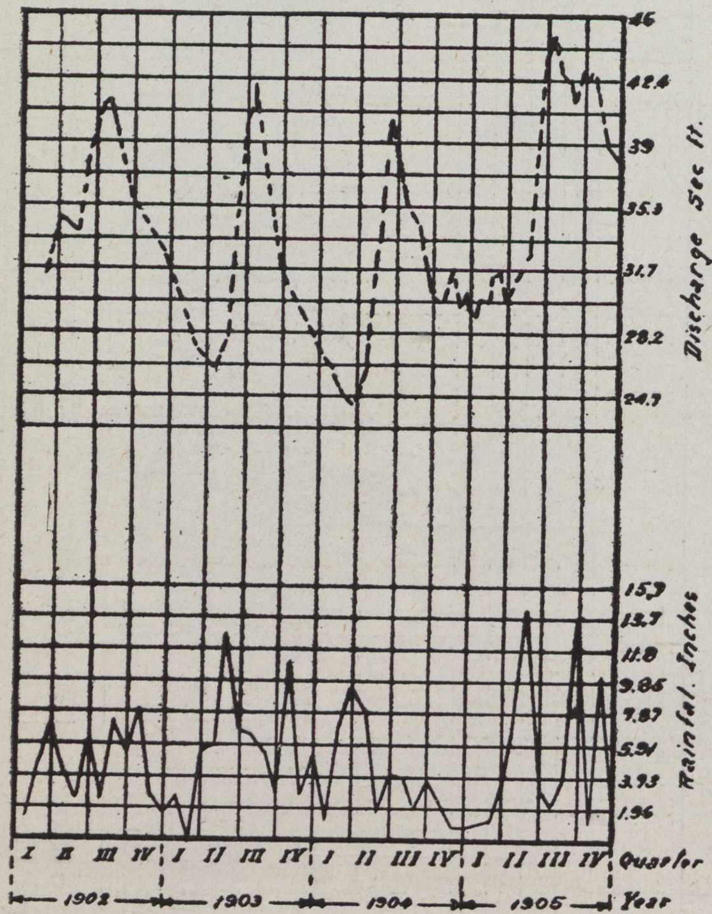
ous ground, for instance, the Italian method has found broad use, whereas in more solid formation the Austrian method has been favored in Europe, and the American method in this country.

Subaqueous tunnels are driven chiefly with the assistance of compressed air, with and without a shield. Soft materials, such as sand and boulders, earth, or materials such as referred to in zone 2, Fig. 3, are driven usually with the American, Belgian or English methods, and in such cases the field of mining operations is restricted to relatively short zones; that is, the heading excavation, enlargement to full section, including the timbering and the lining, follow each other within a few feet, and as



Underground flow and rainfall recorded at South portal of Simplon Tunnel.

Fig. 5.

little ground as possible is disturbed or removed at any one time, and for a short duration of time only. In hard and solid rock, the American method is used chiefly in this country, while abroad, the Austrian method, slightly modified in certain instances, has found a broad application. Here the field of operation is spread over a larger zone, for the formation of the range is such that a relatively small amount of timbering is required, and the latter is not subjected to intense pressure most usually. As the bore increases in length, and the difficulties due to geologic formation increase in magnitude, it becomes necessary to spread the field of operation over a large zone, hence the use of the bottom heading method adopted chiefly in connection with long and deeply overlaid tunnels. This method can be sub-divided into (1) the centre cut, and (2) chambering.

The first method, which consists in driving a bottom heading first, and then stoping down the overlying material, clear up to the tunnel roof, is used chiefly in connection with bores or sections thereof driven through materials not subjected to intense ground pressure, when the amount of timbering is relatively small. The second method, used where rock pressure forbids large sections to be excavated without being heavily timbered and lined within a short time, consists in driving a bottom heading first, then a top heading, and in enlarging the bore to full sections over a short distance at a time.

Too much emphasis cannot be laid on the necessity of using such driving methods that will best serve overcoming natural difficulties. The best, safest and most economical driving method is that which possesses flexibility in being capable of adaptation to suit natural conditions.

Underground Water.—A knowledge of the approximate amount of water to be encountered during construction is valuable, for experience has demonstrated time and again that a large percentage of delays in driving and lining tunnels was directly chargeable to underground springs. Moreover, when owing to topographical reasons it becomes necessary, for instance, to give the bore a uniform grade from portal to portal, then an estimate of the capacity of underground water to be tapped by the bore becomes of absolute necessity. In such a case the tunnel can be driven from one side only, unless adequate means are provided to prevent flooding of that end of the bore driven down grade.

The determination *a priori* of the quantity of water to be encountered in driving a tunnel is impossible practically, and as no two identical cases have ever been recorded, no fixed rules or formulæ have been advocated that would suit any or all cases. The amount of underground water depends chiefly on the amount and distribution of rainfall, on the topography and geologic formation of the site, and although the exact amount of water to be encountered underground is an unknown quantity, yet a general idea can be gained as to whether a tunnel will be wet or dry, and also the approximate location of probable wet zones, provided accurate data are available as to the geologic formation of the range to be tunnelled. The depth overlying a bore plays an important part, not only with reference to the capacity, but also to the distribution, of underground water. This is obvious, for, in little deeply overlaid tunnels, water travels but a short distance from the surface down to the bore, and usually the spouting point lies not very far below the source of supply. In deeply overlaid tunnels, when the formation is complex, the spouting point in the tunnel may lie several thousand feet from the source of supply; an idea of such an occurrence can be gained from Fig. 4, being a longitudinal section of the St. Gothard tunnel, prepared by Stapf. Seven thousand feet from the north portal, the tunnel is overlaid with some 5,000 feet burden, also with a glacier. Water found access in the bore through a fault, spouting in the tunnel approximately 6,500 ft. further towards the south portal, after a travel of some 9,000 ft. along the fault. Similar occurrences have been recorded elsewhere, and experience has taught that the depth overlying a bore is more a criterion in the distribution rather than in the capacity of underground water.

There exists an intimate relation between underground water and fissures in the ground, also faults, bedding planes, jointing, cleavage, as well as the kind of materials penetrated. The belief often prevails that tunnels driven through igneous rocks such as granitoid