses. The *solid brick wall* consists of two tiers or wythes of brick which is bonded together with header bricks. The *composite wall* consists of face brick with a header brick interlocked back into a block backup wall containing header blocks to receive the header brick and regular block. The *insulated cavity wall* consists of two tiers or wythes of masonry separated by a continuous air space and bonded together using metal ties to provide water drainage using flashing and weep holes. The Brick Institute of America recommends the
construction of cavity walls where there is severe weather exposure, or where a maximum resistance to rain penetration is desired. Finally, a **veneer masonry wall** is a single thickness of masonry units attached to the backing with corrugated metal ties but it is not bonded to the backing. A **veneer wall** is a non-load bearing wall used primarily for decorative purposes.

There are various types of **metal ties** used to bind the face wall to the backup wall. For instance, the dovetail anchor is used to tie masonry units to a concrete wall. The anchor fits into a slot embedded in the concrete wall. The galvanized metal tie is used to bind the veneer brick wall to the backing. The rectangular tie is used to tie the face wall to the backup wall in a composite wall or a cavity wall. The **reinforced masonry wall** consists of masonry units tied together using horizontal reinforcing wire or metal ties and vertical reinforcing bars. The vertical reinforcing bars in the masonry cores are grouted in either a low-lift or high-lift grouting process depending upon what it calls for in the technical specifications.

A Masonry Wall contains the following components. **Horizontal joint reinforcement** is used to tie masonry units together to form a single structural unit. There are some types of metal joint reinforcement which are embedded in the horizontal mortar joint. The ladder or truss type reinforcement is used to tie masonry units together. **Control joints** are vertical joints that separate walls into sections and allow freedom of movement. They occur at specified intervals in long, straight walls or where abrupt changes in wall thicknesses occur. They also should be placed at openings; at intersections of main walls and cross walls; and at locations of structural columns in main walls.

A **bond beam** is a continuous, cast-in-place lintel block with reinforcement bars placed in the core of the lintel block. Bond beams may run around the perimeter of a building or between control joints. They may also be utilized as a lintel over an opening. Bond Beams are used as a continuous tie for exterior block walls where control joints are not required. They also act as structural members transmitting lateral loads to other structural members, and they can provide bearing for beams and joists. **Lintels** are used over openings in block walls to carry the load around the opening. They can consist of precast concrete units, structural steel shapes, a bond beam with reinforcement or a combination of materials. Bond beams and lintel are installed in conjunction with the masonry wall is being placed.

**Masonry Brick Positions and Patterns**

Brick is laid in various positions in the construction of solid brick walls, reinforced brick walls, or cavity walls. There are six **Brick Positions**. The **stretcher position** is a brick laid in a horizontal position with the longest, narrowest side facing the front of the wall. The stretcher position is the most common brick position. The **header position** is a brick laid in a horizontal position with the shortest, narrowest side facing the front of the wall. This is also referred to the header course where a masonry unit is laid over two individual wythes of walls, thereby tying them together. The **soldier position** is a brick laid in a vertical position with its longest, narrowest side facing
the front of the wall. The *shiner position* is a brick laid in a horizontal position with the largest side facing the front face of the wall. The *rowlock position* is a brick laid in a horizontal position with the narrowest side or face edge placed in the bed of mortar and the longest side running back into the wall. The rowlock position is commonly used on window sills. The *Sailor position* is a brick that is laid in a vertical position with the largest side facing the front of the masonry wall.

Many times the brick positions are arranged in a wall to form a Brick Pattern or recurring design which is referred to as a *Brick Pattern Bond*. There are five basic structural bond patterns for brick and they are described below. The *Running bond pattern* consists of all bricks laid in a stretcher position with a one-half or one-third lap. This is commonly referred to as the stretcher bond pattern. The *Common or American bond pattern* consists of all stretchers with a course of header brick at a specified interval such as fifth course, sixth course or seventh course header. Another version is the header course contains a Flemish header. The *Flemish bond pattern* consists of alternating stretcher and header bricks on the same course. The headers on every other course should be centered over the stretcher below. The *English bond pattern* consists of alternating courses of header and stretcher bricks. The *Stack bond pattern* consists of masonry units laid directly over one another so that all of the head joints line up in a plumb vertical position. The stack bond is used for decorative purposes and structurally it is the poorest of all of the bonds discussed since there is not overlapping of the masonry units.

**Structural Steel**

The most common Structural Steel Shapes are the Wide Flange (W), the Standard I section (S), the Channels (C), the Hollow Structural Sections (HSS), Structural Tees (T, ST or TS), Angle iron with equal and unequal legs (p), the I-shaped steel pile section (HP), and plate steel. Wide Flange (W), the Standard I section (S), the Channels (C) all follow the same designation format. The letter indicates the steel shape, the first number indicates the nominal depth of the steel member and the second number indicates the nominal weight per foot. For example, the steel shape designation of W 14 x 90 means the capital letter W tells you that the shape is a Wide Flange (W), the 14 indicates that the nominal depth is 14 inches, and the 90 indicates that the nominal weight per foot is 90 pounds per lineal foot.

*Channels* use the same designation sequence as the W and S except the structural steel shape and design properties are different. Channels are usually used as secondary framing members when loads and spans are too great. They are used as wall girts which are horizontal members attached to the columns to support siding. Channel is also used as roof purlins which are the framing members spanning between the roof beams to support the roof deck. Channel can also be used for door and window frames, stairs, stringers, and as web and cord members in trusses. Angles are used as the connecting pieces for beams, as chord and web members in light trusses and joists. They are also used as bracing, and as reinforcing around openings normally called lintels and as supports for mechanical equipment. The American Institute of Steel Construction (AISC)
Level 1 Construction Fundamentals Study Guide


Prior to the fabrication of each structural steel member the manufacturer must submit to the contractor a shop drawing indicating the size of the member, the detailed dimensions for the connectors and dimensions for each member in the structure. During the structural steel fabrication process at the manufacturer’s location, each piece of steel is given an erection mark that allows the contractor to identify each member at the job site. The erection markings for each member are then organized into a set of *erection drawings* which are issued to the contractor indicating the locations and proper positioning of each piece of steel within the structure.

**Open-web Steel Joists**

These are lightweight trusses that are used for supporting roofs and floors. The most common joist series are the K-Series, the LH Series, the DLH Series and the Joist Girders. The K series is normally fabricated in depths that range from 8 inches thru 30 inches and spans up to 60 feet. The LH is fabricated in depths that range from 18 inches thru 48 inches and spans up to 96 feet. The DLH is fabricated in depths that range from 52 inches thru 72 inches and spans up to 144 feet. The Steel Joist Institute (SJI) publishes numerous manuals such as the *Standard Specifications, Load Tables, and Weight Tables for Steel Joists and Joist Girders*.

**Steel Floor and Roof Deck**

These are roll formed metal in varying configurations for composite metal decks, non-composite metal decks and metal roofs. Composite floor deck is designated Type “VL”, “VLI”, and “VLR”. The non-composite floor deck is designated Type “C” and the Roof deck is designated Type “B”, “F”, “A”, “N”, and “E”. The Steel Deck Institute publishes numerous manuals such as the *SDI Manual of Construction with Steel Deck*.

Structural steel and metal decking are extremely susceptible to fire, therefore, they must be fireproofed based upon the major occupancy classification which is assigned to each building during the initial design stages of the project. Some typical occupancy classifications include arena and theater type occupancies, health care and detention type occupancies, business type occupancies, industrial occupancies and residential occupancies.

**Fireproofing Structural Steel**

The amount of *fireproofing* that is applied to a structural steel member depends on the fire-resistance rating required and the type of material that is to be protected. Materials normally used for the protection of a structural steel frame include regular and lightweight concrete, cellular concrete, gypsum wall board, plaster, and sprayed-on mineral wool. There are three common methods for fireproofing structural steel. You can encase the steel member in concrete. Second, you can encase the steel member with gypsum wallboard. Finally, you can protect the structural
steel beams, columns and decking with sprayed-on insulation.

Welding Symbols
The two most common methods for connecting structural steel members in structural steel frame construction are bolting and welding. Welding can be done in the manufacturers shop under controlled conditions and it can be done at the construction site. Welding is the fusing of two pieces of metal together. The two most often used types of welded connections are the fillet weld and the butt or groove weld. A fillet weld is used to weld two pieces of metal together that are perpendicular to each other. A butt weld is used to weld two pieces of metal together that are set end to end or parallel to each other. The typical butt welded, joints are the Square butt weld, the single-V butt weld, and the Single Bevel butt joint. The American Welding Society has established the basic welding symbols for fillet and butt welds, some supplementary weld symbols and a standard location for elements of a welding symbol. Below is an example of the welding arrow symbol and their meanings.

Welding Arrow Symbol

<table>
<thead>
<tr>
<th>FILLET</th>
<th>BUTT OR GROOVE TYPE</th>
<th>WELD ALL AROUND</th>
<th>FIELD WELD</th>
<th>CONTOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SQUARE</td>
<td>V</td>
<td>BEVEL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CONVEX</td>
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</table>

Adapted from the American Welding Society manual titled Structural Welding Code D1.1.
Structural Lumber
Each piece of lumber is assigned on the basis of its expected use to the category of factory and shop lumber or yard lumber. Yard lumber is used structurally and includes most of the lumber for construction. Yard lumber is further divided according to size and shape into boards, dimension lumber and timbers. Most of the lumber in construction falls into the category of dimensional lumber also called Structural Lumber. Boards are defined as 1" to 1-1/2" thick and 2" to 12" wide. Boards are further classified as a common grade or rough sawn or surfaced grade or dressed. Dimension lumber is 2" to 4" thick and 2" and wider. Timbers are 5" and thicker and 5" and wider. Boards and dimensional lumber are known by their nominal size such as a 2 x 4 which is not 2" thick by 4" wide. Its actual dimensions are 1-1/2" thick x 3-1/2" wide.

Dimension lumber is further divided into Joists and Planks, Light Framing and Decking. Joists are members that are 2 inches to 4 inches in nominal thickness and at least 6 inches wide. They are graded according to their bending strength on their narrow edge. Planks have the same dimensions as joists but they are graded on their wider dimension. Light Framing are members that are 2 inches to 4 inches nominal thickness and 2 inches to 4 inches wide. They are sometimes referred to as wood frame construction which consists of studs, plates, joists, and rafters. Decking is 2 inches to 4 inches thick and 4 inches or wider, but they are used on their wider dimension.

Timbers are further divided into Beams and Stringers and Posts and Timbers. Beams and Stringers are members with a width more than 2 inches greater than the thickness. Normally, something called a Beam or Stringer is at least 4 inches thick and at least 2 inches wider than they are thick. They are installed horizontally and they are ranked according to the Extreme Fiber Bending stress ($F_{b}$) when loaded on the narrower of the two dimensions. Posts and Timbers have a width that is no more than 2 inches greater than the thickness. These are members that are either square or nearly square in cross section. Normally, they are installed vertically and they are ranked according to their Compression Parallel to the Grain ($F_{c//}$) because the loads are carried on the cross section.

Structural lumber, also referred to as dimensional lumber, is a classification of lumber for pieces at least 2 inches thick and it is graded according to its ultimate use and its strength in resisting the stresses placed on each piece in that use. The top grade of most species is select structural grade, which is used only where high strength, stiffness, and good appearance are all required. The next lower grade is No. 1 grade lumber which may have tiny knots but otherwise it has almost the same qualities as select structural. The No. 2 grade lumber may have larger knots than No. 1, but they the knots are tight, and the grade is excellent for floor and roof framing members. The No. 3 grade has still more and larger defects and it can be used for sills and some plate members in residential construction. The Construction grade falls somewhere between Select Structural and No. 1 grade and it is used for extreme fiber stress in bending. Construction grade is the standard where straightness and strength are more important, such as in concrete formwork. The Stud
grade is stiff, straight lumber with a high Compression Parallel to the Grain (F //) value. The stud grade is excellent for vertical walls in residential construction. The Standard grade and the Utility grade are still lower grades than stud grade lumber. The bottom grade is Economy grade which is used for nonstructural purposes. The surfaces of a piece of lumber can be rough sawn or dressed. A dressed piece of lumber with the designation of S1S means smooth on one side. The designation of S2S means smooth two sides and S4S means smooth on all four sides. Dressed can also be designated S1E which means smooth on one edge or S1S1E which means smooth one side and one edge.

The ASTM D2555 standard titled Methods for Establishing Clear Wood Strength Values, established the stresses at failure and an accurate modulus of elasticity for each wood species. The samples tested under ASTM D2555 have no defects to reduce their strength or stiffness. Allowable stresses for lumber are determined by reducing the stresses in the samples tested under ASTM D2555 to provide for a safety factor of approximately 2.5. These allowable stresses and the modulus of elasticity are published in ASTM D245, Methods for Establishing Structural Grades for Visually Graded Lumber. The National Forest Products Association (NFPA) publishes a manual titled National Design Specifications for Stress-Grade Lumber and Its Fasteners. This manual includes grades established for each species of wood with allowable stresses for each grade. These stresses are derived by multiplying the basic allowable clear wood stresses by ratios.

Grading standards for softwoods are published by the U.S. Department of Commerce in Product Standard PS 20 titled the American Softwood Lumber Standard. The grading rules for each region are established by numerous organizations whose rules conform to the PS 20 grading standard with additions for the special conditions in each region. Then each regional manufacturer’s association adjusts or refines their grading rules to categorize its lumber products according to their conditions. Some of the regional associations are the Western Wood Products Association (WWPA), the Southern Forest Products Association (SFPA), the Northeastern Lumber Manufacturers’ Association and the National Hardwood Lumber Association.

Each manufacturers’ association then places their Grading mark or stamp on each piece of lumber. A typical grading mark shows in the upper left portion of the stamp the sawmill number that processes the lumber and just below it is the logotype of the manufacturers’ organization establishing the grading rules. In the lower right portion of the stamp is the species abbreviation such as ES-AF which means Englemann spruce and Alpine fir, or Hem Fir for Hemlock and Fir, or the symbol of a backwards P and a forward P together which means Ponderosa Pine or LP for Lodgepole pine. The upper right portion of the stamp states the grade or stress rating such as SEL for Select or CONST for Construction or 2 & BTR STUD which means a No 2. or better grading for Studs. The upper right portion of the stamp may contain the stress rating instead of the grade such as 1650 f or 1500 f 1.4 E. The remaining information which appears in the middle portion of the stamp may contain its moisture content such as MC 15 which means surfaced at Moisture
content of 15% or less. Another abbreviation is S-DRY which means surfaced at M.C. of 19% or less. Dry lumber has been seasoned to a moisture content of 19 percent or less. Green lumber has a moisture content in excess of 19 percent.

Allowable Stresses and Strengths
The allowable stresses and strengths of wood are divided into the following types. The Extreme Fiber Bending stress (F_b), as single member uses or repetitive member uses, is the stress that must be resisted in a beam undergoing bending. The F_b value of a beam is the strength of extreme fibers in bending when a member is used horizontally such as a floor joist. This generally means that the top fibers of a joist will be in compression and the bottom fibers will be in tension. The F_b rating value is the pounds per square inch (psi) that the beam will resist a force exerted downward at the center of the joist.

The Compression Perpendicular to the Grain (F_c ⊥) is the stress induced by pressing the fibers together in a traverse direction. There is no appreciable difference in strength to resist this compression perpendicular to the annual rings or parallel to the rings. The Compression Parallel to the Grain (F_c //) is the stress induced by pressing the fibers together longitudinally. The Horizontal Shear Parallel to the Grain (F_s //) is the stress induced by the tendency for the upper fibers to slide over the lower fibers as a beam bends. The Tension parallel to the grain (F_t //) is the stress induced by pulling apart in a longitudinal direction. The resistance to tension perpendicular to the grain is extremely weak that it is usually considered negligible. The Modulus of Elasticity (E) is a measure of the stiffness or resistance to deflection. The Modulus of Elasticity is a measure of the ability to resist failure due to excessive deformation. It is used to predict movement under a load and avoid failure due to excessive movement. The modulus of Elasticity (E) value of a piece of lumber is the ratio between the load of the member and the amount the member will deflect under the load. The higher the E value, the stiffer the lumber. Among common woods used for structural lumber Douglas fir and Southern yellow pine have the highest F and E values. The table below provides the allowable stresses for some typical species of structural lumber. These stresses were derived from recommendations of the National Forest Products Association (NFPA) and the American Concrete Institute (ACI).

Plywood and Plyform
Plywood contains thin layers or plies of wood called veneers. The veneers are bonded together with glues under heat and pressure. Plywood always has an odd number of plies such as three, five or seven. The grain of the plies is alternated and glued at right angles to each other for maximum strength. Plyform uses seven plies and water resistant glues for formwork.
### Allowable Unit Stresses for Dimension Lumber Derived from the National Design Specification for Stress-Grade Lumber and the American Concrete Institute' *Formwork for Concrete.* Sixth Edition. (p 4-6). *

<table>
<thead>
<tr>
<th>Species</th>
<th>Grade</th>
<th>Size in inches t = Thick w = Wide</th>
<th>Extreme Fiber Bending in psi</th>
<th>Compression</th>
<th>Horizontal Shear ( F_c // )</th>
<th>Tension Parallel to Grain ( F_t // )</th>
<th>Modulus of Elasticity ( E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir-Larch</td>
<td>No. 2</td>
<td>2-4 t, 2&quot; &amp; w</td>
<td>875</td>
<td>625</td>
<td>1300</td>
<td>95</td>
<td>575</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2-4 t, 2-4 w</td>
<td>1000</td>
<td>625</td>
<td>1600</td>
<td>95</td>
<td>650</td>
</tr>
<tr>
<td>Douglas Fir-South</td>
<td>No. 2</td>
<td>2-4 t, 2&quot; &amp; w</td>
<td>825</td>
<td>520</td>
<td>1300</td>
<td>90</td>
<td>525</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2-4 t, 2-4 w</td>
<td>925</td>
<td>520</td>
<td>1550</td>
<td>90</td>
<td>600</td>
</tr>
<tr>
<td>Southern Pine</td>
<td>No. 2</td>
<td>2-4 t, 2-4 w</td>
<td>1500</td>
<td>565</td>
<td>1650</td>
<td>90</td>
<td>1,600,000</td>
</tr>
<tr>
<td>No. 2</td>
<td></td>
<td>2-4 t, 5-6 w</td>
<td>1250</td>
<td>565</td>
<td>1600</td>
<td>90</td>
<td>1,600,000</td>
</tr>
<tr>
<td>No. 2</td>
<td></td>
<td>2-4 t, 8 w</td>
<td>1200</td>
<td>565</td>
<td>1550</td>
<td>90</td>
<td>1,600,000</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2-4 t, 4 w</td>
<td>1100</td>
<td>565</td>
<td>1800</td>
<td>100</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Spruce-Pine-Fir</td>
<td>No. 2</td>
<td>2-4 t, 2 &amp; w</td>
<td>875</td>
<td>425</td>
<td>1100</td>
<td>70</td>
<td>1,400,000</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2-4 t, 4 w</td>
<td>975</td>
<td>425</td>
<td>1350</td>
<td>70</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Hem-Fir</td>
<td>No. 2</td>
<td>2-4 t, 2 &amp; w</td>
<td>850</td>
<td>405</td>
<td>1250</td>
<td>75</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2-4 t, 2-4 w</td>
<td>975</td>
<td>405</td>
<td>1500</td>
<td>75</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Plyform B-B, Used Wet Class 1</td>
<td>1545**</td>
<td>Face 210</td>
<td>57</td>
<td>1,500,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * Design values are in pounds per square inch.
* Plywood stresses include an experience factor of 1.3 recommended by the APA.
Plywood contains a center ply which is called the core, and the exposed plies are called the faces. Any other plies between the core and the faces are called the cross bands. The standard width of a sheet of plywood is four feet and the most common length is 8 feet. The Plywood sheet thicknesses commonly available are 3/8", ½", 5/8" and 3/4" for residential structural purposes. Plyform uses 5/8", 3/4", 1", 1-1/8" and 1-1/4". The 3/4" plyform is common.

Each piece of Plywood contains a grading mark or stamp. The American Plywood Association (APA) organizes their plywood into Appearance grades and Engineered grades of plywood. These grade tables are further subdivided into Interior and Exterior Types of plywood. The interior types of plywood are made with glue that is adequate for indoor use. The exterior types of plywood are made with hot resin glue that is unaffected by water and resists weathering. These types are further subdivided by Grade Designation such as interior, structural I, sturd-i-floor, underlayment, plugged and B-B Plyform.

The engineered grade’s stamp indicates the grade of the veneers, the species group number, the identification index numbers or the species group, the type of plywood use, the thickness, the mill number or product standard and the type of glue is specified. Across the top of most grade stamps are two letters separated by a hyphen. The first letter is the grade of the veneer on the panel face and the second letter is the grade of the veneer on the panel back. The only letters used to grade the face veneers are A, B, C, D, and N. A grade A face veneer is smooth, has no open defects, but may have some neat repairs. A grade B veneer has a solid surface with no splits wider than 1/32" and all of the defects are repaired with smooth plugs. The grade C veneer may have splits up to ½" and knot holes up to 1-1/2" as long as they do not affect the required strength of the plywood. The grade D veneer is the poorest grade and it has a rough appearance and knots. The identification index has two numbers. The first identification index number states the maximum span if the plywood sheet is used on the roof. The second identification number, to the right of the slash provides the maximum span if the plywood is used for a sub flooring.

The B-B Plyform Class I or Class II is a concrete grade with a high reuse factor. This has a smooth surface on both sides with no splits and all of the defects are plugged. The Plyform is seven plies, it is water resistant, and it is milled oiled to resist concrete adhering to the surface. Plyform is made only from certain wood species which conform to the APA specifications. Plyform is also available in High Density Overlay (HDO) and Structural 1 grades. Class 1 is the most commonly available plyform.

Statics and Strength of Materials
All construction materials must resist a force. A force is a push or pull on a material and the most common force in construction is the pull of gravity. However, other forces that must be taken into consideration are wind and water. A force exerted on the surface of an object is assumed to be uniform over the internal areas of the object. Stress is a force per unit area over which the force acts and it is calculated by dividing the force by the areas on which it acts and it is
expressed as pounds per square inch (psi) of kips per square inch (Ksi) where a kip is equal to 1000 pounds. The strength of a material is the ability to resist a force. Also, the strength of a material in technical terms is equal to the stress that the material can resist. Therefore, the strength of a material has the same units as stress which are expressed in psi or Ksi. This also means that the useful strength of a material is equal to the stress at the point of failure. Failure takes place when a material can no longer resist the weight applied upon it and the material either breaks or it deforms. Deformation is defined as a change in the outside dimension of a material caused by a force. This deformation is expressed in terms of strain which is the total change in the dimension divided by the original dimension. The term strain means the total change in dimension divided by the original dimension. Strain is a ratio, therefore, it has no units, but the amount of deformation and the original length must utilize the same unit to provide a correct ratio. They are usually measured in inches. The deformation that can be allowed a material depends upon its intended use. A material that deforms slowly when a force is applied to it for an extended period of years, even though the force is too small to cause failure in a short period of time. This deformation is called creep.

The engineering profession has determined the stress that causes failure for various materials. However, nothing is designed to be stressed to the point of failure. Instead, a lower stress called the allowable stress is selected. The failure stress is greater than the allowable stress by a factor which is called the safety factor. The safety factor and the allowable stresses for various materials are published by various organizations. Some organizations that publish allowable stresses are the American Concrete Institute (ACI) American Institute of Steel Construction (AISC), the Concrete Reinforcing Steel Institute (CRSI), the Steel Joist Institute (SJI) and the National Forest Products Association. Economy requires that the actual stress be near the allowable. If it is not, then the material is being used inefficiently because using less material would be adequate. The actual stress is called the working stress. There are three types of stresses and corresponding strengths. They are compressive, tensile and shearing. Each depends upon the position of the forces with respect to the object.

In Joseph Wujek’s (1999) book titled Applied Statics, Strength of Materials, and Building Structure Design he describes the following terms. A beam is a structural member that rests on certain reactions and it is subject to forces acting normally perpendicular to its longitudinal axis, thereby causing it to bend. In structural design, a beam is a horizontally positioned load-bearing structural member used in buildings. However, in construction, joists, girders, headers, lintels or purlins behave like and are treated as beams. A load is an external force applied to beams and other structural forces. The reacting forces at the beam supports which counter the applied load and keep the beam in static equilibrium are called reactions. The loads and reactions combine to cause the beam to bend.
There are numerous types of beams. The *simple beam* spans between two reactions located at the extreme ends of the beam. The *overhanging beam* is a beam that rests on two reactions and extends beyond one bearing point. The *double overhanging beam* rests on two reactions and both beams ends extend beyond the reactions. The continuous beam is supported by three or more reactions. A *cantilever beam* extends from a single reaction (p 72).

**Moment**

The moment of a force is a measure of its ability to cause turning, rotating or twisting about an axis of rotation. The moment \( M \) can be determined as the product of a force, \( P \), and the perpendicular distance, \( d \), from the line of action of the force to the axis of rotation about which we can find the moment.

The moment \( M = Pd \). A moment is always expressed in unit of force (P) times distance (d) and the common units for moments (M) are pound-inches (lb-in.), pound-feet (lb-ft.), newton-meters (N-m), and kip-feet (k-ft.). A kip is 1000 pounds.

The equations of static equilibrium indicate that the sums of the horizontal forces must be zero. This is expressed as \( \sum F_x = 0 \). Second, the sum of the vertical forces with an upward force assigned a positive (+) sign and a downward force given a negative (-) sign and setting them equal to zero. This is expressed as \( \sum F_y = 0 \). Third, the sum of the moments about any axis must be zero. This is expressed as \( \sum M = 0 \) (p 74).

For example, a wooden beam 12 feet long and it carries a concentrated load of 150 pounds at a distance of 4 feet from Reaction (\( R_2 \)). Reaction (\( R_1 \)) is pinned 8 feet from the load. What are the values for \( R_1 \) and \( R_2 \)?

Using the three equations of static equilibrium from above and the wooden beam example described above, the sum of the horizontal forces is zero since there are no horizontal forces provided. Therefore, \( \sum F_x = 0 \). Second, the sum of the vertical forces must be equal to zero. In the example, \( \sum F_v = 0 \) which is: 150 lbs - \( R_1 \) - \( R_2 \) = 0. We also know that \( R_1 + R_2 = 150 \) lbs.

We know that Reaction \( R_1 \) is pinned which is the axis of rotation and \( R_2 \) is 12 feet from the axis of rotation and is acting with a tendency to cause counterclockwise rotation about \( R_1 \). Therefore,

\[
\sum M = 0 = + (R_2 \times 12 \text{ ft}) - (150 \text{ pounds} \times 8 \text{ feet}) \\
0 = 12 R_2 - 1200 \text{ lb-ft} \\
12 R_2 = 1200 \text{ lb-ft} \\
12 \text{ ft} R_2 = 1200 \text{ lb-ft} \\
12 \text{ ft} \quad 12 \text{ ft} \\
R_2 = 100 \text{ lb}
\]
Finally, $\sum F_y = 0 = R_1 + R_2 - 150 \text{ lb.}$ Also, $R_2 = 100 \text{ lbs.}$

Therefore, $R_1 + 100 \text{ lbs} - 150 \text{ lbs}$

$0 = R_1 - 50 \text{ lbs}$

$R_1 = 50 \text{ lbs}$

Shear

A beam is designed to resist the bending and shearing stresses that are induced by the effects of the applied loads and the resulting reactions. The designer utilizes the loads and the resultant forces to determine the shear forces and the bending moments across the beam length. The shear forces and bending moments determine the beam material properties and cross section required to withstand these stresses. Shear stress occurs when two forces with parallel but offset lines of action act in opposite directions on the beam.

A beam under a load has the tendencies for it to fail due to either vertical shear or horizontal shear. *Vertical shear* is the shearing force that tends to cause a member to fail by cutting perpendicular to the beam’s longitudinal axis. This occurs at or near the beam supports. This type of failure is often a concern in short beams carrying heavy loads. *Horizontal Shear* is the tendency of theoretical layers in a member to slide horizontally.

Joseph Wujek (1999) says that *Vertical shear* $(V)$ is calculated at any point along a beam by summing any forces acting upward $(F_{up})$ and subtracting any forces acting downward $(F_{down})$ to the left of the section under consideration. This method assumes that the beam is in static equilibrium. The definition for calculating a vertical shear force $(V)$ is the vertical shear force at the section under consideration is equal to the sum of the forces acting upward minus the sum of the forces acting downward calculated to the left of the section. The formula is $V @ x = \sum F_{up} - \sum F_{down}$ to the left of the section under consideration (p 189).

The section under consideration and the shear force calculations are cited as a measurement from the left end of the beam. For example, $V @ 2 \text{ feet}$ indicates that the computation is made with the section placed 2 feet away from the left end of the beam. Also, the location of the section of the shear force calculation is followed by a negative (-) or positive (+) symbol which denotes placement of the section just to the left (-) or just to the right (+) of the concentrated force.

Also, there is no vertical shear force that exists directly below a reaction or concentrated load because a shear force requires offsetting forces. Therefore, a reaction or concentrated force has no offsetting forces, hence the vertical shear is undefined at these locations. Consequently, the calculation of the shear force must be made a small distance to the right and left of the reaction or the concentrated force (p189).
Using a wooden beam 12 feet long and it carries a concentrated load of 150 pounds at a distance of 4 feet from Reaction (R₁). Reaction (R₁) is pinned 8 feet from the load. Reaction R₁ = 50 lbs and Reaction R₂ = 100 lbs. The vertical shear forces at just to the right (+) of R₁ at location R₁ + and ending at just to the left (-) of R₂ at intervals of 4-feet along the length of the beam. What are the vertical shear forces at various locations along the beam? The vertical shear forces are calculated below.

\[ V@x = \sum_{u} F_{up} - \sum_{d} F_{down} \text{ to the left of the section under consideration.} \]

\[ V@R₁ + = 50 \text{ lbs} - 0 = 50 \text{ lbs} \]

\[ V@4\text{ foot} = 50 \text{ lbs} - 0 = 50 \text{ lbs}. \]

\[ V@8\text{ feet} - = 50 \text{ lbs} - 0 = 50 \text{ lbs} \]

\[ V@8\text{ feet} + = 50 \text{ lbs} - 150 \text{ lbs} = -100 \text{ lbs}. \]

\[ V@10\text{ feet} = 50 \text{ lbs} - 150 \text{ lbs} = -100 \text{ lbs}. \]

\[ V@R₂ - = 50 \text{ lbs} - 150 \text{ lbs} = -100 \text{ lbs} \]

Therefore, the maximum vertical shear is 100 lbs.

Joseph Wujek (1999) defines the bending moment (M), as a moment found by summing the moments of the external loads and reactions about a selected section. The bending moment is calculated about any section in a beam by the following method. The sum of the moments of the upward forces to the left of the section under consideration minus the moments of the downward forces to the left of the section result in the Moment (M). The formula is \( M = \sum M_{up} - \sum M_{down} \) to the left of the section under consideration (p 212). Using the wooden beam 12 feet long and it carries a concentrated load of 150 pounds at a distance of 4 feet from Reaction (R₁). Reaction (R₁) is pinned 8 feet from the load. Reaction R₁ = 50 lbs and Reaction R₂ = 100 lbs. The bending moments at just to the right (+) of R₁ at location R₁ + and ending at just to the left (-) of R₂ at intervals of 4-feet along the length of the beam. What are the bending moments at different intervals along the beam?

\[ M = \sum M_{up} - \sum M_{down} \text{ to the left of the section under consideration.} \]

\[ M@R₁ = (50 \text{ lb-ft. x 0}) - 0 = 00 \text{ lb-ft.} \]

\[ M@4\text{ foot} = (50 \text{ lb-ft. x 4}) - 0 = 200 \text{ lb-ft.} \]

\[ M@8\text{ feet} = (50 \text{ lb-ft. x 8}) - 0 = 400 \text{ lb-ft.} \]

\[ M@10\text{ feet} = (50 \text{ lb-ft x 10}) - (150 \times 2) = 200 \text{ lb-ft.} \]

\[ M@R₂ = (50 \text{ lb-ft x 12}) - (150 \times 4) = 0 \]

Therefore, the maximum bending moment is 400 lb-ft.
Level 1 Construction Fundamentals Study Guide

Engineering Materials Exercise

1. Which source or organization promotes a uniform organization system for organizing construction materials, specifications and documentation into Divisions and Sections for projects.

☐ A. Sweet’s Catalog.
☐ B. Underwriters Laboratory.
☐ C. Construction Specifications Institute.

2. You are interested in finding all of the manufacturers technical lifting data for a permanent overhead crane that the Contractor will install in a manufacturing facility. What is the name of the Reference source?

☐ A. Sweet’s Catalog.
☐ B. Thomas’ Register.
☐ C. Engineering News Record.
☐ D. Crane and Riggers Association.

3. Which organization is engaged in the standardization of technical specifications and testing methods?

☐ A. Underwriters Laboratories.
☐ B. American Standards Association.
☐ C. Construction Specifications Institute.

4. Which organization investigates and tests materials, products, equipment, construction methods and construction systems to safeguard against hazards to life and property?

☐ A. Underwriters Laboratories.
☐ B. American Standards Association.
☐ C. Construction Specifications Institute.
Engineering Materials Exercise

5. What are Large stones that are placed at the end of culverts or along the edge of a body of water to prevent erosion called?
   - A. Riprap.
   - B. Impurities.
   - C. Weathering.
   - D. Permeability.

6. What are aggregate particles smaller than the size of a grain of sand called?
   - A. Riprap.
   - B. Abrasion.
   - C. Impurities.
   - D. Permeability.

7. What is a measure of the ease with which water will flow through an aggregate’s voids called?
   - A. Riprap.
   - B. Impurities.
   - C. Weathering.
   - D. Permeability.

8. What is the aggregate quality of resisting weathering called?
   - A. Abrasion.
   - B. Adhesion.
   - C. Soundness.
   - D. Permeability.

9. What type of pavement system is subject to abrasion throughout because the pavement continuously flexes under the weight of traffic?
   - A. Asphalt.
   - B. Concrete.
   - C. Gravel road.
   - D. Sandy road
Engineering Materials Exercise

10. What does a sieve size of No. 40, mean?

   - A. There are 40 openings per lineal inch.
   - B. There are 40 openings per lineal foot.
   - C. There are 40 inches of surface area.
   - D. There are 1600 inches of surface area.

11. Which sieve size are the aggregates initially placed into for analysis?

   - A. 4 inches.
   - B. 1/4 inch
   - C. No. 4
   - D. No. 200

12. A gradation chart shows a line with a constant slope which indicates that approximately the same amount of material is retained on each successive sieve. What is this gradation called?

   - A. Gap graded.
   - B. Well graded.
   - C. Skip graded.
   - D. Uniform gradation.

13. What is the weight of a Cubic Yard of concrete?

   - A. 150 pounds
   - B. 1350 pounds
   - C. 2430 pounds
   - D. 4050 pounds

14. What is the term for a material that strains slowly when a force is applied to it for an extended period of years, even though the force is too small to cause failure in a short period of time?

   - A. Creep.
   - B. Deformation.
   - C. Working stress.
   - D. Allowable stress.
Engineering Materials Exercise

15. What is the chemical reaction called when Portland cement is mixed with the water?

- [ ] A. Setting
- [ ] B. Adhesion.
- [ ] C. Hydration.
- [ ] D. Air-entrainment.

16. Which of the following types of soil has high permeability?

- [ ] A. Clay.
- [ ] B. Gravel.
- [ ] C. Solid Rock.
- [ ] D. Fine Sands & Silts.

17. Which type of Portland cement is used where an early strength gain is important?

- [ ] A. Type I.
- [ ] B. Type III.
- [ ] C. Type M.
- [ ] D. Type O.

18. Which concrete characteristic is improved by air-entraining the concrete?

- [ ] A. Strength.
- [ ] B. Hydration.
- [ ] C. Sulfate resistance.
- [ ] D. Freeze-thaw resistance.

19. What is the most important parameter used to control the strength of concrete?

- [ ] A. Air-entrainment.
- [ ] B. Water/Cement Ratio.
- [ ] C. Type of Portland Cement.
- [ ] D. Coarse/Fine Aggregate Ratio.
Engineering Materials Exercise

20. What is Air-entrained Portland cement concrete quite weak in?
   - O A. Tension.
   - O B. Durability.
   - O C. Compression.
   - O D. Bond Strength.

21. Which technical resource must be consulted to determine the bar support spacing for a concrete bridge deck?
   - O A. American Concrete Institute.
   - O B. Concrete Reinforcing Steel Institute.
   - O C. Construction Specifications Institute.

22. What is the diameter in inches of a #8 bar?
   - O A. 1/8
   - O B. ½
   - O C. 1.0
   - O D. 8.0

23. What is the weight of a bag of Portland cement in pounds?
   - O A. 50
   - O B. 90
   - O C. 120
   - O D. 150

24. What is the weight of a #5 deformed bar in pounds?
   - O A. 0.310
   - O B. 0.625
   - O C. 1.043
   - O D. 1.963
Engineering Materials Exercise

25. Which materials are incorporated by reference and not normally shown on the plans or in the Technical Specifications?

- A. Concrete.
- B. Bar Supports.
- C. Reinforcement.
- D. Welded Wire Fabric.

26. Which type of masonry cement is used where bond and lateral strength are important?

- A. Type I.
- B. Type III.
- C. Type N.
- D. Type S.

27. Which type of masonry cement is used for foundation walls and isolated piers?

- A. Type K.
- B. Type N.
- C. Type O.
- D. Type S.

28. Which type of masonry cement is used for reinforced masonry?

- A. Type K.
- B. Type N.
- C. Type O.
- D. Type S.

29. Which of the following mortar ingredients improves the mortar’s workability?

- A. Lime.
- B. Sand.
- C. Gravel.
- D. Portland cement.
Engineering Materials Exercise

30. Which of the following mortar ingredients decreases the shrinkage of mortar while setting and drying?

☐ A. Lime.
☐ B. Sand.
☐ C. Water.
☐ D. Portland cement.

31. What ingredient is added to mortar for retempering?

☐ A. Lime.
☐ B. Sand.
☐ C. Water.
☐ D. Portland cement.

32. Which mortar property is increased by retempering?

☐ A. Oxidation.
☐ B. Bond Strength.
☐ C. Weather Resistance.
☐ D. Compressive Strength.

33. What is the strongest overlap of masonry units when building a wall?

☐ A. No lap.
☐ B. One-quarter lap.
☐ C. One-half lap.
☐ D. One-third lap.

34. Structural bonding can be accomplished by tying two wythes together with a brick. When it is laid in this position, what is the brick position called?

☐ A. Sailor.
☐ B. Header.
☐ C. Soldier.
☐ D. Stretcher.
Engineering Materials Exercise

35. What is the most common brick position?
   ○ A. Shiner.
   ○ B. Header.
   ○ C. Rowlock.
   ○ D. Stretcher.

36. What brick position is commonly used on window sills?
   ○ A. Sailor.
   ○ B. Header.
   ○ C. Soldier.
   ○ D. Rowlock.

37. What is the weakest pattern bond?
   ○ A. Stack.
   ○ A. Flemish.
   ○ B. Running.
   ○ C. Common.

38. Which of the following masonry components allows freedom of movement in a masonry wall?
   ○ A. Bond Beam.
   ○ B. Control Joint.
   ○ C. Vertical Joint reinforcement.
   ○ D. Horizontal Joint reinforcement.

39. Which of the following masonry components are continuous, they may run around the perimeter of a building or between control joints and act as structural members, and they can provide bearing for beams and joists?
   ○ A. Lintels.
   ○ B. Bond Beam.
   ○ C. Control Joint.
   ○ D. Vertical Joint reinforcement.
Engineering Materials Exercise

40. Which of the following masonry components are used over openings in block walls to carry the load around the opening?

- A. Lintels.
- B. Bond Beam.
- C. Control Joint.
- D. Vertical Joint reinforcement.

41. Which type of wall is desired where there is severe weather exposure, or where a maximum resistance to rain penetration is desired?

- A. Cavity.
- B. Veneer.
- C. Composite.
- D. Reinforced Masonry.

42. What does the steel designation C 12 x 20.7 mean?

- A. C is the steel shape, 12 is the nominal depth and 20.7 is the pounds per foot.
- B. C is the steel shape, 12 is the pounds per foot and 20.7 is the nominal depth.
- C. C is the steel series, 12 is the nominal depth and 20.7 is the pounds per foot.
- D. C is the flange width series, 12 is the pounds per foot, and 20.7 is the nominal depth.

43. Which organization publishes structural steel design properties manuals and manuals that cover steel construction methods?

- A. American Welding Society.
- B. The American Iron and Steel Institute.
- C. American Society for Testing Materials.
- D. American Institute of Steel Construction.

44. What are the drawings called that are issued to the contractor from the manufacturer indicating the locations and proper positioning of each piece of steel within the structure?

- A. Shop Drawings.
- B. Erection Drawings.
- C. Working Drawings.
- D. Architectural Drawings.
Engineering Materials Exercise

45. What structural steel component is the steel designation “VL” referring to?
   - A. Angle.
   - B. Steel Shape.
   - C. Metal Decking.
   - D. Open-web joist.

46. What structural steel component is the steel designation “LH” referring to?
   - A. Channel.
   - B. Steel Shape.
   - C. Metal Decking.
   - D. Open-web joist.

47. Which of the following is structural steel most susceptible to for failure?
   - A. Fire.
   - B. Rain.
   - C. Snow.
   - D. Chemical.

48. What is sprayed onto structural steel to increase its fire resistance capability?
   - A. Paint.
   - B. Creosote.
   - C. Preservative.
   - D. Mineral wool.

49. How is the fireproofing of a steel structure determined?
   - A. Size.
   - B. Height.
   - C. Occupancy.
   - D. Adjacent structures.
Engineering Materials Exercise

50. What type of weld fits two pieces of metal together end-to-end for welding?

   O A. Slot.
   O B. Butt.
   O C. Plug.
   O D. Fillet.

51. Assume you have a fillet weld symbol on the top of the welding symbol arrow. Which side will the weld be placed on?

   O A. The ends are welded.
   O B. All sides all the way around.
   O C. Arrow side that it is pointing to.
   O D. Other side from where the arrow is pointing.

52. Assume you have a square weld symbol with a solid flag on a pole coming up from the change in direction of the arrow. What does the solid backwards flag on a pole tell you?

   O A. Field weld.
   O B. Flush weld.
   O C. Contour weld.
   O D. Weld all the way around.

53. If the weld is supposed to be on all four sides, what symbol will be used?

   O A. Circle.
   O B. Single- V.
   O C. Convex.
   O D. Right Triangle.

54. What is the wood member called that is graded according to its bending strength on its narrow edge which is 2-4 inches thick and at least 6 inches wide?

   O A. Joists.
   O B. Planks.
   O C. Boards.
   O D. Timbers.
Engineering Materials Exercise

55. What is the wood member called that is graded according to its bending strength on its narrow edge which is at least 4 inches thick and at least 2 inches wider than they are thick?

- A. Planks.
- B. Light Framing.
- C. Post and Timbers.
- D. Beams and Stringers.

56. What is the stress term called that has the narrow dimension carrying the load with the fibers at the top in compression and the bottom fibers are in tension?

- A. Modulus of Elasticity (E).
- B. Extreme Fiber Bending ($F_b$).
- C. Horizontal Shear Parallel to the Grain ($F_{\parallel}$).
- D. Compression Perpendicular to the Grain ($F_{\perp}$).

57. What is the stress term called in a wood frame structure which works in unison to support the load on the structure and allows part of the load from a weaker member to be distributed to adjacent members?

- A. Modulus of Elasticity (E).
- B. Tension parallel to the grain ($F_{\parallel}$).
- C. Extreme Fiber Bending ($F_b$) in a Single member.
- D. Extreme Fiber Bending ($F_b$) in Repetitive members.

58. What is the wood member called that is graded according to its bending strength on its wider dimension which is 2-4 inches thick and at least 6 inches wide?

- A. Joists.
- B. Planks.
- C. Boards.
- D. Posts and Timbers.
59. What is the wood member called that is graded according to its load being are carried on the cross section?

- A. Joists.
- B. Planks.
- C. Boards.
- D. Posts and Timbers.

60. What is the stress term called that is induced by pressing the fiber together longitudinally on its cross section?

- A. Tension parallel to the grain (F_{t//})
- B. Compression Parallel to the Grain (F_{c//})
- C. Horizontal Shear Parallel to the Grain (F_{c//}).
- D. Compression Perpendicular to the Grain (F_{c\perp}).

61. What is the stress term called that is induced by the tendency for the upper fibers to slide over the lower fibers as a beam bends?

- A. Tension parallel to the grain (F_{t//})
- B. Compression Parallel to the Grain (F_{c//})
- C. Horizontal Shear Parallel to the Grain (F_{c//}).
- D. Compression Perpendicular to the Grain (F_{c\perp}).

62. What is the stress term called which is a measure of the stiffness or resistance to deflection?

- A. Modulus of Elasticity (E).
- B. Extreme Fiber Bending (F_b).
- C. Horizontal Shear Parallel to the Grain (F_{c//}).
- D. Compression Perpendicular to the Grain (F_{c\perp}).

63. Which of the following values is a typical number for the Modulus of Elasticity (E)?

- A. 90
- B. 800
- C. 1,800
- D. 1,300,000
Engineering Materials Exercise

64. Which of the following soft wood species used for structural lumber have the highest Fiber bending and Modulus of Elasticity (E) values?

- A. Cedar and Larch.
- B. Loblolly Pine and Ponderosa Pine.
- C. White spruce and Western White Pine.
- D. Douglas Fir and Southern Yellow Pine.

65. Under the structural lumber classification system, What is the name of the top grade?

- A. No. 1
- B. Stud Grade.
- C. Construction Grade.
- D. Select Structural Grade.

66. What is the structural lumber grade used where straightness and strength are the most important consideration such as in concrete formwork?

- A. No. 1.
- B. Standard Grade.
- C. Construction Grade.
- D. Select Structural Grade.

67. What does the abbreviation of S2S stamp on a piece of lumber mean?

- A. Select Two Sides.
- B. Select Two Edges.
- C. Smooth Two Sides.
- D. Smooth Two Edges.

68. What is the moisture content percentage of the lumber stamp abbreviation of S-DRY?

- A. 1
- B. 8
- C. Less than 19.
- D. Greater than 19.
Engineering Materials Exercise

69. What does the B-B designation plyform refer to?

- A. The category classification of lumber.
- B. The group number of relating to the number of plies.
- C. The front and back surface plies which have knots up to 1 inch on both sides.
- D. The front and back surface plies have a solid surface with smooth repair plugs.

70. What is the term for a material that deforms slowly when a force is applied to it for an extended period of years, even though the force is too small to cause failure in a short period of time?

- A. Creep.
- B. Strain.
- C. Tension.
- D. Compression.

71. What is the stress term called that when the stress is induced by pulling apart in a longitudinal direction?

- A. Tension parallel to the grain (F //)
- B. Compression Parallel to the Grain (F //)
- C. Horizontal Shear Parallel to the Grain (F //).
- D. Compression Perpendicular to the Grain (F_ //).

72. What is the term called that is a measure of its ability to cause turning, rotating or twisting about an axis of rotation?

- A. Tension.
- B. Moment.
- C. Vertical Shear.
- D. Horizontal Shear.

73. What is the term called where the force tends to cause a member to fail by cutting perpendicular to the beam’s longitudinal axis at or near the beam’s supports?

- A. Tension.
- B. Moment.
- C. Vertical Shear.
- D. Horizontal Shear.
Engineering Materials Exercise

74. Assume you have a wooden beam that is 20 feet long and it carries a concentrated load of 500 pounds at a distance of 15 feet from Reaction (R₁). Reaction (R₁) is pinned 5 feet from the load. What are the values in lbs for R₁ and R₂?

- A. 475 and 25.
- B. 500 and 00.
- C. 375 and 125.
- D. 125 and 375.

75. Assume you have a beam that is 16 feet long and it carries a concentrated load of 900 pounds at a distance of 4 feet from R₂. Reaction (R₁) is pinned 12 feet from the load. Reaction R₁ = 225 lbs and R₂ = 675. What is the maximum shear in lbs?

- A. 225
- B. 675
- C. 900
- D. 1800

76. Assume you have a beam that is 16 feet long and it carries a concentrated load of 900 pounds at a distance of 4 feet from R₂. Reaction (R₁) is pinned 12 feet from the load. Reaction R₁ = 225 lbs and R₂ = 675 lbs. What is the maximum bending moment in lb-ft?

- A. 900
- B. 1800
- C. 2700
- D. 3600

Check Answers
Concrete Formwork

The design and use of concrete forms either job built or prefabricated is a common feature of construction work. Most formwork is not shown on the plans or designed by a Registered Professional Engineer, but rather it is designed in the field by the field engineer or project engineer. It is therefore important that construction professionals have a demonstrated understanding of the design principles for concrete formwork.

The American Concrete Institute’s (1995) book titled, *Formwork for Concrete*, is the primary reference for the design of vertical formwork for walls, the design of column formwork and the design of horizontal formwork for elevated slabs. This publication is also referred to as ACI Committee 347 *Recommended Practice for Concrete Formwork* and ACI SP-4 *Formwork for Concrete*. This publication is normally incorporated by reference in Division 03 titled Concrete, Section 100 titled Concrete Formwork, and Part 1 titled General. For example, under Part 1.04 titled Reference Standards, under item D it states that “Each Contractor shall maintain a copy of this publication shall be on the job site at all times.” Also, Part 1.05 titled Quality Assurance it states under item A. “Design of formwork is the Contractor’s responsibility” and under item B. “Tolerances recommended in ACI 347 shall govern, . . .” In conclusion, a copy of the book titled *Formwork for Concrete*, shall be on the job site at all times for the field engineer to consult.

Concrete Rate of Pour

The *Rate of Pour* depends on the type of equipment that is being used to place the concrete. Cast-in-place concrete can be placed by direct chute, crane and bucket, concrete pump, motorized concrete buggy, a conveyor, or by hand using a Georgia buggy. The rate of pour is expressed in Feet (vertical) per hour.

Assume that you are pouring a wall that is 200' long by 8 feet high and it is 8 inches thick and you are given the following information. The crew can place 345 Cubic Yards in a 10 - hour day and the crew consists of 1 - Crew Leader, 5 - Building Laborers and 1 - Finisher. Calculate the Concrete Rate of Pour for the Wall. The Placing Rate in cubic feet per hour is:

\[
\frac{345}{10} = 34.5 \text{ CY} \times \frac{27 \text{ CF}}{\text{CY}} = 931.5 \text{ cubic feet per hour}
\]

The Plan area in square feet for the wall forms is = \[
\frac{200' \times 8'}{12} = 133.33 \text{ square feet}
\]

The Rate of pour in Feet (vertical) per hour is = \[
\frac{931.5}{133.33} = 6.98 \text{ Feet per Hour}
\]
An alternative method to calculate the rate of pour for the 200' long by 8 Feet High by 8 inches thick wall. Assume the pour is 40 feet above grade. The bucket capacity is 1.5 cubic yards, and the rate of travel up for the bucket is 90 feet per minute and the rate of travel down is 120 feet per minute. Assume the load time is 20 seconds and the unload time is 1.5 minutes. The crane and bucket cycle time is:

<table>
<thead>
<tr>
<th>Activities</th>
<th>Calculations</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load time</td>
<td>20 seconds/60 seconds</td>
<td>0.333</td>
</tr>
<tr>
<td>Travel up</td>
<td>40’ / 90 ft/minute</td>
<td>0.444</td>
</tr>
<tr>
<td>Unload time</td>
<td>1.5 minutes</td>
<td>1.500</td>
</tr>
<tr>
<td>Travel down</td>
<td>40’ / 120 ft/minute</td>
<td>0.333</td>
</tr>
<tr>
<td><strong>Total Minutes per Cycle</strong></td>
<td></td>
<td><strong>2.610</strong></td>
</tr>
</tbody>
</table>

The Rate of delivery in cubic yards per hour is:

\[
\frac{60 \text{ minutes}}{2.610 \text{ minutes per cycle}} = 23 \text{ cycles per hour} \times 1.5 \text{ CY bucket/cycle} = 34.48 \text{ CY per hour}
\]

The Volume of concrete in cubic yards to be poured is:

\[
\frac{200 \text{ feet} \times 8 \text{ feet} \times 8”/12”}{27 \text{ CF/CY}} = 1066.666 \text{ CF} = 39.704 \text{ Cubic Yards.}
\]

The number of hours required to pour 39.704 cubic yards of concrete is:

\[
\frac{39.704 \text{ CY}}{34.480 \text{ CY/ hr.}} = 1.15 \text{ hours}
\]

The Rate of pour in feet per hour is: \( \frac{8 \text{ feet high}}{1.15 \text{ hours}} = 6.96 \text{ Feet per Hour} \)

Finally, the rate of pour using a concrete pump which has a capacity of 930 cubic feet per hour. The Volume of the concrete in cubic feet for the 200 feet x 8 feet x 0.667 = 1066.666 CF. Therefore, the number of hours required to pour the concrete using the pump is:

\[
\frac{1066.666 \text{ CF}}{930 \text{ CF/Hour}} = 1.147 \text{ hours}
\]

The Rate of pour in feet per hour is: \( \frac{8 \text{ feet high}}{1.147 \text{ hours}} = 6.97 \text{ Feet per Hour} \)
Lateral Concrete Pressure on Wall Forms

The *Lateral Concrete Pressure* exerted on vertical formwork is affected by several factors. First, the freshly placed concrete initially acts as a fluid exerting hydrostatic pressure against the vertical formwork. Second, the weight of the concrete exerts pressure on the forms and concrete is assumed to weigh between 150 and 154 pounds per cubic foot. Third, the placement rate of concrete affects the lateral pressure. The greater the height of the wall allows the concrete to behave as a fluid which has a greater lateral pressure at the bottom. Fourth, the temperature of the concrete and the atmospheric conditions affect the setting time which affects the pressure on the forms. Fifth, vibration of the concrete increases the lateral pressure because the concrete acts as a fluid for the full depth being vibrated. Sixth, the consistency of the concrete mix affects the lateral pressure. In conclusion, the lateral concrete pressure is a function of the hydrostatic pressure, the weight of the concrete, the rate of the pour, the temperature of the concrete, the consolidation of concrete by vibration and the consistency of the concrete mix all affect the lateral concrete pressure.

The ACI 347 Committee has developed the following formulas for calculating the *maximum lateral pressure* (*p*) *for the design of wall forms*. The lateral pressure (*p*) is expressed in pounds per square foot (psf). The ACI 347 Committee also insists that these formulas were developed for very specific conditions. The basic lateral pressure formulas for the wall forms are based upon the following placement conditions. The concrete is made with a Type I cement weighing 150 pounds per cubic foot, containing no pozzolans or admixtures, with a maximum slump of 4 inches. The internal vibration is limited to a depth of 4 feet or less below the concrete surface, and the maximum rate of pour cannot exceed 10 feet per hour (*p* 5-12). The ACI 347 Committee recommends these formulas with limitations for the lateral pressure on wall forms as follows. For Walls with placement rates of less than 7 feet per hour, the pressure is:

\[
p = \frac{150 + 9000R}{T}
\]

For Wall with placement rates of 7 feet per hour and up to 10 feet per hour, the pressure is:

\[
p = \frac{150 + \frac{43400}{T} + \frac{2800}{T} R}{T}
\]

The abbreviations in the formulas represent the following units:
- *p* = lateral pressure in pounds per square foot (psf)
- *R* = the rate of concrete placement in feet per hour
- *T* = the temperature of the concrete in the form, in degrees Fahrenheit.

Finally, the lateral pressure on the wall forms is limited as follows. The Maximum pressure is 2000 psf but in no case greater than 150 times the height of the wall, whichever is less. This is expressed as *p* = 150h. The minimum pressure is 600 psf.
An example of the maximum lateral concrete pressure for the design of wall forms for a 12-foot high wall that will be placed at 5 feet per hour. The temperature of the concrete at the time of the pour will be 75°F. Also, Type 1 cement was used without admixtures, and the slump with this mix is typically 4 inches or less. The top 3 feet of the concrete must be vibrated according to the specifications. For this case, the maximum fluid pressure is calculated under the assumption that the unit weight of the concrete will be approximately 150 pounds per cubic foot (pcf). Therefore, for walls with a placement rate of less than 7 feet per hour, the maximum pressure is:

\[ p = \frac{150 + 9000R}{T} \]

\[ p = \frac{150 + 9000 (5)}{75} = 750 \text{ psf} \]

Check for maximum pressure: the lesser of 2,000 psf and 150h, whichever is less:

\[ p = 150h = 150 (12) = 1800 \text{ psf} \]

In this example, use the formula value of 750 psf because the conditions for the placement of the concrete match the assumptions for the rate of placement formula, so that this maximum will be reduced by the initial set within the lower portions of the concrete.

This pressure will build up as a fluid pressure based on the 150 pounds per cubic foot (pcf) unit weight of the fluid. To determine the height of the maximum pressure, the 150h represents the pressure of concrete in its liquid state which can be equated to the maximum pressure calculated. The formula is \( p = 150h \) which can be expressed in terms of the distance (h) from the top of the concrete pour as:

\[ h = \frac{p}{150} \]

The h represents the distance from the top of the concrete pour to where the calculated maximum pressure begins. In this example, the distance from the top of the pour to the point of maximum pressure is:

\[ h = \frac{750 \text{ psf}}{150 \text{ p}} = 5 \text{ feet} \]
Lateral Concrete Pressure on Column Forms

The ACI 347 Committee has also developed the following formula for calculating the maximum lateral pressure for the design of column forms. The lateral pressure is expressed in pounds per square foot (psf). The ACI 347 Committee also insists that the column formula was developed for very specific conditions. The basic lateral pressure formula for the column forms is based upon the following placement conditions which are similar to the wall form formula. The concrete is made with a Type I cement weighing 150 pounds per cubic foot, containing no pozzolans or admixtures, with a maximum slump of 4 inches. The internal vibration is limited to a depth of 4 feet or less below the concrete surface (p 5-13).

The ACI 347 Committee states that the column forms are small enough that the concrete is frequently placed to their full height within the time that it takes the concrete to begin to set. Also, the vibration of the concrete frequently extends the full height of the form which results in greater maximum lateral pressures than those that occur in wall forms. Therefore, the pressure in column forms is essentially a fluid (p 5-13). The ACI 347 Committee recommends this formula with limitations for the lateral pressure on columns as follows:

For Columns, where the maximum height of a single lift of concrete for the pour does not exceed 18 feet per hour, the pressure is:

\[ p = \frac{150 + 9000R}{T} \]

Finally, the lateral pressure on the column forms is limited as follows. The Maximum pressure is 3000 psf but in no case greater than 150 times the height of the column, whichever is less. This is expressed as \( p = 150h \). The minimum pressure is 600 psf.

An example of the maximum lateral concrete pressure for the design of column forms given the following conditions is shown below.

- Height of column = 15 Feet
- Rate of pour (R) = 10 Feet per hour
- Concrete Temperature (T) = 40 Degrees Fahrenheit

For columns, the maximum concrete pressure on the column is?

\[ p = \frac{150 + 9000 \times 10}{40} = 2400 \text{ psf} \]

Check for maximum pressure: the lesser of 3000 psf and \( 150h = 150 \times 15 = 2250 \text{ psf} \). Therefore, in this example, use the \( 150h = 2250 \text{ psf} \) as the maximum pressure instead of the formula value.
Wall Formwork Components
Once the lateral pressure from the concrete has been determined, then the size and on-center spacing of each component within the form system can be designed to withstand the forces due to the fluid concrete. The **components of a wall form system** consist of sheathing, studs, wales, ties and lateral bracing. The design proceeds out from the concrete pressures established. First, the concrete is supported by the sheathing, which in turn is supported by studs, which are supported by joists, which are supported by the ties as shown below.

It should be noted that a number of additional components would be provided in practice, including perhaps a bottom plate or mud sill to prevent kickout of the bottom of the form and a **Wall Bracing** system is installed to maintain the vertical orientation of the wall. The braces are angled members and run between the ground and a point near the top of the wall form. These components will not be treated in the design procedures outlined herein. Also note that the function of this section is to review the design procedures outlined by ACI, not to replace them. Readers are directed to the ACI’s publication titled, *Formwork for Concrete SP-4* for more complete design guidelines.

The design of each component is a balance between the size of that component and the spacing of the support for that component. For example, one can select thin sheathing with closely spaced studs, or thick sheathing with widely spaced studs, or something in between. There are economic implications: if new materials are to be acquired, or based on the materials already available.
Plyform Sheathing and Sheathing Tables

*Sheathing* is the material in contact with the concrete. The most common sheathing material for job-built formwork is plyform. The American Plywood Association (APA) defines plyform as a composite material made by gluing together thin layers or plies of wood. The quality of the plies used for the surface has an impact on the smoothness of the concrete surface. Plyform for concrete is graded B-B which is sanded smooth with some plugs allowed. The Plyform strength is given by its Class; most plyform is Class 1 which is the stronger class. The grain direction is alternated in each layer to provide resistance to warping and curling of the plywood. In the United States, the plyform is made with an odd number of layers so that there is one more layer with its grain in the same direction as the face grain than there is perpendicular to that direction as shown below.

![Plywood Grain Directions](image)

As a result, the plywood is stronger when the face grain runs in the direction of the span. Since the sheathing “spans” from stud to stud, the plywood is usually used with the face grain running from one stud to the next, rather than parallel to the studs. This orientation is called “face grain parallel to the span.” In the United States the plywood and the plyform is made with the face grain parallel to the long dimension of the plywood.

The *American Concrete Institute* (ACI) has calculated the safe spans for numerous formwork components and developed a series of formwork tables that provide the field engineer with a quick method for selecting the appropriate spacing for the material sizes available. The tables have been arranged into four groups. Tables 7-2, 7-3 and 7-4 are called plywood sheathing tables and they are utilized to determine the maximum stud spacing. Tables 7-5, 7-6, 7-7 are called joists, studs, stringers or any other beam components of the formwork where the framing members are used singly. The joist tables are used to determine the maximum wale spacing. Tables 7-8, 7-9, 7-10 are called double wale tables where the members are used double. The wale tables are used to determine the maximum allowable wall tie spacing.

In summary, the design of a wall form system uses plywood sheathing tables 7-2, 7-3 and 7-4 to determine the stud spacing. It uses the joist, stud, and stringer tables 7-5, 7-6, 7-7 to determine the wale spacing and it uses the double wale tables 7-8, 7-9, 7-10 to determine the maximum wall tie spacing.
Maximum Allowable Stud Spacing

The formwork design process begins with the selected sheathing and the tables are used to determine the maximum stud spacing. It is common to start with an assumed sheathing thickness, and with that thickness to calculate a stud spacing. The stud spacing comes from the ACI’s Plywood Sheathing Design Tables 7-2, 7-3 and 7-4. They are for plyform sheathing utilized in the construction of walls, columns and elevated slabs. These tables cover three different load situations. Table 7-2 is titled Safe Spacing, in Inches, of Supports for Plywood Sheathing, Continuous over Four or More Supports (p 7-7). Table 7-3 is titled, Safe Spacing, in Inches, of Supports for Plywood Sheathing, Continuous over Two Spans (p 7-8). Table 7-4 is titled Safe Spacing, in Inches, of Supports for Plywood Sheathing with only two points of support (p 7-9). The continuous over many spans approach is usually assumed, because ordinarily there are at most 24” spacing over the 8-foot side of the plywood; hence, there will be at least four spans.

To use the sheathing design tables 7-2, 7-3 or 7-4, first calculate the maximum concrete pressure. Then, select a sheathing thickness, and decide whether the loading will be short term or long term. Short term loading is often referred to as a single use. Long term loading is often referred to as forms that will be used several times. The Sheathing Design Tables 7-2, 7-3 and 7-4 were calculated for both short term and long term using the working stresses for Class 1 concrete plyform. The tables contain the concrete pressures down the left-hand side. Horizontally, the table is divided into two halves by the vertical double line. The values to the left of this double vertical line are the short term loads and the values to the right of the double vertical line are the long-term loads. The long term loading is the more common in practice.

The Sheathing Design Tables also contain the parameters for the allowable bending stress ($F'_{b}$), the rolling shear, and the allowable design value for the modulus of elasticity ($E'$) using B-B Class 1 Plyform. The allowable bending stress ($F'_{b}$) is either 1930 psi or 1545 psi. The rolling shear is either 72 psi or 57 psi. The allowable modulus of elasticity ($E'$) is 1,500,000. Next, the designer must consider the orientation of the plywood and make a selection of which of the two columns on each side of the double line will be used. The orientation of the plywood options on each side of the double line is Face grain parallel to the span and Face grain perpendicular to the span. Face grain parallel to the span is more common, but the Face grain perpendicular orientation is sometimes used. After determining the proper portion of the table, it is a matter of finding the intersection of the column for the sheathing thickness and the row for the maximum expected pressure. The intersection will be the maximum allowable spacing of the studs. An example for determining the maximum allowable spacing of studs for a wall form system based upon the following conditions is:

Concrete pressure: 750 psf.
Stud Support Conditions: Continuous over 3 or more spans
Loading Duration: Short term
Sheathing: 1" B-B Class 1 Plyform, Face Grain Parallel to Span
Using the Partial ACI Sheathing Design Table 7-2 titled, Safe Spacing, in Inches, of Supports for Plywood Sheathing, Continuous over Four or More Supports provided below with a maximum concrete pressure of 750 psi. The Short term loading is to the left of the double vertical line which results in an allowable bending stress \((F'_b)\) of 1930 psi. The Plywood is 1 inch thick and the orientation is given as Face grain is parallel to span, Therefore, use the Short Term Loads half of the table with the heading of Face grain parallel to span and the intersection of the column and the concrete pressure which results in a stud spacing of between 14 and 15 inches. This value is shown on the table as shaded. An interpolation of the spacing would be 14.5 inches, but plywood sheathing is normally 4 feet wide by 8 feet long, therefore, the stud spacing would probably be reduced to 12 inches to accommodate the modular spacing of the materials.

The Joists, Studs and Beam Design Tables 7-5, 7-6 and 7-7 are applicable to formwork members which are loaded uniformly as a beam. The tables in the 7-5 series, 7-5.1, 7-5.2, 7-5.3 and 7-5.4, are all titled, Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Continuous over Three or More Spans, but each table within the series has a different adjusted horizontal shear \((F'_b)\) as shown in the table. All the tables indicate bending \((F'_b)\) varies with each member and the Modulus of Elasticity (E) is either 1,600,000 or 1,300,000 psi. The America Concrete Institute has recommended the following adjusted allowable stresses (p 7-2).

<table>
<thead>
<tr>
<th>Bending (F'_b)</th>
<th>Horizontal shear ((F'_b))</th>
<th>Modulus of Elasticity (E)</th>
<th>Use of No. 2 Lumber of indicated species</th>
</tr>
</thead>
<tbody>
<tr>
<td>960 to 1440 psi</td>
<td>180 psi</td>
<td>1,600,000 psi</td>
<td>Southern Pine and Douglas-Fir-Larch</td>
</tr>
<tr>
<td>1200 to 1810 psi</td>
<td>225 psi</td>
<td>1,600,000 psi</td>
<td></td>
</tr>
<tr>
<td>940 to 1400 psi</td>
<td>140 psi</td>
<td>1,300,000 psi</td>
<td>Spruce-Pine-Fir and Hem-Fir</td>
</tr>
<tr>
<td>1170 to 1750 psi</td>
<td>175</td>
<td>1,300,000 psi</td>
<td></td>
</tr>
</tbody>
</table>

The tables in the 7-6 series, 7-6.1, 7-6.2, 7-6.3 and 7-6.4, are all titled, Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Single Span, but each table within the series has a different adjusted horizontal shear \((F'_b)\) as shown in the table. The Tables in the 7-7 series, 7-7.1, 7-7.2, 7-7.3 and 7-7.4, are all titled, Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Continuous Over Two Spans, but each table in the series has a different adjusted horizontal shear \((F'_b)\) as shown in the table.
Partial ACI Table 7-2: SAFE SPACING, IN INCHES, OF SUPPORTS FOR PLYWOOD SHEATHING, CONTINUOUS OVER FOUR OR MORE SUPPORTS

<table>
<thead>
<tr>
<th>Maximum deflection 1/360 of span, but not more than 1/16 inch.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pressure or load of concrete, pounds per square foot</strong></td>
</tr>
<tr>
<td>Stresses and spans for short duration loads, for all sanded grades of Group 1 plywood, E modified for deflection calculations</td>
</tr>
</tbody>
</table>
| \((F'_b) = 1930 \text{ psi.} \)  
  \text{rolling shear} = 72 \text{ psi}; \quad \text{E}' = 1,500,000 \text{ psi} |
| Sanded thickness, face grain parallel to span | Sanded thickness, face grain perpendicular to span |
| \(\frac{1}{8}\) in | \(\frac{5}{8}\) in | \(\frac{3}{4}\) in | 1 in | \(\frac{1}{8}\) in | \(\frac{5}{8}\) in | \(\frac{3}{4}\) in | 1 in |
| 500 | 10 | 12 | 14 | 18 | 5 | 7 | 10 | 14 | 9 | 11 | 12 | 16 | 5 | 7 | 10 | 14 |
| 600 | 10 | 11 | 13 | 16 | 5 | 7 | 9 | 13 | 9 | 10 | 11 | 14 | 5 | 7 | 9 | 13 |
| 700 | 9 | 11 | 12 | 15 | 5 | 7 | 9 | 12 | 8 | 9 | 10 | 13 | 5 | 7 | 8 | 12 |
| 800 | 9 | 10 | 11 | 14 | 4 | 6 | 8 | 12 | 7 | 9 | 10 | 12 | 4 | 6 | 7 | 12 |
| 900 | 8 | 9 | 10 | 13 | 4 | 6 | 8 | 11 | 7 | 8 | 9 | 12 | 4 | 5 | 7 | 10 |
| 1000 | 7 | 9 | 10 | 12 | 4 | 6 | 7 | 11 | 7 | 8 | 9 | 11 | 4 | 5 | 6 | 10 |
| 1100 | 7 | 8 | 9 | 12 | 4 | 6 | 7 | 11 | 6 | 8 | 8 | 11 | 4 | 5 | 6 | 9 |
| 1200 | 7 | 8 | 9 | 11 | 4 | 5 | 6 | 10 | 6 | 7 | 8 | 10 | 4 | 4 | 5 | 8 |

Note: Above solid, deflection controls span. Below dash line, rolling shear governs. Between the lines, bending controls. Spans are given center to center of supports, assuming 1-1/2 inch support width for shear spans. If supports of a different width are used, detailed calculations should be made to check spans in the range now shown as controlled by shear. Adapted from American Concrete Institute’s publication Formwork for Concrete. Sixth Edition, Table 7-2 (p 7-7). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
Uniform Stud Load and the Allowable Wale Spacing

To use the stud design table 7-5.1: titled, Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Continuous over Three or More Spans, first calculate the uniform load on the studs in pounds per lineal feet which equals the maximum pressure in psf times the stud spacing from the sheathing design table previously. The studs are loaded by the concrete pressure on that portion of the sheathing supported by each stud. From the previous example, the maximum concrete pressure was 750 psf and the spacing was found to be 14.5 inches but it was reduced to 12 inches. Therefore, the uniform load on the stud is as follows:

\[ \text{Uniform Stud Load} = \frac{750 \text{ psf} \times 12 \text{ inches} \times 1 \text{ foot}}{12 \text{ inches}} = 750 \text{ pounds per lineal foot} \]

Next, determine the stud size available and the allowable horizontal shear \((F'_h)\) based upon the materials provided. After you have selected the correct stud design table based upon the adjusted horizontal shear \((F'_h)\), the Bending \(F'_s\) and the Modulus of Elasticity \((E')\). Then it is a matter of finding the intersection of the uniform stud load and the size of the material available. The intersection will be the maximum allowable spacing of the wales.

An example for determining the \textit{maximum allowable spacing of wales} for a wall form system given the following conditions wall formwork design criteria:

- Concrete pressure: 750 psf.
- Rate of Pour: 5 feet per hour
- Temperature of Concrete: 75 Degrees Fahrenheit
- Wall Height: 12 feet
- Wall Thickness: 10 inches
- Loading Duration: Long term
- Sheathing: 1" B-B Class 1 Plyform, Face Grain Parallel to Span
- Stud Load: 750 pounds per lineal foot (plf)
- Stud Lumber: No. 2 Douglas Fir-Larch, S4S
- Stud Support Conditions: Continuous over 3 or more spans
- Stud Horizontal Shear \((F'_h)\): 180 psi
- Studs: 2 x 4 studs, spaced 12 inches center-to-center

Using the Partial ACI Stud Design Table 7-5.1 below titled, Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Continuous over Three or More Spans, and a stud Horizontal Shear \((F'_h)\) of 180 psi stated above. Find the row containing the uniform load of 750 plf and find the 2 x4 column, the intersection of the row and column will provide you with the maximum wale spacing. The shaded area on the table shows that the wale spacing is between 23 inches and 25 inches. The \textit{Maximum Wale Spacing} is 24 inches.
Partial ACI Table 7-5.1: Safe Spacing, in Inches, of Supports for Joists, Studs, or Other Beam Components of Formwork, Continuous Over Three or More Spans.

Maximum deflection is 1/360 of the span or 1/4 in., whichever is smaller.

<table>
<thead>
<tr>
<th>Uniform load, lb per lineal feet (equals uniform load on forms times spacing between joists or studs (feet))</th>
<th>( F'_{b} ) varies with member</th>
<th>( E' = 1,600,000 ) psi</th>
<th>( F'_{v} = 180 ) psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal size of SxS lumber</td>
<td>2x4</td>
<td>2x6</td>
<td>2x8</td>
</tr>
<tr>
<td>( F'_{v} ) psi</td>
<td>1310</td>
<td>1140</td>
<td>1050</td>
</tr>
<tr>
<td>500</td>
<td>31</td>
<td>45</td>
<td>58</td>
</tr>
<tr>
<td>600</td>
<td>28</td>
<td>42</td>
<td>53</td>
</tr>
<tr>
<td>700</td>
<td>25</td>
<td>38</td>
<td>49</td>
</tr>
<tr>
<td>800</td>
<td>23</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>900</td>
<td>21</td>
<td>33</td>
<td>43</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
<td>31</td>
<td>41</td>
</tr>
<tr>
<td>1100</td>
<td>18</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>1200</td>
<td>18</td>
<td>28</td>
<td>36</td>
</tr>
<tr>
<td>1300</td>
<td>17</td>
<td>26</td>
<td>35</td>
</tr>
</tbody>
</table>

NOTE: Span values above solid line are controlled by deflection. Within the dashed box horizontal shear governs span. Elsewhere bending controls span. Adapted from American Concrete Institute’s publication *Formwork for Concrete*. Sixth Edition, Design Table 7-5.1 (p 7-10). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.

The Wale Design Tables 7-8, 7-9 and 7-10 are for double members which are commonly used for wales and frequently used for stringers. A stringer is a member used in the design of elevated slabs. The 7-8 series, 7-8.1 and 7-8.2 are both for Double Wales, Continuous over Three or More Spans, but 7-8.1 covers adjusted horizontal shear (\( F'_{s} \)) of 180 psi and 225 psi respectively and the Modulus of Elasticity (\( E' \)) is 1,300,000. Table 7-8.2 covers adjusted horizontal shear (\( F'_{s} \)) of 140 psi and 175 psi respectively, and the Modulus of Elasticity (\( E' \)) is 1,300,000. Tables 7-9.1 and 7-9.2 are both for Double Wales, Single Span. Table 7-9.1 covers adjusted horizontal shear (\( F'_{s} \)) of 180 psi and 225 psi respectively. Table 7-9.2 covers adjusted horizontal shear (\( F'_{s} \)) of 140 psi and 175 psi respectively. Tables 7-10.1 and 7-10.2 are both for Double Wales, Continuous Over Two Spans. Table 7-10.1 covers horizontal shear (\( F'_{s} \)) of 180 psi and 225 psi respectively. Table 7-10.2 covers horizontal shear (\( F'_{s} \)) of 140 psi and 175 psi respectively.
Uniform Wale Load and the Maximum Allowable Tie Spacing

To use the Wales design table 7-8.1: titled, Safe Spacing, in Inches, of Supports for Double Wales, Continuous over Three or More Spans, first calculate the uniform load on the wales in pounds per lineal foot which equals uniform load in pounds per square foot times the spacing of the wales. This uniform load was calculated from the previous design tables and the spacing of the wales was found in the previous stud design table. From the previous example, the uniform load on the stud was 750 pounds per lineal foot (plf) and the spacing of the wales was 24 inches. Therefore, the uniform load on the wales is as follows:

\[
\text{Uniform Wale Load} = 750 \text{ plf on the stud} \times 24 \text{ inches} \times 1 \text{ foot} = \frac{1500 \text{ pounds per foot}}{12 \text{ inches}}
\]

Next, determine the wale size available and the allowable horizontal shear \((F'_{v})\) based upon the materials provided. After you have selected the correct wale design table based upon the adjusted horizontal shear \((F'_{v})\), the Bending \(F'_{b}\), and the Modulus of Elasticity \((E')\). Then it is a matter of finding the intersection of the uniform wale load and the size of the material available. The intersection will be the maximum allowable spacing of the wall ties.

An example for determining the maximum allowable spacing of wall ties for a wall form system given the following conditions wall formwork design criteria:

Concrete pressure: 750 psf.

- Stud Lumber: No. 2 Douglas Fir-Larch, S4S
- Stud Support Conditions: Continuous over 3 or more spans
- Stud Horizontal Shear \((F'_{v})\): 180 psi
- Studs: 2 x 4 studs, spaced 12 inches center-to-center

- Wale Load: 1500 pounds per lineal foot (plf)
- Wale Lumber: No. 2 Douglas-Fir-Larch, S4S
- Wale Support Conditions: Continuous over 3 or more spans
- Wale Horizontal Shear \((F'_{v})\): 180 psi
- Wales: 2 x 6 double wales at 24 inches center-to-center.

Using the Partial Double Wales Design Table 7-8.1: titled, Safe Spacing, in Inches, of Supports for Double Wales, Continuous over Three or More Spans and a Wale Horizontal Shear \((F'_{v})\) of 180 psi stated above. Find the row containing the uniform wale load of 1500 plf and find the 2 x 6 column, the intersection of the row and column will provide you with the maximum tie spacing. The table shows that the wale spacing is 37 inches which is shown on the table as a shaded area. Therefore, the maximum allowable tie spacing is 37 inches.
Partial ACI Table 7-8.1: SAFE SPACING, IN INCHES, OF SUPPORTS FOR DOUBLE WALES, CONTINUOUS OVER THREE OR MORE SPANS

<table>
<thead>
<tr>
<th>Uniform load, lb per lineal foot (equals uniform load, psf, on forms times spacing of wales in ft.)</th>
<th>( F'_b ) varies with member ( E' = 1,600,000 \text{ psi} )</th>
<th>( F'_v = 180 \text{ psi} )</th>
<th>( F'_b ) varies with member ( E' = 1,600,000 \text{ psi} )</th>
<th>( F'_v = 225 \text{ psi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal size of S4S lumber</td>
<td></td>
<td>Nominal size of S4S lumber</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x4</td>
<td>2x6</td>
<td>2x8</td>
<td>3x4</td>
</tr>
<tr>
<td>600</td>
<td>1310</td>
<td>1140</td>
<td>1050</td>
<td>1130</td>
</tr>
<tr>
<td>700</td>
<td>40</td>
<td>59</td>
<td>74</td>
<td>52</td>
</tr>
<tr>
<td>800</td>
<td>37</td>
<td>54</td>
<td>69</td>
<td>48</td>
</tr>
<tr>
<td>900</td>
<td>35</td>
<td>51</td>
<td>64</td>
<td>45</td>
</tr>
<tr>
<td>1000</td>
<td>33</td>
<td>48</td>
<td>61</td>
<td>42</td>
</tr>
<tr>
<td>1100</td>
<td>31</td>
<td>45</td>
<td>58</td>
<td>40</td>
</tr>
<tr>
<td>1200</td>
<td>30</td>
<td>43</td>
<td>55</td>
<td>38</td>
</tr>
<tr>
<td>1300</td>
<td>28</td>
<td>42</td>
<td>53</td>
<td>37</td>
</tr>
<tr>
<td>1400</td>
<td>26</td>
<td>40</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>1500</td>
<td>25</td>
<td>38</td>
<td>49</td>
<td>34</td>
</tr>
<tr>
<td>1600</td>
<td>24</td>
<td>37</td>
<td>47</td>
<td>33</td>
</tr>
<tr>
<td>1700</td>
<td>23</td>
<td>36</td>
<td>45</td>
<td>32</td>
</tr>
</tbody>
</table>

NOTE: Span values above solid line are controlled by deflection. Within the dashed box horizontal shear governs span. Elsewhere bending controls span.
Adapted from American Concrete Institute’s publication *Formwork for Concrete*. Sixth Edition, Design Table 7-8.1 (p 7-22). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
Load Capacity of Available Wall Ties

The **load capacity of available wall ties** is the last step in the process. This requires the selection of a wall tie that can resist the load, which will be applied to it. The load applied to the wall tie is the concrete pressure times the wale spacing and times the tie spacing. The design process simply requires determining whether the value calculated is less than the manufacturer’s rating for the tie intended for use. When the expected load is less than the tie can resist, the tie is used. When the expected load is too high, one must either reduce the tie spacing to reduce the load, or find a bigger tie. An example for verifying the wall tie load capacity for a wall form system given the following conditions wall formwork design criteria are as follows:

- **Concrete pressure:** 750 psf.
- **Rate of Pour:** 5 feet per hour
- **Temperature of Concrete:** 75 Degrees Fahrenheit
- **Wall Height:** 12 feet
- **Wall Thickness:** 10 inches
- **Loading Duration:** Long term
- **Sheathing:** 1" B-B Class 1 Plyform, Face Grain Parallel to Span
- **Stud Lumber:** No. 2 Douglas Fir-Larch, S4S
- **Stud Support Conditions:** Continuous over 3 or more spans
- **Stud Horizontal Shear (F’<sub>s</sub>):** 180 psi
- **Studs:** 2 x 4 studs, spaced 12 inches center-to-center
- **Wale Load:** 1500 pounds per lineal foot (plf)
- **Wale Lumber:** No. 2 Douglas Fir-Larch, S4S
- **Wale Support Conditions:** Continuous over 3 or more spans
- **Wale Horizontal Shear (F’<sub>h</sub>):** 180 psi
- **Wales:** 2 x 6 double wales at 24 inches center-to-center.
- **Maximum Tie Spacing:** 37 inches

From the example, the concrete pressure is 750 psf, the wale spacing is 24 inches and the maximum tie spacing is 37 inches. Therefore, the load capacity on the wall ties is as follows:

**Wall Tie Load Capacity** = 750 psf x 24/12 x 37/12 = 4,625 pounds

A wall tie with a safe working load of 5,000 pounds will resist the 4,625 pound load calculated above. But based upon uniform or modular spacing, the 2 x 6 double wales would be more practical if a tie spacing of 36 inches was utilized. Therefore, the tie spacing would be less than the maximum allowed by table 7-8.1, and the average wall tie load would be reduced to:

**Tie Load Capacity** = 750 psf x 24/12 x 36/12 = 4500 pounds
Elevated Slab Form Load

The *Vertical Load* on elevated slab forms must be designed to resist the dead loads and the various live loads during construction. Elevated slab forms must also be capable of resisting lateral loads from the placement of the concrete, the movement of construction equipment and the wind. The ACI 347 Committee suggests that the dead load consists of the weight of the fresh concrete, the weight of the reinforcing bar, and the weight of the forms (p 5-1). For example, assume that you have concrete that weighs 154 pounds per cubic foot. It will place a load on the forms of 12.83 pounds per square foot for each inch of slab thickness as shown below.

\[
\frac{154}{12} = 12.8333 \text{ pounds per Square Foot}
\]

Therefore, the *Dead Load* for a 6" thick slab is 12.8333 pounds per Square Foot x 6 inches = 76.999 pounds per square foot

The ACI Committee 347 recommends that a single story-elevated slab be designed for a minimum *Live Load* 50 psf to provide for weight of workers, runways, screeds and other equipment. This does not include the weight of the concrete formwork. If motorized concrete buggies are being used, then the minimum live load should be 75 pounds per square foot (psf). The ACI 347 Committee also says that “regardless of slab thickness, the minimum design value for combined dead and live loads should be 100 psf, or 125 psf if motorized buggies are used” (p 5-1). Using the 6-inch slab dead load from above, and the recommended live load excluding the weight of the forms. Then the minimum total horizontal design load is:

\[
77 \text{ psf dead load} + 50 \text{ psf live load} = 127 \text{ pounds per square foot (psf)}
\]

Using the 6-inch slab dead load from above, and the recommended live load for motorized concrete buggies excluding the weight of the forms. Then the minimum total horizontal design load is: 77 psf dead load + 75 psf live load = 152 pounds per square foot (psf)

The design for an *Elevated Slab* consists of plyform sheathing, joists, stringer and shores or posts. The ACI’s Plywood Sheathing Design Tables 7-2, 7-3 and 7-4 are used to determine the maximum joist spacing. Tables 7-5, 7-6 and 7-7 are used for the stringers to determine the member sizes which can be used for the stringer span designated. Stringers are members placed side by side with their longer dimensions as the depth of the beam. Finally, Tables 7-11 and 7-12 are for selecting the allowable loads on the posts. Table 7-11 is titled, Allowable Axial Load (Pounds) on Simple Wood Shores of the Indicated Strength and Effective Length. Table 7-12: is titled, Allowable Load Based on Maximum Shore Area in Direct Contact with Wood Member Being Supported.
Formwork Design Exercise

1. Which of the following references is incorporated by reference for the design of vertical and horizontal forms and a copy shall be maintained on the job site at all times?

- A. American Concrete Institute’s publication ACI 347 titled, *Formwork for Concrete*.
- C. American Concrete Institute’s publication ACI 301 titled, *Specifications for Structural Concrete for Buildings*.
- D. Concrete Reinforcing Steel Institute’s publication CRSI 65 titled, *Recommended Practice for Placing Bar Supports, Specifications and Nomenclature*.

2. Which party is responsible for the design of the concrete formwork?

- A. Owner.
- B. Field Engineer.
- C. Concrete Supplier.
- D. Architect/Engineer.

3. According to the ACI 347 Committee, What is the Maximum Rate of Pour allowed for a Wall in feet per hour?

- A. 7 feet per hour
- B. 10 Feet per hour
- C. 18 feet per hour
- D. 150 feet per hour

4. What is the weight range of a cubic foot of normal concrete for design purposes?

- A. 65 - 90
- B. 91 - 120.
- C. 121 - 140
- D. 150 - 154
Formwork Design Exercise

5. Assume that you are pouring a wall that is 151 feet - 4 inches long, 14 Feet high and 16 inches thick and the daily placement rate is 375 cubic yards per 8-hour day. What is the Rate of pour in feet per hour?
   A. 00.23
   B. 06.27
   C. 07.51
   D. 60.11

The information provided below is for Questions 6 through 11.
Assume that you are pouring a wall that is 151 feet - 4 inches long by 16 Feet High by 16 inches thick wall, and the placement will be done using a crane and bucket.

6. Assume the bucket has a capacity of 2.5 cubic yards. The pour is 55 feet above the ground and the rate of travel up for the bucket is 80 feet per minute and the rate of travel down is 100 feet per minute. Assume the load time is 30 seconds and the unload time is 4.0 minutes. What is the cycle time in minutes?
   A. 4.55 minutes
   B. 5.74 minutes
   C. 7.77 minutes
   D. 35.24 minutes

7. Assume the bucket has a capacity of 2.5 cubic yards and it takes 7 minutes per cycle. What is the rate of delivery in cubic yards per hour?
   A. 2.86
   B. 8.57
   C. 12.86
   D. 21.43

8. What is the volume of concrete to be poured in cubic yards?
   A. 89.68
   B. 119.27
   C. 1434.83
   D. 3220.30
Formwork Design Exercise

9. Assume that you can place 33 Cubic Yards per hour. How many hours are required to pour the cubic yards of concrete?

- A. 0.28
- B. 3.61
- C. 14.91
- D. 2385.40

10. Assume that it takes 2.25 hours to pour the 151 feet - 4 inches long by 16 Feet High by 16 inches thick wall. What is the rate of pour in feet (vertical) per hour?

- A. 0.14
- B. 7.11
- C. 10.00
- D. 14.91

11. Assume the pour is using a concrete pump with a capacity of 635 cubic feet per hour. How many hours are required to pour the cubic yards of concrete?

- A. 0.03
- B. 5.07
- C. 10.00
- D. 39.69

12. Given the following design conditions for a wall form system:

- Wall height = 10 Feet high
- Rate of Pour (R) = 6 Feet per hour
- Concrete Temperature (T) = 70 Degrees Fahrenheit
- Wall Thickness = 15 inches

What is the maximum pressure on the wall in pounds per square foot (psf)?

- A. 771
- B. 921
- C. 1010
- D. 1436
Formwork Design Exercise

13. A wall form system has the following design conditions:

Wall height = 12 feet high
Rate of Pour (R) = 10 feet per hour
Concrete Temperature (T) = 75 Degrees Fahrenheit
Wall Thickness = 15 inches

What is the maximum pressure on the wall in pounds per square foot (psf)?

- A. 1102
- B. 1200
- C. 1350
- D. 1800

14. A wall form system has the following design conditions:

Wall height = 6 Feet high
Rate of Pour (R) = 10 Feet per hour
Concrete Temperature (T) = 60 Degrees Fahrenheit
Wall Thickness = 15 inches

What is the maximum pressure on the wall in pounds per square foot (psf)?

- A. 900
- B. 1340
- C. 1500
- D. 1650

15. A column system has the following design conditions:

Column Height = 15 Feet
Rate of Pour (R) = 20 Feet per Hour
Concrete Temperature (T) = 70 Degrees Fahrenheit
Column Thickness = 24 inches by 24 inches

What is the maximum pressure on the wall in pounds per square foot (psf)?

- A. 1527
- B. 2250
- C. 2571
- D. 2721
Formwork Design Exercise

16. Using the Partial ACI Design Tables 7-2, 7-5.1, 7-5.2 and 7-8.1 provided at the end of this exercise, and given the following conditions for a wall form system:

- Concrete pressure: 1102 psf
- Rate of Pour: 10 feet per hour
- Temperature of Concrete: 75°F
- Wall Height: 22 feet
- Wall Thickness: 15 inches
- Loading Duration: Long term
- Sheathing: 3/4” B-B Class 1 Plyform, Face Grain Parallel to Span

What is the maximum allowable spacing of the studs in inches?

○ A. 7
○ B. 8
○ C. 9
○ D. 12

17. Given the following conditions for a wall form system:

- Concrete pressure: 1102 psf
- Rate of Pour: 10 feet per hour
- Temperature of Concrete: 75°F
- Wall Height: 22 feet
- Wall Thickness: 15 inches
- Stud Load:
  - Stud Lumber: No. 2 Southern Pine, S4S
  - Stud Support Conditions: Continuous over 3 or more spans
  - Stud Horizontal Shear (F’v): 225 psi
  - Studs: 2 x 8 studs, spaced 10 inches center-to-center

What is the uniform Stud load (rounded) in pounds per lineal foot?

○ A. 220
○ B. 918
○ C. 1102
○ D. 1322
Formwork Design Exercise

18. Using the Partial ACI Design Tables 7-2, 7-5.1, 7-5.2 and 7-8.1 and given the following conditions for a wall form system:

- Concrete pressure: 1102 psf.
- Rate of Pour: 10 feet per hour
- Temperature of Concrete: 75°F
- Wall Height: 22 feet
- Wall Thickness: 15 inches
- Stud Load: 1050 pounds per lineal foot
- Stud Lumber: No. 2 Southern Pine, S4S
- Stud Support Conditions: Continuous over 3 or more spans
- Stud Horizontal Shear (F’h): 225 psi
- Studs: 2 x 8 studs, spaced 10 inches center-to-center

What is the maximum allowable spacing of the wales?

- A. 19.0
- B. 30.0
- C. 39.5
- D. 44.0

19. Given the following conditions for a wall form system:

- Concrete pressure: 1102 psf.
- Stud Load: 1000 pounds per lineal foot
- Stud Lumber: No. 2 Southern Pine, S4S
- Stud Support Conditions: Continuous over 3 or more spans
- Stud Horizontal Shear (F’h): 225 psi
- Studs: 2 x 8 studs, spaced 10 inches center-to-center
- Wale Lumber: No. 2 Southern Pine, S4S
- Wale Support Conditions: Continuous over 3 or more spans
- Wale Horizontal Shear (F’h): 225 psi
- Wales: 2 x 8 double wales at 36 inches center-to-center

What is the uniform Wale load (rounded) in pounds per lineal foot?

- A. 225
- B. 833
- C. 1000
- D. 3000
Formwork Design Exercise

20. Using the Partial ACI Design Tables 7-2, 7-5.1, 7-5.2 and 7-8.1 and given the following conditions for a wall form system:

- Wale load: 1550 pounds per lineal foot
- Wale Lumber: No. 2 Southern Pine, S4S
- Wale Support Conditions: Continuous over 3 or more spans
- Wale Horizontal Shear \( (F'_w) \): 225 psi
- Wales: 2 x 8 double wales at 36 inches center-to-center.

What is the maximum allowable tie spacing in inches?

- A. 36.5
- B. 40.5
- C. 46.0
- D. 51.5

21. Given the following conditions for a wall form system:

- Concrete pressure: 1102 psf.
- Stud Load: 1000 pounds per lineal foot
- Stud Lumber: No. 2 Southern Pine, S4S
- Stud Support Conditions: Continuous over 3 or more spans
- Stud Horizontal Shear \( (F'_s) \): 225 psi
- Studs: 2 x 8 studs, spaced 10 inches center-to-center
- Wale Load: 2000 pounds per lineal foot (plf)
- Wale Lumber: No. 2 Southern Pine, S4S
- Wale Support Conditions: Continuous over 3 or more spans
- Wale Horizontal Shear \( (F'_w) \): 225 psi
- Wales: 2 x 8 double wales at 36 inches center-to-center.

Maximum Tie Spacing: 45 inches

What is the Wall Tie load capacity in pounds (rounded to whole number)?

- A. 2000
- B. 2755
- C. 2918
- D. 12398
Formwork Design Exercise

22. Assume that you have concrete that weighs 150 pounds per cubic foot and the concrete slab is 10 inches thick. What is the dead load in pounds per square foot?

A. 12.5
B. 50.0
C. 75.0
D. 125.0

23. What is the minimum Live Load for motorized buggies in pounds per square foot?

A. 25
B. 50
C. 75
D. 100

24. Which of the plyform orientations provides the strongest formwork system?

A. Parallel to the span.
B. Parallel to the studs.
C. Perpendicular to the span.
D. Perpendicular to the Wales

25. You are ordering the wall ties, which of the following items must you provide the supplier with to have a complete description?

A. Wall height, wall length, shear strength, and allowable deflection.
B. Wall thickness, tie load capacity, break back, and tie extension.
C. Lumber orientation, Type of lumber, wind force, and vibration.
D. Lateral Pressure, sheathing thickness, bending, and rolling shear.

26. What is the standard in North America for the outer layer of plyform?

A. The grain of the outer layer is parallel to the long dimension.
B. The grain of the outer layer is perpendicular to the long dimension.
C. The grain of the outer layer is at a 45-degree angle to the long dimension.
D. The grain of the outer layer is at a 45-degree angle to the short dimension.
Formwork Exercise - Partial ACI Table 7-2: SAFE SPACING, IN INCHES, OF SUPPORTS FOR PLYWOOD SHEATHING, CONTINUOUS OVER FOUR OR MORE SUPPORTS

Maximum deflection 1/360 of span, but not more than 1/16 inch.

<table>
<thead>
<tr>
<th>Pressure or load of concrete, pounds per square foot</th>
<th>Stresses and spans for short duration loads, for all sanded grades of Group 1 plywood, E modified for deflection calculations</th>
<th>Stresses and spans for long duration loads, for all sanded grades of Group 1 plywood, E modified for deflection calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$(F'_b) = 1930$ psi.</td>
<td>$(F'_b) = 1545$ psi.</td>
</tr>
<tr>
<td></td>
<td>rolling shear = 72 psi; $E' = 1,500,000$ psi</td>
<td>rolling shear = 57 psi; $E' = 1,500,000$ psi</td>
</tr>
<tr>
<td>sanded thickness, face grain parallel to span</td>
<td>sanded thickness, face grain perpendicular to span</td>
<td>sanded thickness, face grain parallel to span</td>
</tr>
<tr>
<td>½&quot;</td>
<td>5/8&quot;</td>
<td>3/4&quot;</td>
</tr>
<tr>
<td>500</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>600</td>
<td>10</td>
<td>11</td>
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<td>1100</td>
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<td>8</td>
</tr>
<tr>
<td>1200</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: Above solid, deflection controls span. Below dash line, rolling shear governs. Between the lines, bending controls. Spans are given center to center of supports, assuming 1-1/2 inch support width for shear spans. If supports of a different width are used, detailed calculations should be made to check spans in the range now shown as controlled by shear. Adapted from American Concrete Institute’s publication Formwork for Concrete. Sixth Edition, Design Table 7-2 (p 7-7). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
**Formwork Exercise Partial ACI TABLE 7-5.1:**

SAFE SPACING, IN INCHES, OF SUPPORTS FOR JOISTS, STUDS, OR OTHER BEAM COMPONENTS OF FORMWORK, CONTINUOUS OVER THREE OR MORE SPANS.

Maximum deflection is 1/360 of the span or 1/4 in., whichever is smaller.

<table>
<thead>
<tr>
<th>Uniform load, lb per lineal feet (equals uniform load on forms times spacing between joists or studs (feet))</th>
<th>( F'_{b} ) varies with member</th>
<th>( E' = 1,600,000 \text{ psi} )</th>
<th>( F'_{y} = 180 \text{ psi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal size of SxS lumber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x4</td>
<td>2x6</td>
<td>2 x 8</td>
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<td></td>
<td>F', psi</td>
<td>1310</td>
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</table>

NOTE: Span values above solid line are controlled by deflection. Within the dashed box horizontal shear governs span. Elsewhere bending controls span. Adapted from American Concrete Institute’s publication *Formwork for Concrete*. Sixth Edition, Design Table 7-5.1 (p 7-10). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
Formwork Exercise - Partial ACI TABLE 7-5.2:  
SAFE SPACING, IN INCHES, OF SUPPORTS FOR JOISTS, STUDS, OR OTHER BEAM 
COMPONENTS OF FORMWORK, CONTINUOUS OVER THREE OR MORE SPANS. 
Maximum deflection is 1/360 of the span or 1/4 in., whichever is smaller.

<table>
<thead>
<tr>
<th>Uniform load, lb per lineal feet (equals uniform load on forms times spacing between joists or studs (feet))</th>
<th>F'_b varies with member</th>
<th>E' = 1,600,000 psi</th>
<th>F'_y = 225 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nominal size of SxS lumber</td>
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<td></td>
<td></td>
<td>2x4</td>
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<td>1640</td>
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NOTE: Span values above solid line are controlled by deflection. Within the dashed box horizontal shear governs span. Elsewhere bending controls span. Adapted from American Concrete Institute’s publication *Formwork for Concrete*. Sixth Edition, Design Table 7-5.2 (p 7-11). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
### Formwork Exercise - Partial ACI Table 7-8.1:

**SAFE SPACING, IN INCHES, OF SUPPORTS FOR DOUBLE WALES, CONTINUOUS OVER THREE OR MORE SPANS**

<table>
<thead>
<tr>
<th>Uniform load, lb per lineal feet (equals uniform load, psf, on forms times spacing of wales in ft.)</th>
<th>( F'_b ) varies with member ( E' = 1,600,000 ) psi</th>
<th>( F'_v = 180 ) psi</th>
<th>( F'_b ) varies with member ( E' = 1,600,000 ) psi</th>
<th>( F'_v = 225 ) psi</th>
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</thead>
<tbody>
<tr>
<td>Nominal size of S4S lumber</td>
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</table>

**NOTE:** Span values above solid line are controlled by deflection. Within the dashed box horizontal shear governs span. Elsewhere bending controls span. Adapted from American Concrete Institute’s publication *Formwork for Concrete*. Sixth Edition, Design Table 7-8.1 (p 7-22). This is a partial table for educational purposes only and you must reference ACI’s publications for complete and accurate information.
Soil Mechanics

Soil Investigation Tests

Soil Investigation or Soil Exploration consists of three steps: boring, sampling and testing. First, the boring refers to the drilling of a hole in the ground. Some of the most common types of borings are auger borings, wash borings, test pits, and core borings. Second, sampling refers to the removing the soil from the holes. Samples may be classified as either disturbed or undisturbed. Auger borings and wash boring methods bring the soil sample to the surface where samples are collected. Soil samples by these methods are considered disturbed samples and some of their characteristics are changed. Soil sampling is the equipment used to extract, contain and seal the samples from the borings during the subsurface soil investigation. At the surface, the disturbed soil samples should be placed in airtight containers and labeled for the lab. Third, testing refers to the lab and field tests that can be conducted to determine the soil properties.

There are numerous tests that can be made to evaluate various soil properties, but the most common test in the United States is the Standard Penetration Test (SPT). The *Standard Penetration Test (SPT)* is useful in determining certain properties of cohesionless soils. The SPT utilizes a split spoon sampler which has an outside diameter (O.D.) of 2 inches and it is 18 - 24 inches long. The sampler is attached to the bottom of a drilling rod and driven into the soil with a 140 pound hammer falling 30 inches. As the sampler is driven the 18 inches into the sampler, the number of blows required to penetrate each of the three 6 inch increments is recorded separately on the boring log. The standard penetration resistance “N” value is the number of blows required to penetrate the last 12 inches. Below is an example of a partial Geotechnical or Soil Investigation Report and on the following pages is an example of the Soil Boring Location Plan, the Soil Boring #8 and the Relative Density and Consistency Table. These are the Proposed Public Service Building Procedures:

The borings were drilled using a CME model 45 “skid” drill rig. The drill rig utilized hollow stem augers to sample depths where samples were obtained in a two-inch O.D. split spoon sampler driven by a 140 pound hammer falling 30 inches. The number of blows required to drive the sampler three six-inch increments are recorded on the boring logs. The first six inches is considered the seating drive. The summation of the number of blows required for the second and third six inches is termed the penetration resistance “N” value in blows per foot (bpf). This field procedure is referred to as the Standard Penetration Test (SPT) and is an American Society for Testing and Materials test procedure (ASTM D-1586).

The “N” values from the SPT are used for the determination of the relative density of granular soils (sand, gravel, low plasticity silt, and mixtures of sand and gravel) or the consistency of cohesive soils (clay and plastic silts). A chart is provided in the back of this report which provides a correlation between “N” values and the relative density of granular soils or the consistency of cohesive soils.
Soil Investigation Report
The Soil Investigation Report is used to identify the drilling procedures and the penetration resistance “N” value. From each Soil Boring, you can extract the water table, the Penetration Blow Counts and the Soil Classification provided by the testing firm. Finally, it is the Contractor’s responsibility to determine the Penetration “N” value from the Soil Boring, which is the summation of the number of blows required for the second and third penetration counts. Then using this total number of blows, you must determine the relative density of sand or the consistency of clay and compare the table’s description to the Soil Classification Description on the soil boring.
**Proposed Public Service Building Soil Boring Example**

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>Blue Lake County Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>Blue Ridge Lane</td>
</tr>
<tr>
<td>CLIENT</td>
<td>Brayton AEC</td>
</tr>
<tr>
<td>PROJECT NO.</td>
<td>15-1291</td>
</tr>
<tr>
<td>DATE STARTED</td>
<td>12/17/2039</td>
</tr>
<tr>
<td>DATE COMPLETED</td>
<td>12/17/2039</td>
</tr>
</tbody>
</table>

**PROGRESS REPORT**

- **DATE**: 12/13/
- **WEATHER**:
  - **Cloudy**
  - **Rig No.**: 807
  - **Weather Data**: 3° During drilling (EL 680.6±)

**SOIL BORING DATA**

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>SAMPLE</th>
<th>SAMPLING METHOD</th>
<th>PENETRATION BLOW COUNT</th>
<th>LINER</th>
<th>SOIL CLASSIFICATION</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0.67°</td>
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<td>3</td>
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**PLUGGING METHOD**

- **Natural Soil**
- **Job No.**: 15-1291
Reading the Soil Boring
From the Soil Boring provided you can determine the following information.

<table>
<thead>
<tr>
<th>Soil Boring Number</th>
<th>#8 (Pavement Area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Surface Elevation</td>
<td>683.6 Feet</td>
</tr>
<tr>
<td>Read the Report and Review the Borings for Unsuitable Soil</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Read the Report and Review the Boring for the elevation of Water Data</td>
<td>During Drilling at 680.6 Feet</td>
</tr>
<tr>
<td>Read the Report and Review the Borings to Determine depth of the water Table</td>
<td>3 Feet</td>
</tr>
<tr>
<td>Read the Report and Calculate the Penetration Resistance “N” value in blows per foot (bpf)</td>
<td>$2 + 3 = 5$</td>
</tr>
<tr>
<td>Read the Soil Borings and for #8 at 3 feet the Soil Classification is stated as</td>
<td>Very Loose to Loose Brown Fine to Course Sand</td>
</tr>
</tbody>
</table>

Relative Density and Consistency Table
Finally, the Report of Soil Investigation contains a standard table for determining the relative density for sand and silt and the consistency of clay. This table is called the Relative Density and Consistency Table and it is provided below. It is utilized by the Contractor to compare what is called out at each depth of a soil boring to what the table indicates. The material relative density and consistency is based upon blow count. For example, using the Penetration Resistance “N” value of 5 found on soil boring #8 above at 3 feet, and using the Sand and Silt, Relative Density portion of the table below for the blow count of 5, the soil should be classified as Loose Sand. This matches the Boring #8 at 3 feet called a Very Loose to Loose Brown Fine to Course Sand.

<table>
<thead>
<tr>
<th>Sand and Silt, Relative Density</th>
<th>Consistency of Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of blows required to drive a sampler 1 foot, using a 140# hammer falling 30” 2” O.D. Samplers</td>
<td>RELATIVE DENSITY</td>
</tr>
<tr>
<td>&lt; 4</td>
<td>Very Loose</td>
</tr>
<tr>
<td>4 - 10</td>
<td>Loose</td>
</tr>
<tr>
<td>11-15</td>
<td>Medium Loose</td>
</tr>
<tr>
<td>16-30</td>
<td>Medium Dense</td>
</tr>
<tr>
<td>31-50</td>
<td>Dense</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>Very Dense</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Soil Categories

Soils are separated in three broad categories. They are cohesionless, cohesive and organic soils. Cohesionless soils are gravel, sand, and silt. Gravel has particle sizes of 3 inches down to a #4 sieve. Sand particles range from a #4 sieve down to a #200 sieve. Sand and gravel can be further divided into fine and course such as fine sand and course sand. Finally, clay or the fines is a #200 sieve on down. The common type of cohesive soil is clay which has particle sizes less than a #200 sieve. Organic soil are undesirable for supporting structures and must not contaminate the desirable sands and gravels. Finally, Loam roughly contains equal parts of sand, silt and clay.

A cohesive soils particle sizes may be determined by the hydrometer method which is a process for indirectly observing the settling velocities of the particles in a soil-water mixture. Another technique for analyzing cohesive soils is by use of the Atterberg limits method. Atterberg define four states of consistency for cohesive soils. They are liquid, plastic, semisolid, and solid.

Soil properties and characteristics are influenced by changes in water content and there are three phenomena that are directly related to the water in the soil. They are permeability, capillarity, and frost heave. Permeability is the movement of water within a soil. Capillarity is the rise of water above the ground water table against the pull of gravity but is in contact with the water table as its source. Frost heave is the vertical expansion of soil caused by water freezing.

Soil Classification Systems

The most commonly used Soil Classification Systems based upon grain size are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system. The OSHA Standards for the Construction Industry in 29 CFR PART 1926.650 in Appendix A of Subpart P titled Soil Classification paragraph (c) Requirements (1) Classification and (2) Basis of classification it states that “the classification of the soil deposits shall be made based on the results of at least one visual inspection and at least one manual analysis (p 257). The standard also incorporates by reference the American Society for Testing Materials (ASTM) standard D2488 titled, Standard Recommended Practices Description of Soils. Therefore, a person must have a basic understanding of soil terminology so that they can properly identify and classify the soil. Your daily excavation inspections will require you to use the following soil terminology. According to OSHA 1926 Appendix A paragraph (b) Definitions it states that “the definitions and example . . are based on, in whole or in part, the following: American Society for Testing Materials (ASTM) Standards D653-85 and D2488; The Unified Soils Classification System; The U.S. Department of Agriculture (USDA) Textural Classification Scheme; and the National Bureau of Standards Report BSS-121.

A Cemented Soil means a soil in which the particles are held together by a chemical agent, such as calcium carbonate, such that a hand-size sample cannot be crushed into a powder or individual soil particles by finger pressure. Cemented soils include hardpan. These soils are also extremely hard to excavate.
A Clay is a soil that is hard to break up when dry, but can be crushed to a powder (fine grained soil) and can be moldable when wet and sticks together (cohesive). A Cohesive Soil is a soil with a high clay content which sticks together when wet or dry. Cohesive soil does not crumble, can be excavated with vertical side slopes, and is plastic when moist. Cohesive soil is hard to break up when dry, and exhibits significant cohesion when submerged under water. Cohesive soils include clayey silt, sandy clay, silty clay, clay and organic clay. A Cohesionless soil is a loose sand or granular gravel that freely runs. A Dry Soil is a soil that does not exhibit visible signs of moisture content.

A Granular Soil means a gravel, sand or silt with little or no clay content. Granular soil has no cohesive strength. Some moist granular soils exhibit apparent cohesion. Granular soil cannot be molded when moist and crumbles easily when dry. A Layered System means two or more distinctly different soils or rock types arranged in layers. Micaceous seams or weakened planes in rock or shale are considered layered. Moist soil means a soil condition in which a soil looks and feels damp. Moist cohesive soil can easily be shaped into a ball and rolled into small diameter threads before crumbling. Moist granular soil that contains some cohesive material will exhibit signs of cohesion between particles. A Plastic soil means a property of a soil which allows the soil to be deformed or molded without cracking, or appreciable volume change.

A Saturated Soil is a soil in which the voids are filled with water. Saturation does not require flow. Saturation or near saturation, is necessary for the proper use of instruments such as a pocket pentrometer or torvane. A Spoil refers to the earth and material drawn from an excavation. The term Submerged Soil means soil which is under water or is free seeping. Wet soil means soil that contains significantly more moisture than moist soil, but in such range of values that cohesive material will slump or begin to flow when vibrated. Granular material that would exhibit cohesive properties when moist will lose those cohesive properties when wet.

According to the standards, the acceptable Field Soil Visual Tests shall be conducted to provide sufficient quantitative and qualitative information as may be necessary to identify properly the properties, factors, and conditions affecting the classification of the soil. Visual analysis is conducted to determine the qualitative information regarding the excavation site in general, the soil adjacent to the excavation, the soil forming the sides of the open excavation, and the soil taken as examples from excavated material. Therefore, it is imperative that while making a visual inspection that you look for distress and the signs of trench failure. It should be understood that Clay is one of the most dangerous materials because the vertical walls of an excavation appear to be solid and stable. However, clay is drastically affected by water, wind, and pressure. Water causes it to swell, wind causes it to dry and shrink rapidly, and the soil pressure causes clay to bulge. Any or all of the conditions described above can cause trench failure. Below are the definitions of the types of distress that result in trench failure.
Types of Distress that Result in Trench Failure

Distress means that the soil is in a condition where a cave-in is imminent or is likely to occur. Distress is evidenced by such phenomena as the development of fissures in the face of or surface of an open excavation; the subsidence of the horizontal plane of an excavation; the bulging of the face of an excavation; the heaving of material from the bottom of an excavation; the spalling of material from the face of a rock excavation; the raveling of small amounts of material trickling down into the excavation; and the seeping of water into the excavation.

The initial signs of trench failure begin immediately after removing the soil, the trench becomes unstable and the soil in the trench walls begins to move into the excavation. This movement usually is not visible but the soil is moving because the surface of the ground is in tension, therefore, the weight of the soil causes surface cracks parallel to the trench, approximately one-third to two-thirds of the trench depth from the trench edge. For example, if the depth of the trench is 9 feet deep, these surface tension cracks may be found somewhere between three (3) feet and six (6) feet from the edge of the trench. The edge of the excavation may also subside but this is hard to see.

The second sign of trench failure is in the face of the excavation, Cracks, normally horizontal, may appear on the face and the walls of the excavation may bulge into the excavation but these signs of failure are also hard to see. The third sign of progressive trench failure is when the bottom of the trench initially fails or kicks into the excavation. This leaves the upper portion of the face unsupported and the trench wall is hanging on by the shear force. A second failure will occur soon after the first failure as the upper portion of the excavation collapses into the trench. Often a worker is trapped by the initial cave-in and co-workers will jump into the trench to help, unaware that multiple cave-ins are likely. Normally, the second and third cave-ins are the ones that will kill or injure the rescuers. Therefore, you should be aware that cave-ins normally occur in multiples. The final sign of trench failure is rain flowing into the surface cracks will increase the surcharge load in the soil. These fissures may appear to close while wet but they will reappear wider after some drying takes place. Water will also be retained in the spoil pile and this will create an increase in the surcharge load on the trench.

Field Visual Inspections for Excavation

There are over fifteen potential Types of Distress That Result in Trench Failure that you must periodically visually inspect for when an excavation is open. The following distresses are defined below to help you identify the potential types of soil conditions at the job site that may lead to a trench failure. Fissured means a soil material that has a tendency to break along definite planes of fracture with little resistance, or a material that exhibits open cracks, such as tension cracks, in an exposed surface such as on the existing horizontal surface or on the excavation face. The excavation face means the vertical or inclined earth surfaces formed as a result of the excavation work. This is sometimes referred to as the excavation sides.
Unsupported Faces or Walls are immediately developed once an excavation is excavated and the weight of the soil, due to gravity places vertical and horizontal (lateral) pressure on the wall. This gravity translates directly to weight. In many cases, one cubic foot of soil weighs an average of 120 pounds per cubic foot. A column of soil one foot wide, five feet deep and six long weighing 120 pounds per cubic foot would weigh 3600 pounds per side. (1 foot wide x 5 feet deep x 6 feet long x 120 pounds per cubic foot). If you multiply each vertical wall by two, a full cave-in could easily be 7200 pounds.

Other visual inspections are for Bulging which occurs as a result of the vertical and lateral forces being exerted on the unsupported walls. Bulging will first appear on the face of the wall as protrusions into the open excavation. Subsidence occurs as a result of unbalanced stresses in the soil. Subsidence causes the soil to sink on the surface and bulging of the vertical face of the trench. If uncorrected, this condition can cause face failure and entrapment of workers in the trench. Heaving or squeezing is caused by the downward pressure created by the weight of adjoining soil. This pressure causes a bulge in the bottom of the cut. Heaving and squeezing can occur even when shoring or shielding has been properly installed. Boiling is evidenced by an upward water flow into the bottom of the cut. A high water table is one of the causes of boiling. Boiling produces a "quick" condition in the bottom of the cut, and can occur even when shoring or trench boxes are used. Some additional visual inspections are for Raveling which is evidenced by small amounts of material suddenly separating from the face of an excavation and trickling or rolling down into the excavation. Spalling is evidenced by small fragments of rock break up or scale off the excavation face. This is caused by vibration near a fractured unstable rock face.

Other visual inspections are for a Surcharge Load means an excessive vertical load or weight caused by the spoil pile being too close to the trench edge or equipment being too close to the trench edge. These activities effect the trench stability. Vibration is a dynamic force introduced into the ground from blasting, pile driving, traffic, construction equipment and proximity to railroad tracks and industrial turbines. Undercutting is caused by excavating below the existing foundation of a nearby structures and not providing enough clearance area. A Previously Disturbed Soil is a soil which will never return to its original position or stability. The previously disturbed soil will slide or ravel into the new excavation. Finally, you must inspect for a Layered Soil System where two or more distinctly different soils or rock types are arranged in layers. The soil layers slope into the excavation at a four Horizontal to one Vertical (4H:1V) or steeper slope. A layered system is controlled by its weakest layer and this can result in a wedge failure.

Some trench failure terms are Sliding or slumping may occur as a result of tension cracks, weak soil, water soaked soil, hard soil or rock on top of a weak soil layer. Toppling is also caused by tension cracks. Toppling occurs when the trench's vertical face shears along the tension crack line and topples into the excavation. Sloughing is where the sides cave into the trench during excavation.
Field Tests for Soil Analysis

The OSHA standards states that the classification of soil shall be made based upon the results of at least one Field Manual Soil Analysis Test. The OSHA standards describes these manual tests that can be performed by a qualified person at the test site. The manual tests are the plasticity test, the pat test, the dry strength test, the thumb penetration or pocket pentrometer test and the drying test. The *plasticity test* requires you to mold a moist or wet sample of soil into a ball and attempt to roll it into threads as thin as 1/8 of an inch in diameter by two inches in length. Then the soil sample is held by one end and if the soil sample does not tear or break then it is considered a cohesive soil. The *Pat Test* is used to determine the presence of a cohesive clay or silt. This test is conducted by spreading a 1/8 inch to 1/4 inch thick sample of wet soil on the palm of your hand and then remove any visible water from the surface. With the sample in the palm of your hand, slap the back of the hand moderately approximately eight times. If the surface appears shiny due to water rising to the surface, this soil consists mostly of granular silt or sand and it is considered a weaker soil. If no water appears on the surface, the soil consists of mostly cohesive clay and this is considered a stronger soil.

The *Dry Strength Test* is used to determine the amount of strength and the presence of fissures in dry soils. If the soil is dry and crumbles on its own or with moderate pressure into individual grains of fine powder, it is granular (any combination of gravel, sand, or silt). If the soil is dry and fall into clumps which break up into smaller clumps, but the smaller clumps can only be broken up with difficulty, it may be clay in any combination with gravel, sand, or silt. If the dry soil breaks into clumps which do not break into small clumps and which can only be broken with difficulty, and there is no visual indication the soil is fissured, the soil may be considered unfissured.

The *Thumb Penetration Test* can be used to estimate the unconfined compressive strength of cohesive soils. This test is based on the thumb penetration test described in American Society for Testing and Materials (ASTM) Standard designation D2488 titled *Standard Recommended Practice for Description of Soils (Visual - Manual Procedure)*. This test should be conducted on an undisturbed soil sample, such as a large clump of spoil, as soon as practicable after excavation to keep to a minimum the effects of exposure to drying influences. If the excavation is later exposed to wetting influences (rain, flooding), the classification of the soil must be changed accordingly. The thumb penetration test is used to estimate the unconfined compressive strength of cohesive soils. From the thumb penetration level you can determine the type of soil using the following chart from ASTM Standard Test D 2488.

<table>
<thead>
<tr>
<th>THUMB PENETRATION</th>
<th>UNCONFINED</th>
<th>SOIL TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 &quot; or less</td>
<td>1.5 Tons per sq.ft.</td>
<td>A</td>
</tr>
<tr>
<td>1/4&quot; to 1&quot;</td>
<td>0.5 to 1.5 Tons per sq. ft.</td>
<td>B</td>
</tr>
<tr>
<td>1&quot; or more</td>
<td>0.5 Tons per sq.ft.</td>
<td>C</td>
</tr>
</tbody>
</table>
The Unconfined Compressive Strength is the load per unit area at which soil will fail in compression. This measure can be determined by laboratory testing or it can be estimated in the field using the Thumb Penetration test a pocket penetrometer, or a sheavane (Torravane) test. The Pocket Pentrometer is used to determine the unconfined compression strength on the trench face or on a large clump of soil. Penetrometers are direct reading, spring-operated instruments that are used to determine the unconfined compressive strength of saturated cohesive soils. Once pushed into the soil, an indicator sleeve displays the reading. The instrument is calibrated in either tons per square foot (tsf) or kilograms per square centimeter (kPa). However, penetrometers have error rates in the range of plus or minus 20-40 percent. Another hand operated strength test instrument is the sheavane or torvane. The Sheavane has blades which are pressed into a level section of undisturbed soil, and the torsional knob is slowly turned until soil failure occurs. The direct instrument reading must be multiplied by 2 to provide results in tons per square foot (tsf) or kilograms per square centimeter (kPa).

The Drying Test is used to differentiate between cohesive material with fissures, unfissured cohesive material, and granular material. The procedure for the drying test involves drying a sample of soil that is approximately one inch thick (2.54 cm) and six inches (15.24 cm) in diameter until it is thoroughly dry. After drying, If the sample develops cracks as it dries, significant fissures are indicated. Samples that dry without cracking are to be broken by hand. If considerable force is necessary to break a sample, the soil has significant cohesive material content. The soil can be classified as an unfissured cohesive material and the unconfined compressive strength should be determined. Finally, If a sample breaks easily by hand, it is either a fissured cohesive material or a granular material. To distinguish between the two, pulverize the dried clumps of the sample by hand or by stepping on them. If the clumps do not pulverize easily, the material is cohesive with fissures. If they pulverize easily into very small fragments, the material is granular.

The table is provided below to help you differentiate between the soils using the dry test.

<table>
<thead>
<tr>
<th>UNFISSURED COHESIVE SOIL</th>
<th>FISSURED SOIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface drying cracks are not visible</td>
<td>Surface drying cracks are visible</td>
</tr>
<tr>
<td>Sample breaks with force</td>
<td>Sample breaks easily by hand</td>
</tr>
<tr>
<td>Clumps do not crush easily by hand or when stepped on.</td>
<td>Clumps do not crush easily by hand or when stepped on</td>
</tr>
<tr>
<td>Granular Soil</td>
<td></td>
</tr>
<tr>
<td>Clumps crush easily</td>
<td></td>
</tr>
</tbody>
</table>
Volume Changes, Swell Percentage and Shrinkage Percentage

Soil is found in three fundamental conditions or states. They are Bank, Loose and Compacted states. Bank material is in its natural or undisturbed condition. Bank is often referred to as “in place” or “in situ.” The unit volume is identified as a bank cubic yard (BCY). The Loose Material state is material that has been excavated, stockpiled or loaded a piece of equipment. The unit volume is identified as a loose cubic yard (LCY). The Compacted Material is after applying some type of compaction equipment to consolidate the material. The unit volume is identified as compacted cubic yards (CCY). In conclusion, soil swells if disturbed and shrinks under pressure. Therefore, volume corrections must be made depending on the soils’ change in state. The table below provides the formula for the swell percentage which is used for hauling material and the shrinkage percentage is used for compacting material. Also, the other table below provides the average soil weights for calculating swell and shrinkage percentages based on the soils weight in the various states and conditions.

### AVERAGE SOIL WEIGHTS AND VOLUME CHANGE FORMULAS

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>LCY</th>
<th>BCY</th>
<th>CCY 100% STANDARD PROCTOR</th>
<th>CCY 100% MODIFIED PROCTOR</th>
<th>LOAD FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay - Dry</td>
<td>2050</td>
<td>2675</td>
<td>2835</td>
<td>3159</td>
<td>.81</td>
</tr>
<tr>
<td>Clay - Natural Bed Wet</td>
<td>2800</td>
<td>3400</td>
<td>3575</td>
<td>3959</td>
<td>.82</td>
</tr>
<tr>
<td>Sand - Dry</td>
<td>2420</td>
<td>2740</td>
<td>3362</td>
<td>3510</td>
<td>.85</td>
</tr>
<tr>
<td>Sand - Damp</td>
<td>2760</td>
<td>3130</td>
<td>3362</td>
<td>3510</td>
<td>.85</td>
</tr>
<tr>
<td>Gravel - Damp</td>
<td>2623</td>
<td>2980</td>
<td>3375</td>
<td>3645</td>
<td>.85</td>
</tr>
<tr>
<td>Common Earth - Dry</td>
<td>2185</td>
<td>2883</td>
<td>3375</td>
<td>3510</td>
<td>.80</td>
</tr>
<tr>
<td>Common Earth - Moist</td>
<td>2463</td>
<td>3160</td>
<td>3375</td>
<td>3510</td>
<td>.79</td>
</tr>
<tr>
<td>Loam</td>
<td>2100</td>
<td>2600</td>
<td>2835</td>
<td>3150</td>
<td>.81</td>
</tr>
</tbody>
</table>

\[ Sw \% = \frac{(BCY - 1) \times 100}{LCY} \]

\[ Sh \% = \frac{(1 - BCY) \times 100}{CCY} \]

\[ \text{Load Factor (LF)} = \frac{100\%}{100\% + \% \text{ Swell}} \]

\[ \text{BCY} = \frac{\text{LCY} \times \text{LF}}{\text{BCY}} \]

\[ \text{CCY} = \frac{\text{BCY} \times \text{SF}}{\text{CCY}} \]

Using the tables above and assume that you are excavating a Natural Bed Wet Clay. The Swell percentage is:

\[ \text{Swell} \% = \frac{(BCY - 1) \times 100}{LCY} \]

\[ \text{Wet Clay} = \frac{(3400 - 1) \times 100}{(2800)} = 21.43\% \]
Now assume that you are compacting a wet sand around the structure. The shrinkage percentage is:

\[
\text{Shrinkage \%} = \frac{(1 - \text{BCY}) \times 100}{\text{CCY}} \quad \text{Damp Sand} = \frac{(1 - 3,130)}{3,510} \times 100 = (1 - 0.892) = 10.8\%
\]

*Compaction* is defined as the voids in the soil are reduced as portions of the air and moisture are driven out by the use of mechanical compaction equipment such as rollers, vibrating rollers and tampers. Reduced voids and increased density produce a more stable earth fill, which will provide a greater weight carrying capacity.

A standard laboratory test called a Proctor Test has been developed to evaluate a soil’s moisture-density relationship under specified compaction conditions. Actually, there are two Proctor tests which have been standardized by the American Society for Testing Materials and (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO). These are the Standard Proctor Test and the Modified Proctor Test.

The *Standard Proctor Test* is performed using a steel cylinder mold 4 inch in diameter with a height of 4.59 inches and it is filled with a sample of the proposed material in three layers. Each layer is struck with 25 blows from a 5.5-pound, 2 inch diameter hammer dropped from a height of 12 inches. The *Modified Proctor Test* is performed using the same cylinder and the sample is placed in 5 layers. Each layer is struck with 25 blows with a 10-pound, 2 inch diameter hammer dropped from a height of 18 inches (stroke). The Modified Proctor is specified for fill material designated for use under areas where high design loads are anticipated such as airport run ways and paved areas.

The relationship between moisture content and density of the soil is similar with most soils. Therefore, the amount of moisture required for the soil to attain its maximum density under compaction is called the Optimum Moisture Content. The *Optimum Moisture Content* is the primary factor that will determine if the desired density will be achieved in the least number of passes. Normally the Technical Specifications specify the proctor test that will be utilized, the density percentage that must be achieved and the optimum moisture content range.

Another factor that will effect whether density is attained is the thickness of the compacted material normally referred to as the lift. The normal lift for compaction purposes is between 6 inches and 12 inches.
Soil Mechanics Exercise
Questions 1 through 16 pertain to the Soil Investigation Report and Soil Boring Procedures and the Relative Density and Consistency Table provided at the end of this exercise. Answer the following questions.

1. The Soil Report discusses the Penetration Resistance “N” Blow Count Summation procedure, What is the correct summation procedure?
   - A. Add Blow Counts 1 and 2.
   - B. Add Blow Counts 1 and 3.
   - C. Add Blow Counts 2 and 3.
   - D. Add Blow Counts 1, 2, and 3.

2. What type of hammer and fall distance was utilized for sampling the soil borings?
   - A. a 5-pound hammer falling 12-inches.
   - B. a 10-pound hammer falling 18-inches.
   - C. a 100-pound hammer falling 18-inches.
   - D. a 140-pound hammer falling 30-inches.

3. Which party is responsible for comparing the soil borings to the standard Relative Density and Consistency Table provided in the Soil Report?
   - A. Owner.
   - B. Vendor.
   - C. Contractor.
   - D. Architect/Engineer.

4. What does the abbreviation bpf mean?
   - A. Bulk per foot.
   - B. Bank per foot.
   - C. Blows per foot.
   - D. Borings per foot.

5. What does the abbreviation SPT mean?
   - A. Stiff Penetration Test.
   - B. Standard Proctor Test.
   - C. Standard Penetration Test.
   - D. Society for Proctor Testing.
Soil Mechanics Exercise

6. Which organization established the penetration test boring procedures?
   - B. Standard Penetration Testing.
   - C. Society for Proctor Testing.

7. What is the Ground Elevation for Soil Boring #5?
   - A. 682.3'
   - B. 683.3'
   - C. 697.8'
   - D. 807.0'

8. At what depth did they hit water during drilling for Soil Boring #5?
   - A. 0.0 Feet.
   - B. 1.0 Foot.
   - C. 2.5 Feet
   - D. 15.0 Feet

9. Using Soil Boring #5, What is the Penetration Resistance “N” at 4 Feet in bpf?
   - A. 3
   - B. 6
   - C. 7
   - D. 10

10. Using Soil Boring #5, is there any unsuitable soil?
    - B. Rock and Boulders.
    - C. Very Stiff Clay and Gravel.
    - D. Loose to Very Loose Brown Fine to Course Sand.
Soil Mechanics Exercise

11. Using Soil Boring #5. What is the depth of the unsuitable soil in feet?
   - A. 0.00'
   - B. 1.00'
   - C. 2.50'
   - D. 3.08'

12. What is the Soil Classification for Boring #5 shown at 6 feet?
   - B. Rock and Boulders.
   - C. Very Stiff Clay and Gravel.
   - D. Loose to Very Loose Brown Fine to Course Sand.

13. Using the Relative Density and Consistency Table, Soil Boring #5 and assume the Penetration Resistance “N” is 7. What is the material description from the table?
   - A. Soft.
   - B. Loose.
   - C. Medium Stiff.
   - D. Medium Dense.

14. At what depth was Boring #5 drilling operation stopped?
   - A. 0.0 Feet.
   - B. 1.0 Foot.
   - C. 2.5 Feet
   - D. 15.0 Feet

15. Assume the Penetration Resistance “N” is 29 for a clay, from the Relative Density and Consistency table what is the material description?
   - A. Dense.
   - B. Very Stiff.
   - C. Medium Stiff.
   - D. Medium Dense.
Soil Mechanics Exercise

16. Using the Relative Density and Consistency table, If the soil boring indicated a Sand what term are you looking for at the top of the Table?

- A. Consistency.
- B. Medium Stiff.
- C. Medium Dense.
- D. Relative Density.

17. Which of the following soils is considered cohesionless?

- A. Silt.
- B. Clay
- C. Gravel.
- D. Topsoil.

18. Which of the following soils is considered cohesive?

- A. Clay
- B. Sand.
- C. Gravel.
- D. Topsoil.

19. Which of the following tests is performed on cohesionless soil to determine the distribution of grain size?

- A. Vane Test.
- B. Sieve Analysis.
- C. Atterberg Limits.
- D. Penetration Test.

20. Which of the following techniques is used to determine the liquid, plastic, semisolid, and solid states of consistency for a cohesive soil?

- A. Vane Test.
- B. Sieve Analysis.
- C. Atterberg Limits.
- D. Penetration Test.
Soil Mechanics Exercise

21. Which of the following terms refers to the ability of water to flow through a soil by traveling through the void spaces?

- A. Capillarity.
- B. Frost heave.
- C. Permeability.
- D. Ground Water Table.

22. What are the most commonly used soil classification systems based on grain size?

- A. Atterberg Limits and Permeability.
- B. The U.S. Department of Agriculture (USDA) Textural Classification Scheme and the National Bureau of Standards Report BSS-121.
- D. Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO).

23. What is the earth material drawn from an excavation called?

- A. Spoil.
- B. Saturated Soil.
- C. Submerged Soil.
- D. Cohesionless Soil.

24. What type of soil is the most dangerous because the excavated faces appear to be solid and stable, but they are drastically affected by water, wind, and pressure?

- A. Clay.
- B. Sand.
- C. Gravel.
- D. Stable Rock.

25. According to OSHA, what is the minimum ratio for a layered soil system?

- A. 1H:1V
- B. 3H:1V
- C. 4H:1V
- D. 1H:4V.
Soil Mechanics Exercise

26. A small amount of material suddenly separates from the face of an excavation and trickles or rolls down into the excavation. What is the visual inspection term called?

- A. Spalling.
- B. Heaving.
- C. Toppling.
- D. Raveling.

27. The layers on the face of the excavation slope at a ratio of four horizontal to one vertical (4H:1V) or greater. What is the visual inspection term called?

- A. Sliding.
- B. Toppling.
- C. Undercutting.
- D. Sloped system.

28. There is upward water flow into the bottom of the excavation. What is the visual inspection term called?

- A. Boiling.
- B. Sloughing.
- C. Submerged.
- D. Surcharge Load.

29. The soil has sunk on the horizontal surface. What is the visual inspection term called?

- A. Boiling.
- B. Bulging.
- C. Heaving.
- D. Subsidence.

30. The soil is protruding from the face of the open excavation into the excavation. What is the visual inspection term called?

- A. Boiling.
- B. Bulging.
- C. Heaving.
- D. Subsidence.
Soil Mechanics Exercise

31. the soil is protruding up from the bottom of the excavation. What is the visual inspection term called?

- A. Boiling.
- B. Bulging.
- C. Heaving.
- D. Subsidence.

32. the soil has open cracks on the horizontal ground or on the open face of the excavation. What is the visual inspection term called?

- A. Fissure.
- B. Bulging.
- C. Sloughing.
- D. Subsidence.

33. What is the term for an excessive vertical load caused by the spoil pile or construction equipment being too close to the trench edge?

- A. Impact load.
- B. Undercutting.
- C. Underpinning.
- D. Surcharge load.

34. What do the field thumb penetration, pocket penetrometer and the shearvane measure?

- A. Shear Stress.
- B. Impact Load.
- C. Surcharge Load.
- D. Unconfined Compressive Strength.

35. Which field manual test is used to differentiate between cohesive material with fissures, unfissured cohesive material, and granular material?

- A. Pat Test.
- B. Drying Test.
- C. Plasticity Test.
- D. Dry Strength Test.
36. Which field manual test checks for a cohesive soil?

- A. Pat Test.
- B. Drying Test.
- C. Plasticity Test.
- D. Thumb Penetration Test.

37. Which field manual test is used to determine the presence of a cohesive clay or silt?

- A. Pat Test.
- B. Drying Test.
- C. Plasticity Test.
- D. Thumb Penetration Test.

38. What is another name for a soil that contains equal parts of sand, silt and clay?

- A. Spoil.
- B. Loam.
- C. Moist Soil.
- D. Common Earth.

39. Which of the following soil has no cohesive strength?

- A. Clay.
- B. Moist Soil.
- C. Layered Soil.
- D. Granular Soil.

40. What is the soil state called if it is in its natural, or in place or in situ or undisturbed state?

- A. Bank.
- B. Loose
- C. Solid.
- D. Compacted.

41. What is the soil state called when the soil is excavated?

- A. Bank.
- B. Loose
- C. Solid.
- D. Compacted.
Soil Mechanics Exercise

42. Using the Average Soil Weights Table, What is the swell percentage using a Loam?
   ○ A. 08.3%
   ○ B. 23.8%
   ○ C. 31.9%
   ○ D. 81.0%

43. Using the Average Soil Weights Table, What is the shrinkage percentage for a Damp Sand under the Modified Proctor method?
   ○ A. 10.8
   ○ B. 12.1
   ○ C. 13.4
   ○ D. 85.0

44. Which of the following is the primary factor that will determine if 97% density using the Modified Proctor Test will be achieved in a predetermined number of passes?
   ○ A. Soil Type.
   ○ B. Moisture Content.
   ○ C. Swell Percentage.
   ○ D. Shrinkage Percentage.

45. Which of the following procedures describes the Modified Proctor Test?
   ○ A. It uses a 5-pound hammer dropped from a height of 12 inches.
   ○ B. It uses a 10-pound hammer dropped from a height of 18 inches.
   ○ C. It uses a 13,000 pound hammer dropped from a height of 20 feet.
   ○ D. It uses a 140-pound hammer dropped from a height of 30 inches.

46. Which of the following procedures describes the Standard Proctor Test?
   ○ A. It uses a 5-pound hammer dropped from a height of 12 inches.
   ○ B. It uses a 10-pound hammer dropped from a height of 18 inches.
   ○ C. It uses a 13,000 pound hammer dropped from a height of 20 feet.
   ○ D. It uses a 140-pound hammer dropped from a height of 30 inches.
Soil Mechanics Exercise

47. What is the normal lift range in inches stated in the documents for attaining the specified density percentage when compacting structural fill?

   A. 6 - 12.
   D. 49 - 60.

48. Which document specifies the Proctor Test and the percentage range and the Optimum Moisture Content?

   A. Bid Documents.
   B. General Requirements.
   C. Technical Specifications.
   D. Supplementary Conditions.

49. Which test is specified for fill material designated for use under areas where high design loads are anticipated such as airport run ways and paved areas?

   A. Shearvane.
   B. Penetrometer
   C. Standard Proctor.
   D. Modified Proctor.

50. The Soil Tables and formulas contain the abbreviation BCY, What does BCY mean?

   A. Bulk Cubic Yards.
   B. Bank Cubic Yards.
   C. Basic Cubic Yards.
   D. Borrow Cubic Yards.

51. Which test instrument measures the unconfined compressive strength of soil?

   A. Standard Proctor.
   B. Modified Proctor.
   C. Pocket Penetrometer.
   D. Standard Penetration.
Soil Mechanics Exercise - Soil Investigation Report

Geotechnical Investigation Report
The purpose of this report is to present the results of a soil investigation performed at the project site located in Big Rapids Township, Michigan. We have appended Drawing No. 1 which identifies the project site location in Big Rapids Township.

The borings were drilled by Testing Services (TS), Inc., using a CME model 45 “skid” drill rig. The drill rig utilized hollow stem augers to sample depths where samples were obtained in a two-inch O.D. split spoon sampler driven by a 140-pound hammer falling 30 inches. The number of blows required to drive the sampler three six-inch increments are recorded on the boring logs. The first six inches are considered the seating drive. The summation of the number of blows required for the second and third six inches are termed the penetration resistance “N” value in blows per foot (bpf). This field procedure is referred to as the Standard Penetration Test (SPT) and is an American Society for Testing and Materials test procedure (ASTM D-1586). The “N” values from the SPT are used for the determination of the relative density of granular soils (sand, gravel, low plasticity silt, and mixtures of sand and gravel) or the consistency of cohesive soils (clay and plastic silts). A chart is provided in the back of this report which provides a correlation between “N” values and the relative density of granular soils or the consistency of cohesive soils.

### Relative Density and Consistency Table

<table>
<thead>
<tr>
<th>Sand and Silt, Relative Density</th>
<th>Consistency of Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of blows required to drive a sampler 1 foot, using a 140# hammer falling 30”</td>
<td>No. of blows required to drive a sampler 1 foot, using a 140# hammer falling 30”</td>
</tr>
<tr>
<td>2” O.D. Samplers</td>
<td>RELATIVE DENSITY</td>
</tr>
<tr>
<td>&lt; 4</td>
<td>Very Loose</td>
</tr>
<tr>
<td>4 - 10</td>
<td>Loose</td>
</tr>
<tr>
<td>11-15</td>
<td>Medium Loose</td>
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<tr>
<td>16-30</td>
<td>Medium Dense</td>
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<tr>
<td>31-50</td>
<td>Dense</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>Very Dense</td>
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</table>
Soil Mechanics Exercise - Soil Boring #5

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>SAMPLE</th>
<th>SAMPLING METHOD</th>
<th>PENETRATION BLOW COUNT</th>
<th>LINER</th>
<th>SOIL CLASSIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/12&quot;</td>
<td>1</td>
<td></td>
<td></td>
<td>2.5&quot;</td>
<td>Organic Topsoil</td>
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<tr>
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<td>3</td>
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</tbody>
</table>

Boring Terminated at 15.0'

Plugging Method: Natural Soil
Psychrometry and the Psychrometric Chart

This is the field of study concerned with the behavior of atmospheric air. Air in the atmosphere is a mixture of gases including oxygen and nitrogen, and water vapor. When one wishes to condition an air space to create comfort for the occupants of the space, one will make changes in important properties of the air, including the temperature and the humidity. The impact of these changes on the comfort of the occupants is determined by considering the changes in a number of other properties, which could result. The most common approach to evaluate this impact is by using a chart solution of a number of thermodynamic relationships.

The *psychrometric chart* is a representation of all the important properties of atmospheric air and the relationships between them. There are a number of properties shown, and a great many axes which run in different, often curving directions. The various properties and the direction of the appropriate axis are shown below.

<table>
<thead>
<tr>
<th>Psychrometric Property</th>
<th>Direction of Axis on the Psychrometric Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dry Bulb Temperature</em>: The reading on a thermometer in the air.</td>
<td>![Dry Bulb Temperature Chart]</td>
</tr>
<tr>
<td>Read vertically from the axis across the bottom.</td>
<td></td>
</tr>
<tr>
<td><em>Wet Bulb Temperature</em>: The reading on a thermometer inserted in a saturated cotton wick.</td>
<td>![Wet Bulb Temperature Chart]</td>
</tr>
<tr>
<td>Read axis printed along the upper curve, and follow the diagonal axis down to the right down</td>
<td></td>
</tr>
</tbody>
</table>
Problems in psychometrics are solved by connecting lines on any two intersecting axes to identify a point which represents the properties of the air under the conditions of the problem. The remaining properties can be read on the other axes.
Psychrometry Example

Using the Psychrometric chart, and given a Dry-Bulb (DB) Temperature is 90 degrees Fahrenheit and the Wet-bulb (WB) Temperature is 76 degrees Fahrenheit, Determine the following values.

First, what is the Relative Humidity (RH) value from the chart?

This found by following the downward curving lines and it reads greater than 50% and less than 60%. Therefore, the interpolation would be 54%.

Second, what is the Humidity Ratio (HR) value from the chart?

This is found by using the point of intersection between the Dry-bulb and the Wet-Bulb Temperatures and then drawing a horizontal line to the right side. The Humidity ratio reads 0.0162. This is the humidity ratio or the pounds of moisture per pound of dry air.

Third, What is the Dew Point (DP) value from the chart?

This is found by using the point of intersection between the Dry-Bulb and the Wet-Bulb Temperatures and then drawing a horizontal line to the left side. The Dew Point reads 71 degrees F. This is the Dew Point of saturation.

Fourth, What is the Enthalpy value from the chart?

This is found using the point of intersection between the Dry-Bulb and the Wet-Bulb Temperatures and then following the diagonal line to the left side. The Enthalpy reads 39.6 Btu per lb of dry air.

Heat is measured in *British Thermal units*, or BTU. A BTU is the amount of heat required to raise 1 pound of water 1 degree F. The rate of heat flow is measured in BTU per hour abbreviated btuh. Heating, Ventilating and Air Conditioning (HVAC) systems use fluids to transport heat and cold to satisfy loads and maintain comfort. The fluids such as air, water, steam, and refrigerant are used to transport the heat and cold.
Psychrometric Exercise

Using the Psychrometric Chart and given a Dry Bulb Temperature of 85 degrees F and a Wet Bulb Temperature of 65F answer the following questions.

1. What is the Relative Humidity (RH) value?
   - A. 28
   - B. 34
   - C. 57
   - D. 72

2. What is the Humidity Ratio (HR) value?
   - A. 0.0030
   - B. 0.0088
   - C. 30.0000
   - D. 52.0000

3. What is the Dew Point (DP) value?
   - A. 0.0030
   - B. 0.0088
   - C. 30.0000
   - D. 52.0000

4. What is the Enthalpy value?
   - A. 0.0030
   - B. 0.0088
   - C. 30.0000
   - D. 52.0000

5. What is it called that measures the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit?
   - A. Enthalpy.
   - B. Saturated.
   - C. Relative Humidity.
   - D. British thermal units.
Psychrometric Exercise

Using the Psychrometric Chart and given a Dry-Bulb Temperature of 75 degrees F and Relative Humidity of 50% answer the following questions.

6. What is the Wet-Bulb (WB) value?
   - A. 56
   - B. 63
   - C. 70
   - D. 90

7. What is the Humidity Ratio (HR) value?
   - A. 0.0092
   - B. 28.5000
   - C. 56.0000
   - D. 69.0000

8. What is the Dew Point (DP) value?
   - A. 0.0092
   - B. 28.5000
   - C. 56.0000
   - D. 69.0000

9. What is the Enthalpy value?
   - A. 0.0092
   - B. 28.5000
   - C. 56.0000
   - D. 69.0000

10. What is another term for the total heat content of air?
    - A. Enthalpy.
    - B. Saturated.
    - C. Relative Humidity.
    - D. British thermal units.