## NOTES ON TRANSMISSION LINE CONSTRUCTION.

In our issue of July 8th a description appeared of the types of transmission line tower foundations used by the Toronto Power Company on its Niagara-Toronto line. The following notes relate to the general subject of line construction. It is shown conclusively that the weakest link of any transmission system is the line and that this part of the system has never been given adequate consideration. The author, Mr. P. M. Downing, strongly advocates the use of towers for important trunk lines and recommends the use of concrete footings in preference to those of metal set directly in the ground. The paper from which the following notes are abstracted was presented by Mr. Downing at the annual convention in June of the American Institute of Electrical Engineers.

The use of wooden poles in connection with high-voltage transmission lines, especially important trunk lines, is fast being superseded by steel towers. The wonderful growth of the electrical industry during the past few years has resulted in the construction of larger generating stations, and the transmission lines carrying these heavier loads have become of correspondingly greater importance.

During all of this time, except for a noticeable increase in the sizes of the units used, there has not been any radical change in the equipment of hydro-electric generating stations. The same general types of turbines and impulse wheels as were used fifteen or twenty years ago, during the infancy of the industry, are still being used. Slight modifications in the design of the generators, the use of the better material now available, and higher speeds have resulted in larger units and increased efficiencies. Transformers have kept pace with the generators and water-wheels, both as regards size and efficiency, but have never been in any respect the limiting feature in high-voltage transmission work.

The line is and has always been the weakest link of the entire system, and it is only during the last few years that this part of the work has received the attention it deserves. Wooden pole lines with pin type insulators were for many years used almost exclusively, regardless of the voltage, or the importance of the line; in fact, it was not until 1903 that the first commercial tower line in America was constructed by the Guanajuato Power Co., in Mexico. The first line using towers with suspension insulators was the 140-mile 100,000-volt line of the Stanislaus Power Company in California (now the Sierra and San Francisco Power Company).

The tower designs first constructed called for each structure to be self-supporting under strains due to the breakage of all conductors on one side of the tower together with maximum ice and wind strains. This resulted in a heavy, durable structure of high first cost, and imposed a very much more severe condition than could be met by pole lines.

Little attention had ever been given to the determination of the strength of wood poles, either by calculation or actual test, and there is no doubt but that such strength requirements in line towers was unreasonable. Subsequent experience has shown that the average tower is too complicated a structure to accurately calculate the stresses in the different members, and it is now generally conceded that the best and only safe way to get reliable information as to the stability of a tower is to subject it to actual test.

A very safe condition under which to test towers to be used in a country not subject to severe snow and sleet conditions, is to consider a wind pressure of 14¼ lb. per sq. ft. on flat surfaces, combined with a temperature range of 125 deg. F., or a pressure of 21 lb. per sq. ft. on flat surfaces under ordinary temperatures; also two broken wires in any span of a circuit carrying six wires. These breakages to be in such positions on the tower as will give maximum strain. The height of the tower will depend on the spacing and the required clearance of the conductor above the ground. Considerable difference of opinion exists as to the most economical length of span that can be used. These range from 400 to 1,200 ft., depending to a considerable extent on the character of the country, the climatic conditions and the voltage of the line.

Where the line is subject to heavy snow and sleet conditions, the spans must be short, and very often under such conditions it is inadvisable to place the three conductors in a vertical plane. A very much better and safer construction can be had by using single circuit towers with the conductors in a horizontal plane. Under these conditions any unequal distribution of the snow load on the different conductors will not cause them to come in contact with each other. On 100,000-volt lines carrying two circuits of three wires each, located in vertical planes on the two sides of the tower, a spacing of 800 to 1,000 ft. will generally be found to give maximum economy.

Tower foundations depend largely on the character of the soil in which they are located. In heavy ground a metal footing having sufficient resistance against up-lift may be used, but they are not to be recommended. The permissible strains borne by well tamped dry earth do not always obtain under water-soaked flood conditions. Where metal footings without concrete have been used, too often they have been found inadequate and resulted in the ultimate failure of the tower. Under no circumstances, except on very short towers, should single post footings be used. Two or three posts give a much more rigid and substantial construction, but materially increase the first cost of the structure; in fact, for the same factor of safety, it is very doubtful whether under any normal conditions the difference in first cost between the metal and concrete footings will be great enough to justify a decision in favor of the metal.

On a number of different lines originally constructed with all metal footings, tower failures have occurred, and it has since been found necessary to reinforce them with concrete.

On the basis of an 800-ft. spacing between towers, and an allowable stress of 15,500 lb. per sq. in. for copper conductors, the sag at 60 deg. F. would be approximately 20 ft. On a double-circuit tower line, having conductors strung to this tension and spaced 10 ft. apart, with a required clearance of 30 ft. above the ground, a 75 to 80-ft. tower would have to be used. The footings of a tower of this height under the assumed load conditions should contain not less than 1¼ cu. yds. of concrete per leg. On the basis of concrete weighing 140 lbs. per cu. ft., earth 110 lb. per cu. ft., and assuming the angle of cleavage of the earth as 30 deg. from the vertical, a footing of this kind would have a factor of safety of approximately two.

In pouring the concrete in a footing of this kind, the bottom pan-cake is placed without a form, and allowed to set just long enough to support a metal form for the upper portion.

To insure against weakness due to possible poor bonding along the plane of contact between the upper and lower portions of concrete, it is advisable to use short