INTRODUCTION

Rockfill in its various forms—dumped, compacted in layers, hand-placed cobbles and masonry, equipment-placed masonry, and wet masonry—has been known since ancient times as a useful, reliable, and durable construction material. Progressing from low, hand-placed walls that have endured for centuries around farmlands, to the base courses and cobbled pavements of ancient roads of similar longevity, and then in the mid- to late 1800s to rock dams of modest size in California, Europe, and North Africa, followed in the 1900s by even larger rockfill dams worldwide, high rockfill dams have become recognized for their safety, adaptability to widely varying site conditions, practicality of construction, and economy. Many papers have been published, testifying to their value and widespread use. Cooke¹ in his Terzaghi Lecture, provided the collective experience to 1984. In his chapter on the “Design of Rockfill Dams,” Taylor² listed 160 papers covering most aspects of the subject. Bureau et al.³ listed 47 papers on seismic analysis alone.

Rockfill dams have been successfully constructed to great heights, and among the highest are those shown in Table 12-1. Each of these dams has performed safely, with no evidence of instability in spite of several instances of appreciable leakage, each case being safely repairable. Accordingly, the cumulative experience to date demonstrates the satisfactory performance of a variety of high, rockfill dam cross sections and rockfill types (central earth core, sloping earth core, and concrete face types, together with rockfill materials including quarried basalt, quarried metandesite, quarried sandstone, quarried conglomerate, quarried granitic-gneiss, quarried limestone, alluvial cobblegravels, and alluvial dredger tailings). With these satisfactory precedents, and the fact that no rockfill dam has ever failed except possibly because of overtopping, it is evident that rockfill dams well over 1000 ft (300 meters) high can now confidently be designed and constructed.

DEFINITION AND NATURE OF ROCKFILL

Because of its extreme heterogeneity and variety of particle sizes, gradation, particle shapes, and mineral constituencies, a comprehensive yet concise definition of the term rockfill is virtually impossible. Perhaps the fundamental property that most engineers consider generally identifies rockfill is the apparent or predominant large average particle size. It is particle size that distinguishes the material from earthfill. One common approach is to say that, to be termed rockfill, the material must have an average particle size of at least 2 in. (5 cm), but that no more than 40 to 50% of the average sample should pass a 1-in. (2.5-cm)
screen. Thus a limit is imposed on the finer fraction (which approaches the texture and properties of earthfill), but no limit is imposed on the maximum particle sizes. In this context, it should be appreciated that, if the percentage of minus 1-in. (2.5-cm) material exceeds 45 to 50%, that fraction will begin to dominate the stress–strain and permeability properties, as it becomes the matrix that, when perfectly blended, completely surrounds and separates the larger rock particles. The result is lower shear strength and lower permeability, and thereby a diminution of the fundamental assets of rockfill.

The heterogeneity and infinite variety of particle size gradations of rockfill are even further exaggerated by the fact that severe segregation inevitably occurs during dumping and spreading of the material. Hence, the average gradation of a lift is a scientifically misleading characteristic, in that the fill is never perfectly blended. The coarser particles always concentrate at the bottom of each lift and the finer constituents at the top. Although this behavior makes small-scale tests of the in-situ fill relatively meaningless, from a practical point of view it can be judged to have little or no adverse influence on the fill’s overall strength and permeability.

Against this background it seems appropriate to comment that, despite the extreme lack of homogeneity that is the nature of rockfill, there has been and continues to be, an excess of testing, research, and technical writing directed chiefly at studying and attempting to quantify the properties of ideal, perfectly blended rockfill. But normal rockfill is never blended. It should by now be apparent to anyone who has observed and considered the field conditions of quarrying, loading, hauling, and placing rockfill that the end product, rockfill in place, is unlikely ever to be appropriately, precisely, and meaningfully tested and evaluated by the carefully developed methods of soil mechanics, despite extensive historical efforts to so quantify it. The only true indication of the competence of rockfill embankments may be the observable performance of the prototype. The most realistic procedure for ensuring the competence of rockfill, assuming that a good source exists, is to enforce performance specifications that stipulate lift thickness, the number of compaction passes of a heavy vibratory roller, and the maximum allowable percentage of material passing a 1-in. (2.5-cm) screen.

FUNCTIONS OF ROCKFILL

It seems obvious that the primary function of rockfill in embankment dams is to provide structural support for whatever type of impervious zone in the dam may be desired. The impervious zone historically has had many forms, including both vertical and inclined compacted earth and asphalt cores, and both vertical and inclined membranes of portland cement concrete, asphaltic concrete, sheet steel, laminated wood planking, and wet masonry. In providing structural support for such impervious zones, the primary requirements of rockfill have been that it be structurally strong (have high shear strength), and that it be minimally deformable.

Until about 1960, when the vibratory steel roller began to be practical for compacting rockfill placed in “thin” lifts, the general practice in constructing rockfill was to dump and sluice the material in the highest lifts that were practical for the given damsite and construction equipment. The resulting fill was reasonably strong, as evidenced by the evident stability of 1.3H:1V dumped slopes; but the rockfill mass, as shown by experience particularly at many concrete face rockfill dams, was seriously compressible and deformable, permitting damaging deformations through, for example, face slab translations of as much as 5 ft (1.5 meters). Similarly, for central core dams, large differential settlements of dumped rockfill have been experienced, particularly in the zone upstream from the earth core during first filling of the reservoir.

This experience stimulated the development of reliable vibratory rollers, and concurrently brought recognition that high, dumped lifts were no longer acceptable, necessary, or economical. The basic results of compacting rockfill in “thin” lifts have been slightly increased rockfill strength and greatly increased resistance to settlement and deformation. Thus, the modern practice for constructing structural rockfill zones is placement in 2- to 5-ft-thick (0.6- to 1.5-meter) lifts and compaction, frequently without watering, by at least four passes of a 10-ton or heavier vibratory roller.

Other uses for rockfill include slope protection to resist erosion and/or wave action, and specialty applications, each of which involves a marked departure from the use of normal, quarry-run rockfill. The needs of such special designs result in specification of the processing of the available quarry-run product to provide closely limited particle sizes. For riprap, the larger sizes are emphasized, and are obtained by selective loading in the quarry, or by passing quarry-run material over a grizzly, often with bar spacing of about 6 in. (15 cm).

Other specialty applications include the use of steel-bar-reinforced rockfill for slopes subject to overtopping flows, as for example, in cofferdams37,40,42 and for internal spillways in rockfill embankments, such as those in Australia documented by Parkin.39 The design of rockfill for these cases is very special, and the processing of particle size gradation requires careful and relatively expensive screening.

ROCKFILL PROPERTIES

As indicated earlier, despite its comparatively unique and heterogeneous nature, and extremely wide-ranging varia-