THE RELATION OF SOIL TO BASE ROCK ON LOGGING ROADS

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The past ten years have witnessed a large scale swing toward permanent, high quality timber access roads. We are now in a transition period of access road engineering. This transition will probably result in the application of better engineering practices to access than are now given to many highways. Many companies have built access roads parallel to government roads because of vehicle economies involved. These private roads are designed for high speed heavy loads. In a proper design, the engineer should attempt to balance the cost of the road construction and maintenance with the costs to the vehicles which use the road.

Design

There are two phases to the problem of road design: (1) geometrical layout (location, curvature, grade, width) and (2) structural properties (drainage, subgrade, base, surfacing.). The major part of logging road engineering has been concerned primarily with geometrical layout. This has reduced vehicle cost per unit by increasing speed of travel and decreasing fuel consumption. Further reductions in
vehicle cost per unit through fixed and operational costs may be obtained by good design in regard to structural properties. This affects speed of travel, maintenance of vehicle, tire cost, fuel consumption, and size of vehicle. Size of vehicle, amount of travel, soil type length of use and rainfall are criteria on which structural design is based. Many studies have been made as to most efficient size of vehicle with the general conclusion that as length of haul increases, larger vehicles are more efficient, the optimum being dependent on local conditions. From these studies the savings effected by increased speed can be estimated. With small speed increases from 20 to 25 miles per hour or 30 to 40 miles per hour there would result a saving of from 6-9 cents per mile for smaller units and 9-11 cents per mile for larger units. These cost reductions mean considerable savings over the period of one year. From these same studies large units can save up to 25 cents per mile on a paved surface as compared to gravel; a saving up to 15 cents per mile on gravel as compared to earth. In many cases these savings would pay for an adequate base and a light bituminous treatment of about $4,000 per mile, in one year. This does not take into consideration the intangible savings from hazard reduction (dust etc.) and reduced maintenance, both road and vehicle. It therefore
seems logical that many logging roads, could receive at least a suitable base course at savings greater than the cost. This can not be carried out efficiently and at least cost with out the use of the basic principles of soil mechanics. There are many factors that affect the size and thickness of base rock.

**Size**
1. Available material
2. Crushing equipment
3. Plasticity of soil

**Thickness**
1. Applied load
2. Bearing power of soil
   a. Density of soil
   b. Moisture content (rainfall)
   c. Drainage

**Location**

In logging road location, the road can not always be placed in the best soil type, therefore in most cases the use of soil mechanics principles will be a cure rather than a preventative; in other words, based on the location, rather than the location based on it.

**BASE THICKNESS**

**General**

The function of the base is to distribute the wheel load until it can be carried under the worst conditions expected in the soil. The thicker the base the greater the area over which the load is placed. See fig. 1.
For any given road the size of load will be known. The problem will be to estimate the bearing power of the soil. This problem is further complicated by the fact that in most cases it is not economically sound, at this time, to perform a full scale laboratory test on the soil of logging roads. The problem, therefore, seems to call for answers that can be reached in the field with reasonable reliability and least cost. There is a further complication of the problem; a given soil will have different bearing powers in different areas. This is because of the complex relation between bearing power and such factors as amount of rainfall, elevation, aspect, etc. Thus the means for answering the question of base thickness should be taken on the area involved rather than trying to fit the research findings of one area to another area with different conditions. I feel that an answer derived from simple field tests on the area and establishment of a thickness curve to fit the local conditions would prove more satisfactory than detailed
laboratory tests and the use of one of the highway design thickness curves. This could be established on an area-wide basis with all interested persons contributing to the solution. It would give answers on the basis of economical limitations and other factors, both industry wide and local, that affect the logging industry.

**Soil Bearing Power**

This is an involved subject, and can lead into very complicated analysis. The problem can be approached from a practical, basic viewpoint. The approach will depend on the variety of soils in an area, or the predominant soil, or the factors affecting the soil. For example, an area with soils of fairly high bearing power may receive an extensive approach, and areas with soils of low bearing power may receive an intensive approach. There are a number of different soil classification systems; highway, geologic, and agricultural. The agricultural classification might be best suited for forest roads because the same system could then be used for both forest management and road construction. The bearing power will vary within a soil due to the amount of organic matter present and differences in particle distribution or grading. The bearing power is increased with less organic matter and well distributed grading. A
general rule is the coarser the soil the better the bearing power. The bearing power of the soil is measured by empirical means; there is no exact formula that fits every situation. Any single method of measurement, no matter how involved, is still only an estimate. For forest roads and field methods the manner of arriving at an answer is narrowed down to simple, practical methods.

There are three general methods to choose from:

1. **Feel and sight** - An extensive method of arriving at thickness curves on the basis of soil texture and test thicknesses. See page 1, appendix

2. **Penetration** - Under desired soil conditions, force a piston into soil sample and measure force required, compare with force required to force same piston into crushed rock; run test thicknesses.

3. **Plasticity index and % passing #200 sieve (200 meshes per in.)**
   Take field soil tests of both values. Make graph with one value as ordinate and other as abscissa. Run test thicknesses. See page 2, appendix

The results derived from these methods, using simple field tests under actual conditions, should be quite reliable.

When establishing test thicknesses, highway design data can be used as a guide; something to start from. The advantages of knowing the proper thickness of base will appear when running thickness tests. If a soil has a base of insufficient thickness, the applied load will rut the subgrade bearing surface. This will cancel the effort of crowning and compacting be-
cause of improper drainage. This is one of the reasons why it is better to apply an initial base of adequate thickness rather than building up base thickness as the road requires. If the base for a soil is over designed, there is needless expense involved; a decrease of 2" on a 20' wide running surface would save about 650 cu. yards per mile. This represents a large amount of money in areas where rock is scarce.

**Drainage**

Proper drainage is the most important single factor in successful sub-base construction. There are two types of road drainage; surface and subsurface. Surface drainage is dependent on amount of crown and degree of compaction. Quick removal of surface water does not allow it to soak into the ground. Runoff is collected in side ditches and passes under the road through culverts placed at natural drainages. Side ditches should be wide, and the slopes should be as flat as possible so that surface water will be drained away from the subgrade and kept away from it. Subsurface water is that which enters the subgrade by surface penetration, by ground-water seepage, or by capillary action. This internal water will reduce the soils bearing power. By increasing the depth of the side ditch, ground water will be intercepted, and this
will lower the water table in the subgrade. The lowered water table in turn increases the depth below subgrade surface that capillary water can rise. See fig. 2

Soil Density

The bearing power of a soil is directly proportional to the degree of compaction. On many logging roads, because of economical aspects, the only compaction received is from the machines building the road. This is slight pressure in comparison to compactors. As an illustration: Cats, have a ground pressure of about 8 lbs. per square inch.; sheepsfoot rollers can attain pressures up to 500 lbs. per square inch. Different types of compactors and different pressures are most efficient in different types of soil. In general, a rubber tired wobble-wheel roller is the best all around compactor for roads. In any soil there is an optimum moisture content for compaction. This is the moisture content that will produce the maximum soil density for a given pressure. Adequate compaction is
probably the cheapest method that can be found to increase roadway strength. It is much more important to compact the subgrade than the base. If rock is to be applied as soon as the road is built, compacting is essential. This is because of differential settling, particularly in fills after the road is used. If differential settling takes place after rock is placed, the rock is wasted. This is due principally to maintenance attempts to smooth the surface. When this is done, base is removed from high points and deposited in low spots with resulting weak links in the base. See fig. 3

Moisture Content (rainfall)

Soil bearing power is directly related to the moisture content of the soil. This varies widely as to soil type. Generally, the more permeable the soil the less affected by moisture content. On non-permeable soils such as clay, moisture content controls "pumping action", where the clay works up into the base. This generally happens
only in a certain plastic moisture content range and will stop when the clay becomes drier or wetter. This phenomena is a function of the plasticity of a soil.

**SIZE OF BASE ROCK**

The effectiveness of a given base thickness is dependent on the size of the rock and the grading. To obtain the greatest efficiency from a base at least cost the base rock size must be suited to the subgrade soil. In general, the lower the bearing power of a soil, the smaller and better graded rock required to distribute the wheel load. To illustrate: Imagine a base one foot thick made up of aggregate on foot in diameter. When a wheel load passes over this base it applies its entire load to the group of stones in contact with the tire and this load is passed directly downward to the subgrade where it is concentrated on the points of contact between stone and subgrade. It would only be a matter of time until the rocks would be submerged in the soil squeezed up between them. See fig. y.

![Diagrams showing effect of rock size on load distribution. Fig. y.](image)
Available material

Economy of construction can nearly always be obtained through the use of local material. A river sand, decomposed granite, or similar material will make an excellent blanket course over plastic soil. In bases of considerable thickness, the greater part could be made up of bar run or pit run rock with a top layer of well graded crusher run rock. It is usually better to keep round rock out of the surface layer because of the rough wearing course which will result. The important point is that low-cost, local pit run materials can be used to make high quality bases.

Crushing equipment

When a road warrants rocking, it warrants a well graded smooth wearing surface in most cases. In order to effect a proper grading it is usually essential to have a primary and a secondary crusher. The crushers will produce high quality graded material and can be controlled to a certain extent. With the new portable breakers it is conceivable that the pit run base could be placed on the road and crushed in place.
Plasticity of soil

For soils of high plasticity it is essential to blanket the soil with sand or other densely graded material which will not fail in shear as readily as the soil. This will prevent the plastic soil from working up through the base and reducing its effectiveness. The size and thickness of a blanket layer is a function of the plasticity index and could be related under test conditions. See page 2, appendix.
With the growing need for permanent logging road systems it is becoming more important, from an economic standpoint, to use better engineering practices. In order to have a high quality road, the base must be adequate. The question of when to apply base rock should be answered from cost records. Base thickness is a function of applied load and bearing power of the soil. Considerations for base thickness and size of rock should be based on the soil of the area. The bearing power of the soil should be derived on the basis of important local conditions. The bearing power is measured by empirical means. The method of measurement should be based on the conditions that exist in the area. Over or under designed thickness will result in wasted rock. Drainage, density, and particle size are the most important factors that influence the bearing power of soil.

Size of base rock and thickness of base are closely related, particularly on plastic soils. In many situations they are dependent on each other. Size of rock is also dependent on available material, crushing equipment, and plasticity of the soil. High quality bases can be built with low-cost, local pit-run material properly placed.
APPENDIX
Determining Soil Texture by Feel And Sight

**Sand.** Sand is loose and single-grained. The individual grains can readily be seen or felt. Squeezed in the hand when dry it will fall apart when the pressure is released. Squeezed when moist, it will form a cast but will crumble when touched.

**Sandy Loam.** A sandy loam is a soil containing much sand but which has enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart, but if squeezed when moist a cast can be formed that will bear careful handling without breaking.

**Loam.** A loam is a soil having a relatively even mixture of the different grades of sand and of silt and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling, while the cast formed by squeezing the moist soil can be handled quite freely without breaking.

**Silt Loam.** A silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay, over half of the particles being of the size called "silt". When dry it may appear quite cloddy, but the lumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together. Either dry or wet will form casts that can be freely handled without breaking, but when moistened and squeezed between thumb and finger it will not "ribbon" but will give broken appearance.

**Clay Loam.** A clay loam is a fine textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin "ribbon" which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact ball.

**Clay.** A clay is a fine textured soil that usually forms very
hard lumps or clods when dry and is quite plastic and usually is sticky when wet. When the moist soil is pinched between the thumb and fingers it will form a long, flexible "ribbon".

**Gravelly of Stony Soils.** All of the above grades of soil, if mixed with a considerable amount of sand, gravel, or stone, are designated as sandy clay loams, sand clays, etc., as gravelly sandy loams, gravelly clays, etc., or as stony sandy loams, stony loams, etc.
Field Procedures for Plastic Limits

Soil preparation. The soil is passed through a 2 m.m. sieve to remove stones and gravel. Then it is passed through a 60-mesh sieve (20-mesh sieve for sandy soils), being ground with a mortar and pestle as necessary.

Apparatus. For the determination of the plastic limits and plastic range the following apparatus is required:
- 4 - 9 cm. evaporating dishes
- 1 - nickel-plated, flexible spatula
- 1 - 6 x 6" glass plate
- 1 - 2 x 4 x 6" wood block and steel hammer.

Upper plastic limit. The upper plastic limit is defined as that moisture content of a soil at which the soil will just begin to flow when jarred. A sample of 20 to 30 gm. of soil is placed in a 9 cm. porcelain dish and distilled water added in small increments. The soil and water are mixed with a spatula. When the soil is moist enough to form a ball, it is kneaded with the spatula or by hand. After kneading thoroughly it is rolled into a ball, placed in the center of the porcelain dish, and flattened into a layer of approximately 1 cm. thickness. A wedge-shaped (90°) furrow is formed with a spatula, extending from one side approximately 3/4 across the soil cake.

The dish is struck three times against the heel of the hand or the wooden block ("yield value" force). When the faces of the wedge bulge slightly, but the soil does not flow together, the correct degree of plasticity has been obtained. If the soil flows together the sample is to wet and a slight amount of dry soil should be added, kneading continued, the wedge reformed, and the flow-test repeated. If the faces of the wedge do not bulge, the soil is too dry. A few drops of water are added, kneading repeated, the wedge reformed, and flow-test repeated. When the correct plasticity is reached, the percentage water is determined by weighing to 0.01 gm. and oven-drying. The percentage water is the upper plastic limit.

Lower plastic limit. The lower plastic limit is the minimum percentage of moisture that can be present in the soil without its losing its cohesiveness. The test for cohesiveness is sufficient cohesion to permit rolling out into a cylinder or thread.

A sample of 10 to 20 gm. of the sieved soil is placed in a
9 cm. porcelain dish. Distilled water is added in small increments and the soil mixed with a spatula. When the soil barely adheres into a mass, it is formed into a mass in the hands, and mixed thoroughly with the aid of a wooden pounding block and a hammer. A small portion (about \( \frac{1}{3} \) ml.) is broken off and rolled out against a glazed surface. When the moisture content is correct, the lump will roll out into a wire about 3 mm. in diameter before breaking into fragments. If too wet, the soil will roll out into a wire less than 3 mm. in diameter before breaking. If too dry it will fragment before rolling out to 3 mm. It is advantageous to begin on the too-moist side, since drying out occurs during the rolling process. If too wet, the kneading is continued, with the aid of the hammer for heavy clay soils, so as to maintain all portions of the soil mass to uniform moisture, as testing proceeds. If too dry, drops of water are added by breaking the lump open.

It is the minimum wetness that is sought, and with some sandy loam soils, it is necessary to proceed until a wire barely forms, in order to show a positive plasticity number. When the correct plasticity is reached, the sample is weighed to 0.01 gm. and dried at 110° C. The percentage moisture in the dry basis is the lower plastic limit.

**Plastic range (plasticity number).** This range is defined as the difference between the plastic limits:

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\text{Plastic range} = (\text{upper limit}) - (\text{lower limit})
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