blasting, timbering, lining, etc., and on the formation of the range, whether badly faulted or contorted, and chiefly on the care taken in checking at the very outset initial movements of the strata. Other things being the same, the surface or plane of rupture will depend on the angle of repose of the material penetrated, it being admitted for practical purposes that the plane of rupture has an angle of $45 + \frac{\alpha}{2}$ with a horizontal line passing at the elevation of the tunnel floor, as shown in Fig. 2.

From the above it becomes evident that disturbances are liable to take place, more or less slowly, in a range pierced by a bore, and made up of materials possessing a low crushing strength. If, on the other hand, harder materials, such as crystalline rocks, are tunnelled, results of an apparently different, though similar nature, are also capable of causing disturbances, in a slower period of time, however. Reference is made here to such mechanical actions as expansion or contraction of the rock, also shelling or popping of same, and of chemical actions such as oxidation and carbonization of certain rock-forming minerals.

Shelling of Rocks.—The phenomenon of rock shelling or popping has been observed in many instances in mines, tunnels, shafts and quarries, both in this and other countries. Prof. Heim expressed himself on the subject as follows: "The sudden separation from tunnel walls of rock slabs takes place in various kinds of rock; shelling has been observed in granite, aplite, porphyry, gneiss, diabase, sandstone, quartzite, limestone, dolomite, coal and others, always under the condition that the rock was homogeneous, compact, solid, without cracks or seams. The slabs loosen themselves from and parallel to the tunnel walls (periphery) often not immediately after blasting, but frequently after weeks and months, often increasing in intensity as time passes, and increasing especially with the size of the bore."

Prof. Dr. Schmidt noticed that in the Simplon tunnel rock shelling increased with the overlying depth, and that in steeply inclined strata of gneiss, with 2,300 ft. burden, no shelling took place, whereas in the same rock, with 4,000 ft. overlying depth, heavy shelling took place.

Rock shelling has been observed to occur at various depths below the surface of the ground, and in horizontally, vertically and steeply inclined strata, as, for instance, in the gneiss of the Simplon tunnel, in gneissoid granite of the Wattinger, Leggistein and Pfaffensprung tunnels. Lazarus White states that shelling took place in the west shaft of the Hudson siphon, in granite gneiss and that "the rock appeared to be under considerable stress and peeled off in layers for three or four weeks and continued to scale and pop, although perfectly sound when first exposed." A similar phenomenon was observed in the shale and limestone formation crossed by the Rondout siphon. In the Leggistein tunnel, shelling took place in the roof, several years after its completion and would last for a month at a time. In the Wattinger tunnel, violent shelling occurred in the tunnel floor, and in the Tauern tunnel, throughout its periphery. In every instance the phenomenon has taken place in sound and solid rock.

Effects on Rocks of Oxidation and Carbonization.—Moisture in tunnels is high, usually varying from 80 to 100 per cent., and those rocks which contain iron pyrites soon become oxidized and sulphuric acid is formed, the effects of which, on rocks, cause disintegration, more or less rapidly. Carbonization leads also to disintegration, and, the larger the percentage of carbondioxide contained in the air, the more rapidly rocks will disintegrate. Air contains about 0.045 per cent. of carbondioxide, by weight, and in tunnels a large amount is exhaled by human beings and animals, also by the consumption of explosives, the use of artificial lights, etc. The chemical action of agencies such as referred to above has but a slow action on the rock surrounding a bore; nevertheless, the combined action of the several elements capable of destroying the strength or cohesion of rocks is worthy of due consideration. For instance, if in Fig. 2 the rock surrounding both the main and pioneer bores was to reach a high state of disintegration, it becomes evident that, in due time, the width or thickness of the material between the bores would become inadequate to resist the

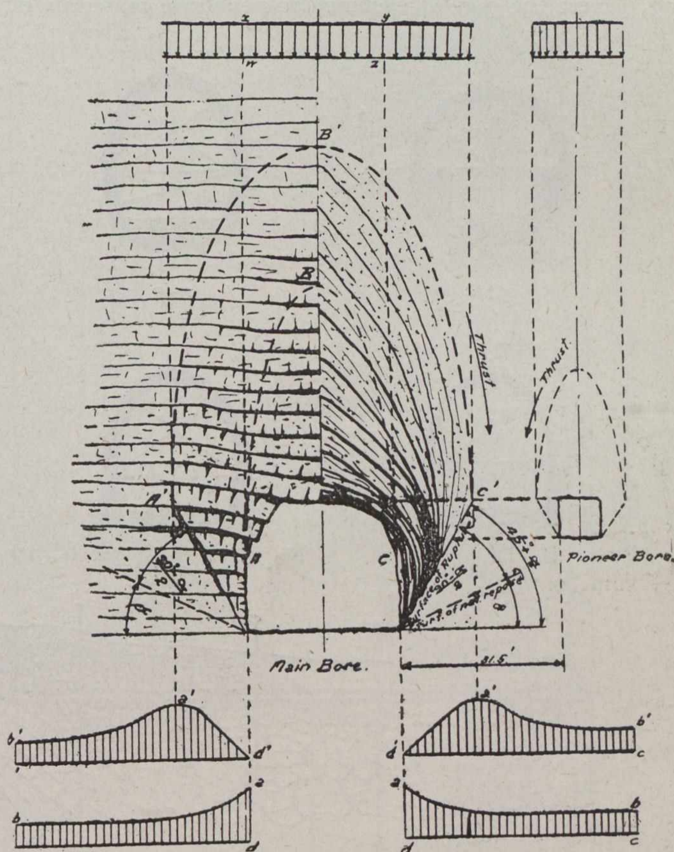

Fig. 2.

thrust of both the main and pioneer bores, in addition to the overlying weight, and crushing could then take place in a manner similar to that observed in the Simplon tunnel.

Thus, the question as to the distance to provide between bores of a twin tunnel system, and the necessity of lining the parallel heading or the pioneer bore, when deeply overlaid, becomes an item of vital importance, both from a standpoint of construction and maintenance.

Cross-section of Bore.—Other things being the same, the shape or cross-section of a tunnel plays by far a greater part than the thickness of its lining, and economy will be realized by giving a bore the shape best appropriate to resist the weight of the overlying material rather than by keeping the internal stresses in the lining within a reasonable limit, by increasing the thickness or dimension of its various elements, beyond a reasonable or practicable limit. As the geologic formation of a range varies very often, within a limited distance, also the overlying depth, it is obvious that the burden or load acting upon a tunnel lining varies also in intensity or direction,