Possible Causes of the Overturning Movement.

There are several known stresses and other possible causes that would tend to open the cracks and overturn the mass of rock between the headrace and the gorge. These may be divided into the stresses and weaknesses created by the engineering works undertaken, geological factors, and earth-tremors.

Engineering Factors.—The engineering factors require little more than mention. They include the hydrostatic head on the penstock block, the headrace, and the overflow-channel; the weight of water in the penstock tunnels; the kinetic energy of the moving water; the vibration of the generators; and the weight of water in the headrace, and also the weight of the transformer-house. In addition, the blasting of the rock during the driving of the penstock tunnels, and the removal of the rock itself, no doubt weakened the mass. The excavation of over 100,000 yards of rock to provide room for the power-house and its extension is more important, as this mass formed a buttress supporting the moved block.

Geological Factors.—" Any excavation in the earth's crust sets up stresses in the contiguous rocks, because of the unbalanced pressures created by the substitution of atmospheric pressure for the greater pressure of the material excavated." The horizontal components of these stresses exert a pressure toward the excavation, in this case, toward the gorge, and would tend to open cracks sub-parallel with the gorge and with maximum deformation near the surface.

The floor of the old river-channel, followed by the headrace and the overflow channel, has now been largely stripped, by the moving water, of its cover of soil and forest debris that up till now almost entirely concealed the rock. A number of relatively straight cracks, some of them several chains long, obliquely cross the smooth gently hollowed rock floor of the old channel. The cracks are now sealed and as watertight as the somewhat altered rock they traverse. They are undoubtedly old and may have been formed in the manner suggested after the gorge was cut, a time which, as judged from the size of the trees growing in it, was at least several hundred years ago. One would expect cracks of this kind to gape more widely near the edge of the gorge than those farther back, and the cracks on the east side of the river above the dam may be cited. These are from 6 in. to 12 in. wide at the surface, but disappear at a depth of 40 ft. On the west or headrace side of the river the heavy cover of sands and gravels may conceal widely opened cracks, but there is no evidence of this. The crack that traverses the upper end of the headrace nowhere reaches an inch in width. The fracture that opened in the forebay on the 7th June closely resembles the cracks described above, and may have been produced in the same way.

The well-developed vertical joints of the great bulk of the rocks greatly reduces the tensile strength of the mass, and it is not improbable that the tensional stresses developed when the gorge was cut were not wholly dissipated during the many years it has existed. The residuum of these tensional stresses combined with similar stresses due to the power-house excavations may have been sufficient to rupture the rock.

Shortly after the crack formed, bubbles of gas were observed rising discontinuously at several points in the forebay. Later gas emanations were found on the floor of the forebay and headrace, and at one point gas was feebly rising to the 23rd June. The gas generally escaped from joint-planes near the crack, but some of the points of issue were some distance from it. The Dominion Analyst examined a sample and found it to consist chiefly of nitrogen, no oxygen being present. This gas may be interpreted as air so long imprisoned in the joint-planes, and pores of the rock mass, as to be completely deoxygenated. Its expulsion may be explained as being due to the slight contraction of the rock-mass as soon as the tensional stresses were relieved by the cracking of the rock.

Failure of Basal Rocks.—The tuffaceous indurated clays, banded sandstones, and breccias on which the power-house is built are undoubtedly the weakest rocks of the area, and their position at the toe of a deep excavation places on them the maximum crushing and gravity stresses due to the weight of the moved mass between the headrace and the gorge. The crushing-strength of these weak rocks, as determined by experiment, is not much more than sufficient to sustain the weight of the superincumbent mass. This critical area was carefully examined, but no sign of failure was observed. Possibly failure occurred below the river-level, but against this the block, after its maximum deformation, has moved back within a few days more than half way to its original position, a fact suggesting that the elasticity of the rock is not destroyed as it would be if failure and crushing had occurred. Had sand and grit not entered the crack in considerable amount the fissure would probably have closed entirely. Again the available data on the correlation of the strengths of rocks in small blocks, and in mass, indicate clearly that as the area under load is increased the load per unit area may also be much increased without crushing. It must, however, be pointed out that most of the investigations on the strengths and elasticities of rocks have described the properties of rocks much harder and denser than are the tuffs and breccias of Arapuni, and possibly the results of these studies are not altogether applicable. When, however, it is also considered that the weak rocks at the power-house have not failed during the hundreds of years the gorge has existed, it appears unlikely that the deformation is due to rock failure and crushing at this point.

Hydrostatic Head of Water in Rocks.—The rocks of the headrace, forebay, and overflow-channel, though porous, do not readily permit the passage of water. Small pools on their surface remain till the water evaporates, and the penstock tunnels driven as much as two years after the headrace was filled, were dry. There is, of course, some slow percolation and the base of the columnar rhyolite tuff exposed in the cliff above the power-house became slightly damper after the headrace filled. Assuming that the partings in the columnar tuff, though too small to allow the flow of water, were yet large enough efficiently to transmit the pressure due to hydrostatic head, this pressure must have been fully operative for over two years. The same applies to the underlying pumice breccia which floors the whole of the headrace from a point a few chains above the spillway.