perature, if proper precautions are taken. It should be noted, however, that it is quite easy to over-heat the finished concrete and to drive out a portion of the water.

In the St. Louis work, it has been customary to heat the water by turning exhaust steam into the water tank whenever the temperature goes below 40 degrees or whenever there is frost in the materials. In colder weather, steam coils are used in the sand storage piles and often in the piles of coarse aggregate. It is also customary in freezing weather to place salamanders inside the arches and to hang tarpaulins at each end of the unit constructed. The top of the sewer has generally been protected by a covering of tarpaulin or plank, on top of which manure is piled.

The loads to be considered are: First, direct weight of the earth filling; second, horizontal or inclined pressures induced by the weight of this filling and the adjoining earth; third, pressures due to transmitted surface loads.

The relative values of these pressures will depend on the depth and size of the sewer and on the use to which the ground surface may be put.

Vertical Loads.—It is always safe and usually reasonable to design for vertical loads equal to the full weight of the superimposed earth. Recent investigations of small sewers and pipes have shown that, due to some arching action of the earth itself, the full dead weight is not always applied to the sewer. The allowable reduction, however, seems to be of little importance until the depth of the fill is at least equal to the width of the trench and would only amount to about 25 per cent. when this depth is twice the width. The work of Marston and Anderson indicates that for depths of 10 to 15 times the width, only 30 to 40 per cent. of the load is carried by the sewer. For a sewer more than 8 feet in width, the depth of cover will rarely exceed twice the trench width, so that the reductions are hardly worth taking into account. There must also be reasonable doubt whether the gradual settlement does not finally increase the weight on the sewers considerably above the values given.

Horizontal Pressure.—There is so much doubt as to the correct values of horizontal pressures even for a given soil condition, and the pressures will vary so greatly in the different soils that the designer can only attempt to make a safe guess at the correct amounts to be used.

According to Rankin's theory, the intensity of horizontal pressure cannot be less than one-third of the intensity of vertical pressure for a particular depth and in ordinary clay it is customary to consider it as one-half of the vertical. For saturated ground, the earth will approach the condition of a fluid and the horizontal and vertical pressures would be equal.

Surface Loads.—Where sewers are constructed in city streets, the heaviest surface load would be the weight of a road roller, and this might be taken as 15 tons on an area of 5 square feet, at the surface, distributed downward along an angle of 30 degrees with a vertical. At a depth of 10 feet this would approximately be equal to 200 pounds per square foot on an area of 11 x 15 feet, or roughly equivalent to an additional 2 feet of fill. If there are railroads crossing the line of the sewer, or if it seems at all possible that such roads may be built, the sewer should be designed for locomotive loading in the same way. A fair value for this loading would be 80 tons on an area of 10 x 20 feet at the surface. Distributed as above, this would be equivalent to about 300 pounds per square foot over an area of 20 x 30 feet, at a 10-foot depth and would give the same pressure as 3 feet of additional fill.

For very light covers, these values would, of course, be increased, and it might even be reasonable to provide for impact, but for depths of cover for 6 feet, or more, it is usually satisfactory to treat such loads as additional weight of earth and allow them to increase both the vertical and the horizontal pressures. Allowance for foundations and for piles of material may be handled in the same manner.

Combination of Loading.—For final conditions, that is, after the backfill has reached a state of settled equilibrium, the sewer will be subject to a direct combination of horizontal and vertical pressures. It should be noted that the greatest bending moments in the arch will be due to vertical loads alone. Horizontal pressures usually induce moments of the opposite kind. The combination of vertical and horizontal pressures, therefore, while increasing the direct normal compression in the arch, will give smaller bending moments than those from the vertical loads. While the stress in the arch may finally reach the values derived from a proper combination of the two classes of forces, yet it is quite common for the sewer to be subject only to pressure of one kind during the construction period. Examples of this are as follows:

(*a*) A trench is excavated through hard clay which requires little bracing and will stand vertically for some time. The trench is backfilled with the same material. Then the full weight of the backfill may act vertically on the arch for some time before the sides of the trench finally slip and add also a horizontal pressure.

(*b*) In the example above, the sides of the trench may slip in against the sewer before the backfill is placed, producing heavy horizontal pressure and bending moments of reverse character.

(*c*) A trench through soft ground is held by sheet piling. When this piling is pulled there may be an appreciable time before the earth at the sides closes in and fills the void left by the piling. During this time the vertical loads only will act.

(*d*) In the above example, if the sheet piling is drawn before the backfilling is started, the earth at the sides may move in and produce horizontal pressure with very little vertical load.

Loads of these kinds will only occur while the arch is new, possibly before the concrete has attained more than half of its normal strength. If the design contains a factor of safety of four for combination of pressures, and the concrete is only 10 or 15 days old, the arch would be about on the point of failure for vertical loads.

It would seem, therefore, that the design should provide for vertical loads alone, or at least in combination with a very small horizontal pressure on the arch only (not against vertical side walls). This loading will be critical and from it the dimensions of the concrete and one set of reinforcements will be determined. The arch so determined should then be designed for horizontal pressure in combination with as little vertical loads as may seem possible. From this the reverse reinforcement may be calculated. Finally, it is of interest to compute the stresses under normal combination of the two.

The simplest case of arch design occurs when the sewer is built in a rock cut. In this instance, that portion above the rock may be taken as an arch with fixed ends, provided that the reinforcement extends well below the rock level. Where the sewer rests on rock or other incompressible material, the arch may still be treated as fixed, if sufficient mass is given to the invert to resist the overturning moment in the side walls.