be entrained by an approved and effective air-entraining agent and should be dispersed throughout the mortar fraction at an average spacing of 0.007 inch to assure optimum durability. Many factors such as consistency, gradation, sand content, particle shape of aggregate, and type and amount of agent influence the characteristics of the initial air void system formed during mixing. However, characteristics or parameters are little influenced by subsequent handling and consolidation. In fact, consolidation of freshly mixed concrete improves the air void system by decreasing air content through elimination of the undesirable larger air voids; these larger voids are broken up into smaller voids, thus increasing the number but reducing the average size of the air voids with the spacing factor remaining essentially constant.

It has been observed that a normal amount of consolidation or vibration tends to improve the durability of air-entrained concrete even though some of the entrained air is lost in the consolidation process. This reduction in air has a beneficial effect on strength in that it allows recovery of some but not all of the compressive strength lost through initial entrainment of air. An excessive amount of vibration may cause segregation of the mortar and coarse aggregate with detrimental effects on many of the properties of the concrete.

Entrained air further contributes to the durability of concrete because it reduces the water channel structure in hardened concrete by improving workability and reducing bleeding in the fresh concrete.

Reduction in water-cement ratio materially increases the resistance of concrete to sulfate attack. Test results indicate that entrained air, up to 6 percent, slightly increases resistance of concrete to chemical attack. This improved resistance is undoubtedly obtained by the increased watertightness due to the reduction in water channel structure.

Resistance of concrete to erosion is related to compressive strength; therefore, resistance to erosion is increased as the water-cement ratio is decreased. When air entrainment results in a reduction in strength, erosion resistance is likewise reduced.

(c) *Effects on Permeability.*—The pronounced effect of water-cement ratio on permeability of concrete is depicted in figure 17. Note that permeability increases rapidly for water-cement ratios higher than 0.55 by weight.

Water-pressure tests on concrete containing entrained air show that permeability is not appreciably affected by entrained air in the percentages ordinarily used in construction if the water-cement ratio remains unchanged.

Tests of lean mass concretes containing pozzolans indicate increased resistance to the flow of water when finely ground pozzolans are used.

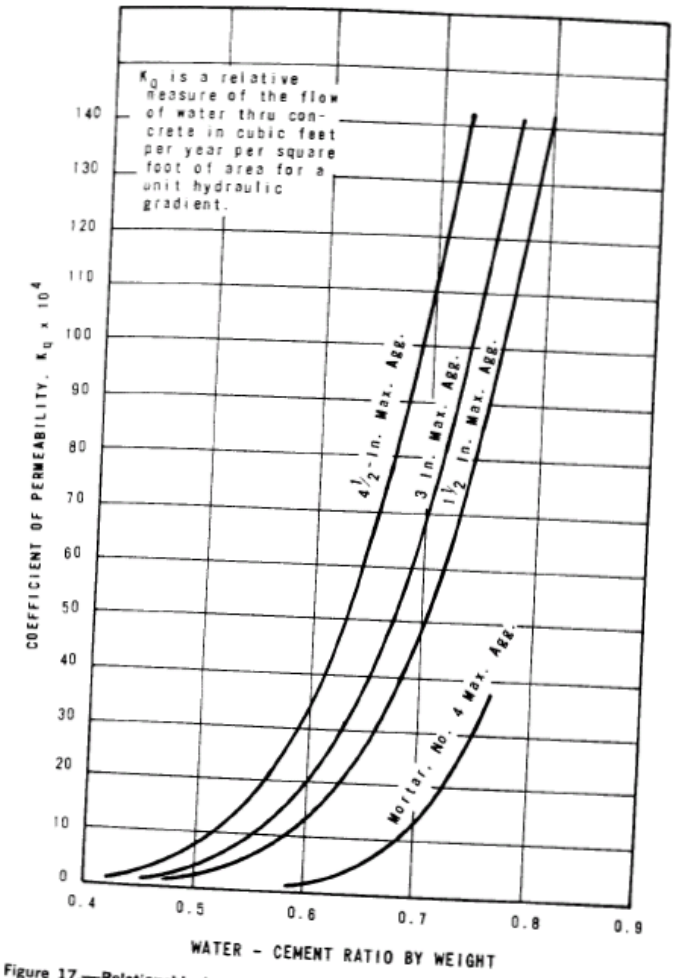

Figure 17.—Relationship between coefficient of permeability and water-cement ratio, for mortar and concrete of three maximum sizes. Relatively low water-cement ratios are essential to impermeability of concrete. 288–D–1522.