# The Economics and Practicability of Layered Drains for Roadbeds

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This paper presents benefit-cost studies that demonstrate outstanding advantages for layered drains for roadbed drainage and the complete inadequacy of single-layer drains constructed of "well-graded" (low permeability) drainage aggregates. Discontinuation of the practice of using single-layer drains for roads where water removal is a problem is recommended.

Modern, wide multilane highways are considerably more difficult to protect from groundwater and seepage than older narrower roads. If any appreciable quantities of water must be removed from highways, the conventional single-layer drains are extremely uneconomical and quite ineffective. Both from an engineering standpoint and from economics, layered drains (often called "graded filters") are superior for protecting roadbeds from the damaging effects of water.

A two-layer drain system constructed early in 1967 in northern California is described. While this section of road has not been tested under rainy conditions, the rapid drainage potential was tested by pouring water over the open-graded drain layer and watching it emerge from the drain pipe within 2-3 minutes. This test section demonstrated that layered drains are perfectly feasible from the construction standpoint.

•AS THE highway system of the world requires the construction of multilane highways to greater widths, gentler slopes and milder curves in all kinds of terrain, the physical problems of developing stable roads have multiplied. This is equally true of subsurface drainage. Doubling the road width, for example, makes drainage about four times as difficult as before. Consequently, practices that worked when roads were only two narrow lanes do not work for four and six lanes. Greater amounts of groundwater and seepage enter wider roadbeds constructed in deeper cuts, and must be conducted greater distances for removal from places where it could cause damage or failure.

Designing adequate subsurface drainage systems has been considered primarily an engineering problem, one of using the proper filter criteria to select aggregates capable of removing troublesome groundwater and seepage without becoming clogged by adjacent fine-grained water-bearing soils. Early road builders, such as John L. McAdam of Britain and Pierre M. Tresaguet of France, must have instinctively known of the high water-removing capabilities of one-sized stone, as they used this class of material in their roads. These coarse materials had high permeabilities when first placed, but unfortunately there developed a practice of placing open-graded stone or gravel directly upon soft, erodible soils without the use of a layer of sand or graded material; hence these roads often deteriorated as soil worked up into the stone, making it about as impermeable as the underlying soil.

Because of these experiences with coarse, one-sized stone in drainage systems, and with the development of modern criteria for filters for earth dams, the practice developed of using well-graded "pervious" subbases and drainage layers for highway drainage, using washed concrete sand and comparable materials. As long as the quantities

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of water to be removed were small, little trouble occurred due to groundwater and seepage. Consequently, there developed a tendency to look upon these well-graded (low permeability) aggregates as adequate for underseepage collection and discharge.

Unfortunately, well-graded filter aggregates that are fine enough to hold in place fine-grained soils are too fine to pass much water. As a result, many roads and freeways throughout the world are deteriorating prematurely from a lack of subsurface drainage, even though they have been built with single-layer drains constructed with permeable aggregates.

A number of recent technical publications have pointed out that the proper solution to subsurface drainage of highways often is through use of multiple-layer drains (1, 2, 3), which were originally invented by K. Terzaghi (4) for the control of seepage in hydraulic structures such as sheet-pile walls and earth dams. This kind of drain, often called a "graded filter," is referred to in this paper as a "layered drain." It is composed of coarse, one-sized gravel or rock, enclosed within enveloping layers of finer material that serve as filters to prevent clogging of the inner conducting layer. Engineering considerations alone point up the great advantages of these drains for highway roadbeds. From theoretical, granulometric considerations, Winterkorn (5) demonstrated that one-sized, coarse rock is essential for the removal of seepage. These layers require filter protection. With the heavy emphasis on designing drains that will not clog, the economics of subsurface drainage systems have been largely disregarded. If one considers the potential water-removing capabilities of various kinds of commonly used drainage systems, it is found that as little as $3.50 can be spent or as much as $90,000 for two sections of subsurface drain having exactly the same water-removing capability. The lower cost represents a layered drain with an internal layer of 1-in. to ¾-in. diameter gravel or crushed rock sandwiched between two thinner layers of finer filter material. The higher cost represents a single-layer drain constructed of washed filter aggregate comparable to concrete sand, a class of material erroneously being used in many subsurface drainage systems. The purpose of this paper is to emphasize the need to look at what we are getting for our money when we design and build subsurface drainage systems for roads and other civil engineering works.

## A METHOD FOR EVALUATING THE BENEFIT-COST FACTORS FOR DRAINS

In examining the benefit-cost relationships for subsurface drainage systems constructed of various grades of aggregate, it is important to keep in mind that subsurface drains serve two very vital functions:

1. They must provide filter protection to all soft, highly weathered rocks and erodible soils that are being drained.
2. They must remove all of the groundwater and seepage that reaches them without much buildup of head.

To provide filter protection, drainage layers must be designed on the basis of appropriate filter criteria (1, 3, 4, 6, 7) that assure that openings in the filter aggregate will be too small for the passage of adjacent soil particles. This function is primarily one of properly applying engineering principles. All of the cost studies presented in this paper assume that designs do provide the necessary filter protection.

To fulfill function 2, drainage aggregates serve as conductors or conveyors of water, much as sewer pipes or water pipes serve as conductors or conveyors of water. Although this capability is partially one of meeting engineering requirements, it is also one of economics (2, 3). It is important to keep in mind that a material that provides excellent filter protection may be a very poor conductor.

Subsurface drains often utilize pipes for part of the seepage conducting system, almost always after it has been collected by line drains or blanket drains that remove seepage from large surface areas of surrounding water-bearing soil. If the quantities of seepage are quite small, it may be possible for the aggregate seepage collectors and conductors to be a single layer of relatively fine-grained material comparable to clean, washed concrete sand. But, in most cases involving any appreciable quantities of seepage, it is more economical to utilize layered drains for the prime water collecting and conducting elements.

Assuming that a subsurface drain is properly designed to provide the needed filter protection, its cost can be determined in relation to its capabilities for removing water.

Any conveyor or conductor of any material can be rated in terms of the cost of moving a given amount of material over a given distance. Thus, in earthwork, it is customary to use the term "station-yard," and in freight hauling the cost is expressed by the ton-mile. Similarly, the water-carrying capabilities of drainage aggregates can be expressed in any convenient units of quantity and distance. In this paper, a number of classes of drainage aggregates, in a number of kinds of systems, are rated in terms of the cost of conducting a unit quantity over a given distance. The unit of quantity is 1 gpm; the distance is 100 ft.

The water-conducting potential of porous aggregate drains can be estimated with Darcy's law:

$$Q = kiA \qquad (1)$$

This identity is not changed by multiplying the right side by unity, so

$$Q = kiA\,(L/L)$$

Hence

$$Q = \frac{kiV}{L}$$

And

$$V = \frac{QL}{ki} \qquad (2)$$

In Eq. 2, V is the volume of filter aggregate needed to conduct seepage quantity Q a distance L under hydraulic gradient i in a material with a permeability k.

Eq. 2 can also be derived by considering that the quantity Q is being conducted by cross-sectional area A. If it is conducted a distance L, the amount of filter aggregate needed must be AL, which is the volume V in Eq. 2. In most subsurface drains, both Q and i will vary from point-to-point; however, Eq. 2 assumes these factors are constant. The solutions are therefore somewhat approximate.

## SOME TYPICAL CASES

Using Eq. 2, the relative costs of a wide range of commercially available filter aggregates are compared in Figure 1. The required quantities of aggregates were calculated for hydraulic gradients from 0.02 to 1.0. All aggregates were assumed to cost \$5.00 per cubic yard, in place. Over a range of filter permeabilities from under 1 ft/day to about 50 ft/day, the drains are assumed to be constructed as a single layer in which the total thickness is available for the discharge of seepage. With a filter permeability of more than 50 ft/day, it is assumed that layered drains are required to prevent piping or clogging and provide the needed capacity. This is a necessary assumption for filters draining highly weathered soft sandstones, other highly erodible rock formations, and all highly erodible

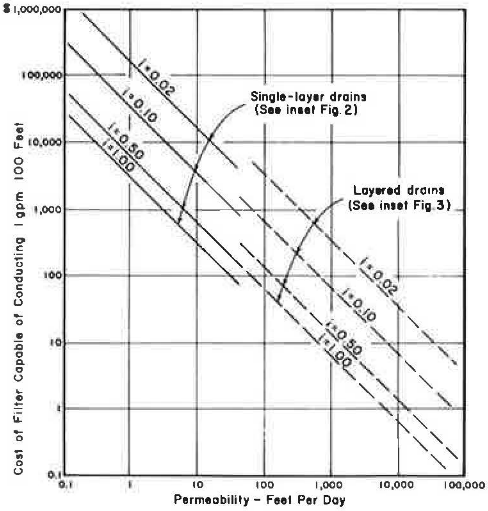

Figure 1. Cost of filter aggregate per seepage unit (1 gpm conducted 100 ft).

soils. The costs for layered drains in Figure 1 provide two filter layers totaling the same thickness as the inner conducting layer. Thus, if the conducting layer is 12 in. thick, the costs in Figure 1 for layered drains allow for an upper filter layer 6 in. thick and a bottom filter layer 6 in. thick, making a total thickness of 24 in.

Referring to Figure 1, it is seen that for a single-layer drain constructed with washed concrete sand having a permeability of 2 ft/day (corresponding to a class of material that is sometimes used for roadbed drains), the cost of conducting 1 gpm a distance of 100 ft (for a slope of 0.02) is nearly $100,000. If a cleaner, washed concrete sand or well-graded filter aggregate with a permeability of 10 ft/day is used, the cost is reduced to around $18, 000 for each gpm conducted 100 ft.

In contrast with the astronomically high costs of single-layer drains compared to quantity of water transported, it is seen from Figure 1 that a layered drain containing a core of fine pea gravel with a permeability of 3,000 ft/day (on a 0.02 slope) is around $100 for each gpm conducted 100 ft. Also, a layered drain utilizing washed, screened gravel or $\frac{3}{4}$-in. to 1-in. diameter crushed rock (k = 100,000 ft/day) can conduct 1 gpm a distance of 100 ft for about $3.50.

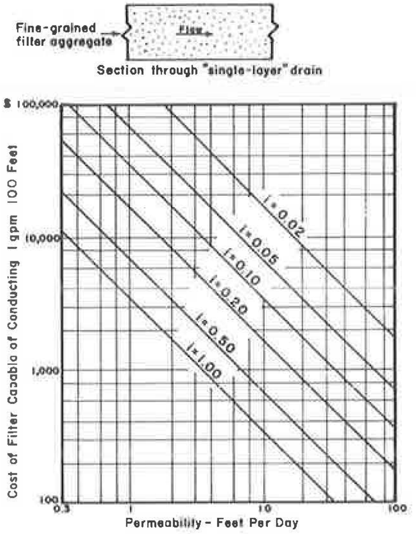

Figure 2. Cost of fine-grained aggregates in single-layer drains per seepage unit (1 gpm conducted 100 ft).

A study of Figure 1 leads to the conclusion that whenever roadbed drainage layers a few feet in thickness are constructed with low-permeability filter materials, structural damage may be expected, if any appreciable rate of inflow occurs. The practice of using these well-graded materials for roadbed drainage should be discontinued as they are extremely uneconomical and do not protect roads from water damage. The use of these materials is justified only as a filter protection for a drainage layer of high-permeability aggregate.

Since the discharge capacities of aggregate drains increase in proportion to the hydraulic gradients that can develop in drains, steeply inclined drains (such as are frequently used in earth dams or in stabilization trenches in highway foundations) require less quantities of filter materials or less permeability than the nearly horizontal drainage blankets placed beneath roadbeds in wet cuts and below the natural groundwater level in flat terrain.

The charts in Figures 2 and 3 show the relative costs of single-layer and multiple-layer drains. Figure 2 shows the cost of single-layer blanket drains utilizing fine-grained aggregates capable of providing a high level of filter protection to adjacent erodible soils. Figure 2 is similar to the upper left portions of the chart in Figure 1, but is enlarged, and is in more detail to permit more accurate applications. Similarly, Figure 3 shows the costs of layered drains that utilize a core of coarse one-sized aggregate within protecting envelopes of finer material capable of providing high filter protection (shown in inset). Two protective filters are provided having a combined additional thickness that is equal to the thickness of

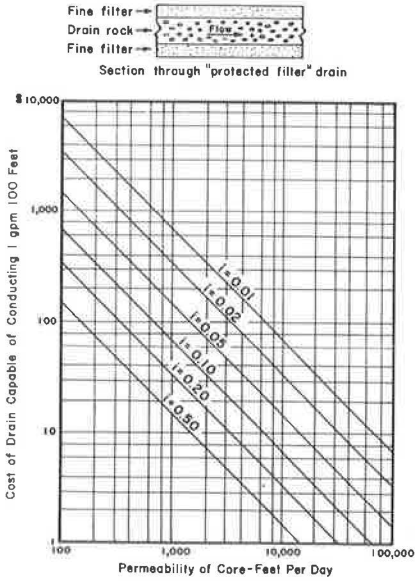

Figure 3. Cost of "protected filter" drains per seepage unit (1 gpm conducted 100 ft).

the inner conducting layer. Figure 3 is similar to the lower right part of Figure 1, but is enlarged and increased in detail to give increased accuracy. In normal highway design the subbase material may, in most cases, serve as the upper filter layer. These charts are presented as typical of conditions in blanket drains in which the quantity of water conducted is important.

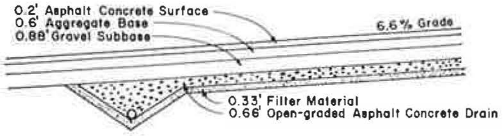

Figure 4. Longitudinal section of Humboldt County drain.

## EXAMPLE OF A LAYERED ROADBED DRAIN

A two-layer graded structural section drain of the type discussed in this paper has been placed experimentally in Humboldt County in the north coastal area of California. A typical section is shown in Figure 4.

Geologically, this area consists of Jurassic to Pleistocene sedimentary deposits that have been folded and faulted. The rainfall is heavy, 40 to 80 in. per year. This combination results in many water-bearing formations and numerous spring areas. With these conditions, cut and fill slope stability is a serious problem and adequate pavement subsurface drainage a necessity.

The site chosen for the experimental construction was in a side hill cut area with heavy seepage from the bank, both above and below the pavement. The existing pavement had been built with a blanket of filter material to remove seepage. Failure of this filter material to effectively remove all of the seepage had resulted in the buildup of hydrostatic head beneath the pavement. Pavement failure was the result, with water rising through cracks in the deteriorated pavement.

To correct this condition, a two-layer drain was designed and built by County forces. Two additional purposes of this construction were (a) to determine the capability of this type of drain, and (b) to evaluate construction feasibility of layered roadbed drains.

The design of the drain included 0.33 ft of filter material on the prepared silty clay subgrade, and 0.66 ft of open-graded asphalt-concrete drain material. The drain was covered by the regular structural section of base and surface as follows (see Fig. 4): 0.88 ft of river-gravel subbase, 0.60 ft of aggregate base, and 0. 20 ft of asphalt-concrete surface.

Since this was a small isolated project, it was not practical to specify special requirements for the above materials. The materials used, therefore, consisted of aggregates already available in stockpiles at a nearby commercial plant. A filter layer with a smaller amount of fines would have been desirable but the material used should be adequate for the site. The important criteria for the filter layer in a drain of this type are (a) that it must have a grading that will prevent migration of the subgrade soil into the drain layer; and (b) that it must have a permeability at least as high as the formation or soil supplying the seepage water (preferably several times as permeable). The filter material used met these criteria.

TABLE 1

GRADATION AND LABORATORY PERMEABILITY OF MATERIALS USED

| Sieve Size | Percent Passing | | |
|---|---|---|---|
| | Filter Material | Asphalt Concrete Drain Rock | Aggregate Subbase |
| 2 in. | 100 | — | 99 |
| 1½ in. | 98 | — | 93 |
| 1 in. | 90 | — | 78 |
| ¾ in. | 83 | 100 | 68 |
| ½ in. | 70 | 75 | 55 |
| ⅜ in. | 60 | 47 | 46 |
| No. 4 | 46 | 14 | 32 |
| No. 8 | 35 | 3 | 25 |
| No. 16 | 27 | 2 | 19 |
| No. 30 | 20 | 2 | 11 |
| No. 50 | 13 | 2 | 5 |
| No. 100 | 8 | 2 | 4 |
| No. 200 | 6 | 1 | 3 |
| Percent asphalt | — | 2. 2 | — |
| Laboratory density, pcf | 130 140 | 102 110 | — |
| Permeability, ft/day | 7 0.7 | 9000 5400 | — |

The drain rock used for the open-graded layer consisted of aggregate from the No. 4, or coarse bin, of a four-bin asphalt plant, mixed with approximately 2 percent of 85-100 penetration paving asphalt.

The gradings and permeabilities of the materials used as determined by tests by the California Division of Highways are given in Table 1. The overlying aggregate subbase had a gradation that did not sift appreciably into the open-graded layer,

Figure 5. Placing filter material in transverse trench.

Figure 6. Placing open-graded asphalt-concrete drain material around pipe.

eliminating the necessity for a special upper filter layer. For this reason this drain is a two-layer drain, although it is in reality a true "protected filter" drain.

This drain was placed on a 6.6 percent grade and the length was only 150 ft. Because of the steep grade and short length, a perforated metal pipe (PMP) was not placed along the pavement edge, but a single PMP was placed as a transverse drain at the downhill end of the section. The PMP was placed in a trench having a depth 2 ft below subgrade elevation (Figs. 5 and 6). Figure 5 shows filter material being placed in the transverse trench, while Figure 6 shows the open-graded asphaltic-concrete drain material being placed over the filter material and around the PMP. A general view of placement of the open-graded drain layer is shown in Figure 7.

Construction was somewhat hampered by the steep grade and the fact that the site could not be by-passed with construction equipment. This necessitated rolling only in an uphill direction.

Compaction was with an 8- to 10-ton tandem Galion Rollomatic without ballast. This weight roller was heavier than desirable for compacting the open-graded asphalt-concrete mix in the thick section placed in the cross trench. Also, some difficulty was experienced in rolling up the grade on the first 4-in. lift of open-graded mix. The second lift was placed just before quitting time, and as a result was not compacted except by the Barber-Greene paver. The following morning, however, the surface could not be dented with the wheels of a loaded truck, proving the advantages of stabilizing open-graded layers with a low-asphalt content.

Figure 7. Placing open-graded asphalt-concrete drain layer.

Figure 8. Flow from cross drain 2 to 3 minutes after sprinkling open-graded mix with watering truck.

The experiment indicated that construction of two-layer drains using an open-graded asphalt concrete as a drain layer is perfectly feasible. On future work, a lighter weight roller should be considered, possibly a light pneumatic roller. It is doubtful, however, that any difficulty would have been experienced on this project, even with the heavy roller, if the construction had been on more nearly level terrain.

The performance of the drain cannot be properly evaluated until after at least one rainly season; however, water put on the surface of the open-graded asphalt-concrete drain material with a watering truck demonstrated that the drain layer has a high capacity for removing water (Fig. 8). The flow shown developed within 2 to 3 minutes after applying the water.

## SUMMARY

Aggregates for subsurface drainage systems for highways and other civil engineering works often represent a substantial part of the total cost of a job. An important question to be asked about any construction material is "does it give full value for the money spent?" When this question is asked about subsurface drainage aggregates, some surprising answers are obtained. As conveyors of seepage, conventional single-layer drains constructed of washed, fine-grained aggregates are enormously expensive. When any appreciable quantities of groundwater and seepage must be removed by subsurface drains constructed of selected aggregates, layered drains offer the best engineering solution at the least cost. The project described in this paper demonstrates the practicability of this kind of construction.

Just as the hauling of construction materials can be evaluated in terms of the cost per unit of material hauled and the distance it is hauled, systems for conveying seepage can be rated in terms of the cost of conducting a given quantity a given distance (see Figs. 1 to 3).

All aggregate drains that are designed for the removal of groundwater and seepage for the protection of roadbeds and other civil engineering structures should be designed using appropriate filter criteria that assure permanent functioning without piping or clogging. But, in addition, the systems should give an adequate return for the money spent. Consideration of the potential returns in terms of capabilities for conducting water is an aspect of subsurface drainage that has received very little attention. When this factor is considered, it points out that if any appreciable quantities of water must be removed, layered drains offer financial advantanges that must not be overlooked.

With the seepage flows normally encountered, a layered drain using the minimum practicable lift thicknesses of drain rock will provide a very large safety factor. This is an important advantage. If a drain is filled to capacity or near capacity, slight variations in the permeability of the filter layer, on grades, can cause uplift of the pavement structure.

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