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# Protection of Soil From Erosion by Swiftly Flowing Water

C. J. Posey
*State University of Iowa*

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C. J. POSEY[1]

*Abstract.* Changing direction of flow in a watercourse is accompanied by non-hydrostatic pressure distribution, fixed in location where the curvature is steady, and constantly shifting in location and magnitude when the deviations are dueto turbulence. The response of the subflow in the boundary soil, from high pressure areas to low pressure areas, is practically instantaneous. Erosion (or rupture of waterproof linings) is most likely to occur at the low pressure areas, where the direction of flow is from the soil into the watercourse. Terzaghi's reverse filter can be used to prevent removal of soil as long as the topmost layers of the filter remain stable. This is achieved by using the ancient Chinese rock snake or sausage. The economy and practicality of the method for new and old erosion problems are under continuing investigation, as illustrated by a 16 mm silent motion picture prepared by the author.

Water flowing in an open channel at any depth greater than a few inches is almost certain to be turbulent flow. This means that the pressure on the bottom and sides of the channel is fluctuating, and not steady, as it would be if the flow were laminar. Where the channel is prismatic, that is, with uniform cross-section and straight alignment, these fluctuations are transitory, and are random in location and magnitude, but they have a mean value at any fixed point on the boundary that is very close to the hydrostatic pressure value.

Where the walls or bottom change direction, or where an obstacle such as a bridge pier is introduced into the flow, the pressure fluctuations due to turbulence are superimposed upon a mean value which may differ considerably from the hydrostatic. Wilson measured wall pressures below the free surface that were not only below hydrostatic, but actually below atmospheric (Wilson, 1940).

[1] Department of Civil Engineering, State University of Iowa, Iowa City, Iowa.

We have, therefore, to consider two components of non-hydrostatic wall-pressure variations, which may act separately or together.

(1) Transitory, due to turbulence

(2) Fixed, due to changes in direction of the main stream.

Note that the magnitude of the first depends upon the intensity of turbulence, while the second (which can act alone only in the case of laminar flow) depends upon the velocity.

If, in protecting against erosion, the channel is lined with a relatively impervious membrane, the membrane must be strong enough to resist the greatest pressure differentials that can act across it. For very low velocities, the impervious lining need have little strength, but if the velocity can become high the lining must have considerable structural strength if it is to resist failure.

## Underflow

When the walls are pervious, the variations from hydrostatic pressure distribution induce flow through the pervious medium. The flow is in toward the stream at the points where the pressure is low. Inasmuch as ground water flow in saturated soil responds to pressure fluctuations with a speed comparable (if not actually equal) to the velocity of sound in water, the subflow easily follows the most rapid fluctuations due to turbulence.

At points on the bottom or walls where the pressure is less than hydrostatic, ground-water flow returns to the stream, and if its velocity is high enough, erosion will occur. Now it so happens that specifications for the grading of protective layers of coarse material that will prevent these flows from removing any soil were proposed by Terzaghi and were the subject of extensive experiments at the U. S. Waterways Experiment Station at Vicksburg, Mississippi (Terzaghi, et al., 1948; U. S. Waterways Experiment Station, 1941, 1948). Such protective layers, called inverted filters, are often essential to insure the safety of dams, and it is in this connection that the Vicksburg tests were made. In application to erosion-proofing, it is evident that the successive layers, each protecting the finer material below, must be carried up to a size large enough to resist being washed away. In many locations the size required would be too large to obtain or handle. The necessary resistance can be obtained by covering the top layer with rock "snakes" or "sausages," a device used by the Chinese for many centuries.

## Rock Sausages

Tests show that when rock sausages are used without the Terzaghi-Vicksburg foundation, failure will occur, though very slowly (Chu, 1961). With the proper foundation, they will apparently stand indefinitely, as far as we have been able to determine by model tests. The Terzaghi-Vicksburg protective layers used alone resist erosion about as well as uniform material of the same size as the largest 15 per cent of the topmost layer. If placed on steep slopes (approaching 1 to 3) the sausages are necessary for depths of overflow approaching the size of the rock itself.

Several series of tests have been undertaken to determine the limiting head that a rock sausage installation with underlayers meeting the Terzaghi-Vicksburg specifications will withstand. Each time, the limitations of the apparatus prevented a failure head from being reached. In one series, the diameter of the sausages was reduced until it was only 0.05 ft., but a long run with a head of 0.7 ft. on the crest produced no sign of failure (Chu, op. cit.). A larger -scale run had a head of 2.5 feet or more for hours, as many as the water supply permitted, without sign of failure (Posey, 1957).

During one of the tests, a leak developed in the apparatus, and part of the fine sand being protected was carried out the bottom. The protective layers and rock sausages settled down, closing the cavity without any sign of loss of protective capacity (Chu, op. cit.). This kind of occurrence would surely result in the failure of a rigid impervious protective layer.

## Future Development and Investigation

Although the large-scale model tests made show that sausages with proper protective layers are adequate for many situations, the question of the upper limit that can be withstood remains for future experimentation. Much remains to be done, too, in developing economical means of constructing and placing the sausages. Galvanized No. 9 wire will apparently last about 20 years, while the same strength of stainless steel, which would last indefinitely, costs 2½ times as much. But the principal cost is in making and placing the sausages. These operations must be mechanized if the method is to gain wide usage in this country.

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