Distance Between Bores.—The double-bore system of tunnelling has attracted much attention during the past years, and much has been learned from the experience gained in driving the Simplon tunnel. When the latter project was considered, little information was available to guide the engineers in charge of this work as to the distance suitable centre to centre of bores, and 56 feet were then considered adequate for the purpose intended. During construction of this bore, heavy ground pressure and shelling took place in apparently hard and sound rock such as gneiss, and it became necessary to line certain sections of the parallel heading at the very outset. As years passed, more shelling occurred at the roof, side walls and floor of the unlined parallel heading, in certain instances partly choking it with loose rocks, and it became evident that, unless it were lined with masonry, or

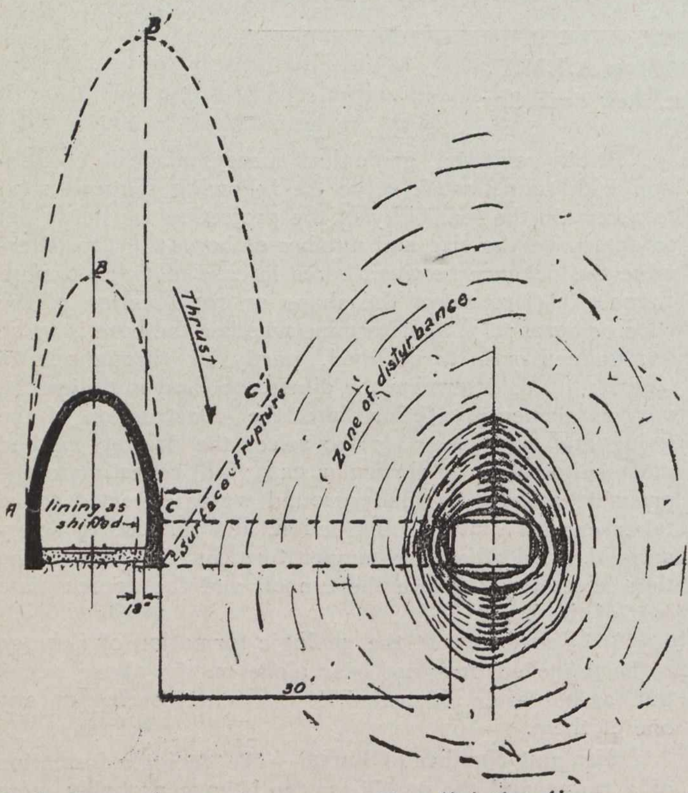

Fig. 1.

else enlarged to full section, and then lined definitely, extensive damage would result, with the possibility for the latter to extend over to the main bore.

Work of enlarging the parallel heading was then started and in July, 1914, as this work was going on between kilometer 3 and 3.5, heavy shelling took place at kilometer 3.3. The bottom of the drainage canal was lifted 10 in. and the side walls were shifted sideways about 12 in.; the width of the canal was reduced from 24 to 12 in. Seven days later, heavy shelling took place again in the parallel heading, and the masonry side wall in tunnel No. 1 was moved sideways 18 in., as illustrated in Fig. 1, and the width of the drainage canal was reduced also. Thus, after 14 years, the mountain, far from having reached a state of rest, was still exerting its crushing effects. The lining in the main tunnel had been completed in 1901, and as the ground stood well, at this particular point, the minimum lining section had been provided, *i.e.*, an arch thickness of 13.7 in. and, as no lateral or upward pressure was anticipated, the side walls were made light and no masonry invert had been provided.

Thus, Prof. Heim's theory of "latent plasticity" had been demonstrated.

In Fig. 1 an attempt has been made to illustrate the occurrence of the disturbance referred to above. On account of the enormous pressure acting on the unlined parallel heading, shelling and crushing of the roof, sidewalls and floor took place. This loosening and disturbing action, on the surrounding strata, and especially of the material lying between the main tunnel and the parallel heading, rendered same unfit to resist the thrust of the material overlying the main tunnel. Thus, the overlying weight, originally limited within the line A-B-C (Fig. 1) was increased in magnitude and shifted over to A-B′-C′, thus subjecting the tunnel to eccentric pressure. Lateral pressure was then exerted on the side wall lining of the main bore, shifting it 18 in. out of place. The compression in the material adjacent to the side wall nearest to the pioneer bore, which originally could be represented by a-d-c-b (Fig. 2) was subsequently changed to d′-a′-b′-c′. The latter, representing a cross-section of Roger's Pass tunnel, now being driven through the Selkirk Range, in British Columbia, illustrates also the possibility for disturbances to take place in a bore, when the adjacent bore is left unlined. The tunnel system here consists of a main double track bore and a 7 x 8-ft. heading or pioneer bore driven some 31.5 feet from it.

On the assumption that the side walls are solid and capable of resisting the excess weight of the ground brought upon by tunnelling, the weight acting on the roof of the main bore (Fig. 2) can be represented by the parabola A-B-C. Through the process of tunnelling, it becomes evident that the weight or pressure w-x-y-z, acting upon the bore must be resisted by the side walls of the bore, and the intensity of the stresses in these can be illustrated by a-b-c-d, the maximum compression occurring at the side wall, and the minimum or normal, at a certain distance therefrom, at c-b for instance, where, other things being the same, c-b is equal to w-x. The location of B above the tunnel roof, that is, the load acting on the tunnel roof depends on: (1) the width of the bore; (2) the cohesion of the overlying material, and (3) the skill displayed in tunnelling. The wider the bore and the less the cohesion of the overlying material, the more will become the roof deflection, and the greater will be the disturbed zone. Also, the heavier the blasting, the more shattered will be the surrounding material. It is obvious that the same remark holds good also for the pioneer bore. Now, if the material lacks cohesion, in a crush zone, for instance, or if it possesses a low compressive strength, as for instance, soft sandstone or shale do, and if the overlying depth is large, the side walls will yield, crush, and the stresses will then become a maximum at a certain distance away from the side walls' face, at a′, for instance (Fig. 2). Also, if the material is well stratified, with layers of clay or other soft material, the pressure may become so intense as to squeeze out the soft material, thereby causing the strata to drop and break at right angle to the bedding planes, as shown in Fig. 2, on right-hand side of main bore. In a wet tunnel, water may also, in course of time, wash away the soft material and cause a similar effect.

If the materials penetrated are such as laminated clays, shales, schists, etc., which, when exposed to air, swell or disintegrate, the sides and roof will part, pull away from the adjacent material or strata in more or less concentric rings, and cause disturbance in the surrounding material, as shown. The time necessary for such disturbances to take place depends on the care exercised in