REVIEW OF SEWER SURCHARGING PHENOMENA AND MODELS

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Large variations in inflows into and outflows from sewerage systems means that flow conditions in these systems vary from dry flow, to open channel flow, to partly open channel partly pressurized flow, to fully pressurized flow. Transitions from one flow regime to another are governed by flow instabilities. The seminal articles by Yen (1978) and (1986) classified the flow instabilities in a sewer pipe into the following five types: (1) 1. Dry Bed Instability; (2) Supercritical-Subcritical Instability; (3) Roll Wave Instability; (4) Open Channel-Pressurized Flow Instability; and (5) Fully Pressurized Flow Instability.

Yen (1986, pg. 283) wrote “None of these instabilities has been investigated in detail for unsteady flows, and perhaps except the second type instability they are not very well under- stood by most engineers.” Unfortunately, and by and large, this remark is as valid today as it was then. While a few research attempts illuminated some of the features of these instabilities, this has not yet provided sufficient understanding to guide the development of new mathematical models. The major revolutions in sewer modeling in the last decade are (i) in the speed by which these models can now be executed, allowing users to test numerous flow scenarios, (ii) in the incorporation of powerful graphics packages, allowing users to develop better intuition through the use of animation, and (iii) in the development of user friendly interfaces, making it easier to use such models.

While flow details in a roller (a subcritical-supercritical instability) are not important for the computations of water level and flow rate in sewers and channels, the subcritical-supercritical instability is highly relevant to sewer surcharging. It is possible that this instability can induce water depths higher than the roof of the sewer, causing the transition to closed conduit flow. In addition, it also possible that this instability triggers the open channel-pressurized flow instability even when the jump height is lower the sewer crown. It is important to point out that the conceptualization of a roller by a discontinuity poses theoretical and numerical problems. Indeed, the differential form of the shallow water equations is invalid at the discontinuity, as the concept of derivatives simply fails at a jump. On the other hand, the integral form of the open channel flow equations across the discontinuity is valid since one can integrate a discontinuous function. Indeed, the integral form (also called the weak solution) gives the so-called shock conditions, which simply represent mass and momentum conservation across a jump. The validity of the integral form of the solution at the jump favors the use of Finite Volume (FV) schemes.

There are a number of mechanisms that lead to the transition from open channel to pressurized flow in a sewer, including: (1) the rapid increase of water depth following a sudden change at the boundaries of the sewer lines; (2) the Helmholtz instability that occurs in regions inside the sewer where there is large difference between the speed of the air layer and the speed of the water layer; and (3) the geometrical instability, which is due to the fact that the maximum steady surface flow in a converging sewer occurs at a water depth below the crown.

Single phase models study the behavior of the water, but totally ignore the air phase and its interaction with the water flow. As a result, such models are not applicable to flows in which the Helmholtz instability occurs and to problems with poor air ventilation. Single phase models are expected to be reasonable only when there is an unrestricted air supply into and out of the system and when the velocity is not large enough to produce any flow instability.

Single phase models can be subdivided into models which use the Preissman slot theory and models which use the open channel-closed conduit theory.

The open channel-shock-rigid column model and the open channel-shock-waterhammer model model use the Saint-Venant equation for the open channel part, a shock condition at the interface between the open channel and the pressurized flow, and the rigid or elastic waterhammer theory, respectively, for the surcharged part.

Two-phase models account for both the water and air phases, modeling pressurized water phase using the rigid waterhammer (column) theory and the water phase in the open channel part as one dimensional uniform unsteady flow. Once the relative velocity between air and water becomes large enough that the critical stability condition is exceeded, the models assume that air gets trapped in a air bubble between two surcharged water columns and an open channel column underneath it.

The transition from one flow behavior to another is governed by flow instabilities. Therefore, stability theory can play a significant role in understanding the transition mechanisms and to establish transitional boundaries from one flow behavior to another. These transitional boundaries are essential for ensuring that a model incorporates the essential physics needed to describe a particular flow regime. It would be highly desirable to apply the stability theory to the same conditions as the experiments and see how well do they agree.

Numerical models for sewer surcharging problems need to be developed with the view of handling shock waves, roll waves, expansion waves, interfaces and instabilities. Finite Volume approaches have been successfully applied in other fields such as gas dynamics and multiphase flows which involve similar features as the ones that occur in sewers. These schemes are also inherently conservative, ensuring that mass and momentum are not artificially created or destroyed. Such schemes need to be considered for sewer problems.

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