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SAFETY DESIGN FOR STORM WATER RETENTION AND DETENTION

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Abstract

Safety of detention and retention basins is an increasing major concern in urban areas. This paper analyzes the flow condition similar to a case of a boy and his dog being sucked into a pipe reported in Rocky Mountain News (July 2004). During the storm event in this case, the unseen subsurface current was the hazard. As soon as the outfall pipe becomes plugged, the acting force quickly switches from the flow dynamic to water-weight static force. The case study indicates that the hydrostatic force of 3-ft water acting on a 24-inch plugged pipe can be so lethal that the removal of a body from the pipe opening is virtually impossible. Comparison of flow momentum forces between with and without a trash rack reveals that a trash rack can significantly improve the safety of a detention basin and prevent loss of life resulting from getting impinged onto and then stuck to the outfall pipes.

INTRODUCTION

Storm water detention has become widely accepted methods in urbanized areas for runoff quality and quantity control. In an urbanized catchment, the man-made network of sewers and channels collects a huge quantity of urban debris and directs it quickly and efficiently into the stormwater detention facilities. The increased quantity of organic matter creates problems for the health of the waterways and destroys food chain or habitat for flora and fauna on floodplains (FHA 1996). The effective strategy to reduce the concentrations of debris, sediment and nutrients in a receiving water body is to install trash racks (Atlanta 2001, California 2003, Idaho 2005).

Trash racks are designed to trap the larger gross pollutants in stormwater. As recommended, all culverts and outlet pipes must be protected by trash racks (Denver 1999, Washington 2001). In addition to serving our best interests in debris control, trash rack is in deed a life saver for small domestic animals and children because a pool of water is always a fascination, even a magnet, to them. An urbanized catchment is hydrologically categorized as small watershed that responds to rainfall quickly with a sharp rise in flow rates and volumes. Often, basin outlet pipes are open and unprotected with trash/safety racks or inflow and outflow pipes are too close to avoid short-circuiting the flow currents. When inflow and outflow pipes in a basin are inundated during a runoff event, the turbulent currents in the pool may not create a disturbance on the water surface, but the subsurface vortices and wakes do form an unseen hazard (Jones et. al 2005). In July 2004, Rocky Mountain News in City of Denver, Colorado reported that an 8-year old boy and his dog played in a pond of 3-ft water. Both were dragged into the 24-inch unprotected pipe and then flushed through the dark tunnel of 40 feet. Many appalling such and even worse cases have continuously raised public concerns about the safety around retention and detention ponds.

Many recommendations on storm water pond designs were triggered by maintenance, esthetics, bank stability, and safe accessibility. This paper presents an investigation on the water flow forces during an event in a detention basin. The main purposes of this study are: (1) to formulate the suction forces due to the water currents in the basin, (2) to identify the critical condition for loss of life, and (3) to compare the force difference with and without a trash rack.

MOMENTUM FORCE IN BASIN

In an urban area, most neighboring detention basins are local, small, and off-stream from a major stream. A storm water detention basin is shaped to cope with multiple events (Guo and Urbonas 2002, Guo 2004). The typical layout of a local basin is illustrated in Figure 1. During an event, the inflow pipe issues a turbulent jet into the basin. The jet flow carries a potential core for a distance of seven times of the pipe diameter and then it begins to decay in strength and gradually diffuses into the pool of water (Albertson et al. 1950, Guo and Maxwell 1984b, Daily and Harleman 1966). Depending on the pool geometry, the jet flow can create a circulation in the middle of the water body, and wake zones at the upstream corners. Of course, the energy dissipator always accelerates the decay of jet flow and creates a uniform flow into the pool.

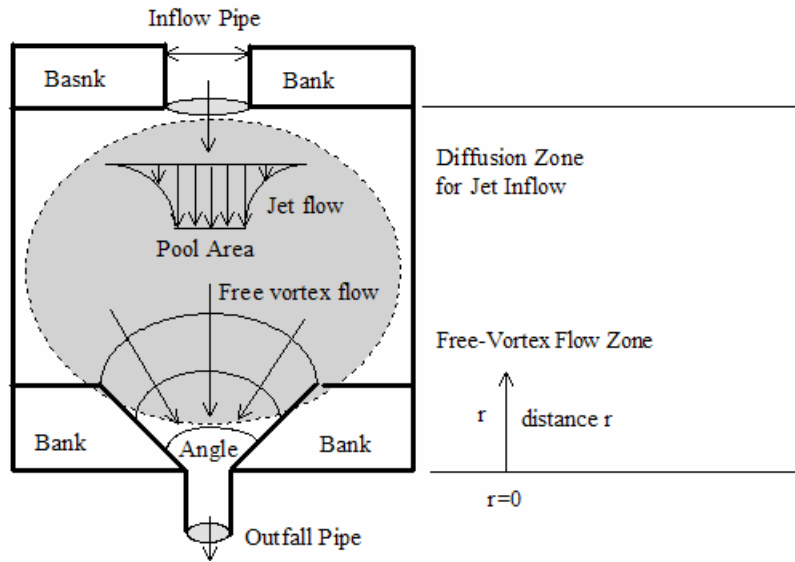


Figure 1. Layout of Detention Basin

Upstream of the outlet, a free vortex flow is formed to radially concentrate water flows toward the outfall entrance (Finnemore and Franzini 2001). Considering that the flow depth is uniform, the radial velocity of the free vortex flow is described as:

$$U_v = \frac{Q_o}{2\theta ry} \quad (1)$$

In which U_v = radial velocity of free vortex, Q_o = outflow rate, r = radial distance from the entrance of outfall pipe, θ = flare wall angle of entrance, and y = flow depth. The momentum force associated with the free vortex flow is:

$$F_v = \rho Q_o U_v \quad (2)$$

in which F_v = vortex flow force, and ρ = water density. In a small basin, the momentum of the jet flow presents the impinging force that may tip over a movable vertical object, and the free vortex flow presents the suction force that may draw and drag an object (Guo and Maxwell 1984b). At the entrance of the outfall pipe, the free vortex flow changes to a forced vortex due to the friction and viscous effects. A forced vortex creates a downward drag as a result of the low pressure and high velocity in the outfall pipe. In case that the outfall pipe is protected by a trash rack, Eq 2 is a

simple model that describes the dominating flow momentum immediately upstream of the trash rack.

TRASH RACK EFFECT

As illustrated in Figure 2, a trash rack is installed in front of the outfall pipe to intercept debris. The surface area of a trash rack is recommended to be 4 times of the opening area of the outfall pipe (WEF 1992). A large trash rack is installed to lean against the walls with a drop inlet on the top to collect high flows. Of course, a small trash rack may be installed vertically (Maryland 2000).

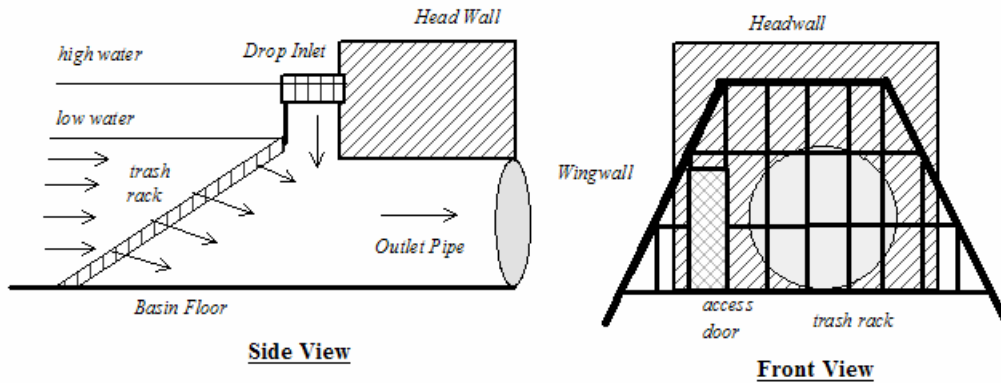


Figure 2 Trash Rack Installed in Front of Outfall Pipe

The surface area of a trash rack is recommended to be large enough to maintain the flow continuity through the rack while debris is being captured and accumulated on the surface of water. As long as the flowing process remains aerated, the dynamic nature of the flow can be sustained by the rack. Illustrated in Figure 3, when a block is being washed against the trash rack, the force acting on the block is

$$F_D = \rho Q_0 \Delta U = \rho Q_o (U_v - U_r) \quad (3)$$

in which F_D = force in the flow direction acting on the block on trash rack, ΔU = change of flow velocity, and U_r = flow velocity through trash rack, depending on the area opening ratio of trash rack. As long as the trash rack maintains the flowing process, it is concluded that $U_r > 0$. Aided by Eq 2, Eq 3 has its limitation as:

$$F_D < F_v \quad (4)$$

Aided by Eq's 1 and 2, Eq 4 yields:

$$F_D < \rho \frac{Q_o^2}{2\theta r y} \quad (5)$$

The force to remove the block along the trash rack surface is:

$$F_F = v F_D \sin \theta \quad (6)$$

in which F_F = friction force, ν = friction coefficient, and α = inclined angle of rack. Aided by Eq 4, Eq 6 becomes:

$$F_F < \nu F_V \sin \alpha \quad (7)$$

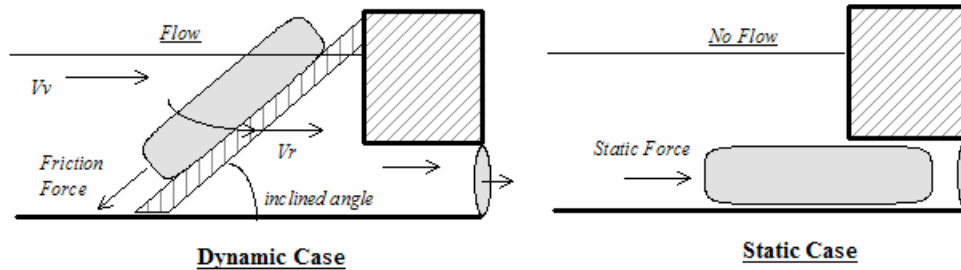


Figure3 Plugging Conditions With and Without Trash Rack

Without a trash rack, a block can be washed into the outfall pipe. As soon as the outfall pipe is getting plugged, the flow velocity vanishes and the dynamic force will switch to its hydrostatic force as:

$$F_s = \gamma \bar{y} A \quad (8)$$

in which F_s = static force, γ = specific weight of water, \bar{y} = centroid of pipe opening area, and A = pipe opening area. When the circular outfall pipe is laid on the floor of the basin, its centroid from the surface of water is:

$$\bar{y} = y - \frac{D}{2} \quad (9)$$

In comparison, the hydrostatic force is much higher than its dynamic force and creates a hammer effect to continuously push the block into the pipe. The block may or may not be flushed through the pipe, depending on pipe length and friction forces along the pipe walls.

CASE STUDY

The flow condition in the basin is depicted in Figure 4. The jet flow from the 42-inch (106.7 mm) incoming pipe is assumed to be dissipated into the water pool. During the event, the water depth five feet (1.52 meter) upstream of the outfall pipe is four feet (1.21 meter). The corresponding out-flow is 30 cubic feet per second (1.11 cubic meter/second) for this case.

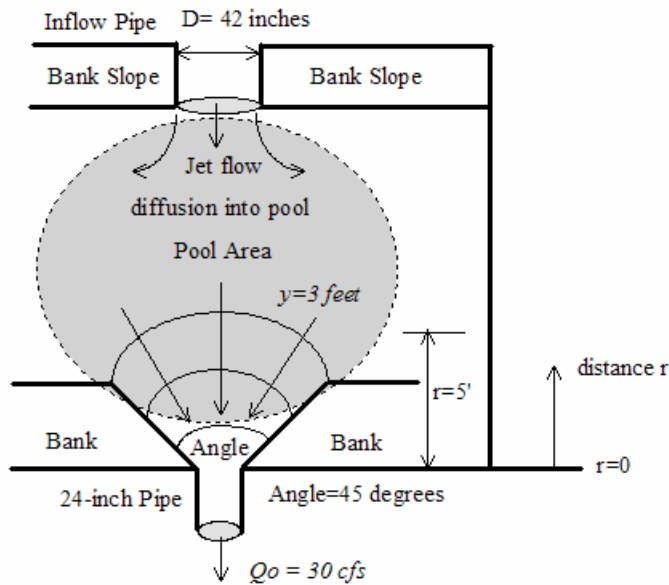


Figure 4 Flows in Example Basin

For this case, $\theta = \pi/4$, $\rho = 1.94$ slugs/cubic foot, and $Q = 30$ cfs. The momentum force associated with the free vortex flow is calculated by Eq 2 as:

$$F_v = 1.94 \frac{30^2}{2 * \frac{3.14}{4} * 5 * 3} = 74 \text{ pounds (33.6 kg)}$$

Consider the friction coefficient of 0.5 and the inclined angle of 60° for the trash rack. In case that a block is washed against the trash rack, the friction force applied to the block along the trash rack surface is estimated as:

$$F_F < 0.5 F_v \sin 60^\circ$$

Or $F_F < 24.2$ pounds (11 kg)

In case that the outfall pipe becomes plugged, the hydrostatic force is calculated as:

$$\bar{y} = 3 - \frac{2}{2} = 2 \text{ feet}$$

$$A = 3.14 \text{ sq feet}$$

$$F_S = 62.4 * 2 * 3.1416 = 392 \text{ pounds (178 kg)}$$

In comparison, the friction force (<24.2 pounds) is not as deadly as the hydrostatic force of 392 pounds. As soon as the flow changes from its dynamic condition to a hydrostatic condition, the increase of force is 16 times for this case. This example explains why an open, unprotected outfall pipe is unsafe. During a storm water loading process in a basin, it takes almost no time for an unprotected outfall pipe to change from being clogged to plugged. When a child is trapped into the outfall pipe, such a momentary change in flow condition does not give enough warning before the situation enters into a fatal condition of no return.

CONCLUSION

From the aspects of aesthetics and maintenance, safety criterion recommended for retention and detention pond designs emphasize the allowable water depth, stable bank slopes, fence, and guard rails (Mays 2001). Trash rack is often considered for debris control only. In fact, a trash rack is the most economic measure to protect the outfall pipe from debris clogging and also to sustain a continuous flow through the outfall pipe. Obviously, an inclined trash rack provides assistance for a child or animal to climb up. A vertical trash rack prevents a child from plugging the pipe opening. It is imperative that the outfall opening remains unclogged. Once the outflow pipe is getting plugged, the acting force quickly switches from the dynamic to hydrostatic force. Case study indicates that the hydrostatic force of 3-foot water on a 24-inch clogged pipe can be lethal.

In comparison, the friction force along an inclined trash rack surface is 5 to 10 percent of the hydrostatic force. When a child was dragged by the currents into the pipe opening, the water flow would quickly slow down and the hydrostatic force of several hundred pounds would be immediately developed to continuously hammer the body into the pipe. Therefore, it is advisable to install a trash rack on any outfall pipes because it is a life saver.

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APPENDIX II

A = pipe opening area

F_v = vortex flow force

F_F = friction force

F_D = force in the flow direction acting on the block on trash rack,

F_S = static force

Q_o = outflow rate

r = radial distance from the entrance of outfall pipe,

ΔU = change of flow velocity

U_v = radial velocity of free vortex

U_r = flow velocity through trash rack

y = flow depth

\bar{y} = centroid of pipe opening area

α = inclined angle of rack

ρ = water density

γ = specific weight of water

θ = flare wall angle of entrance,

ν = friction coefficient,

.

