

Aspect and necessity of hydraulic transient analysis in water distribution system in Dhaka

A.Hassan, R.Chowdhury & D.M. Khan
Institute of Water Modelling, Dhaka, Bangladesh

ABSTRACT: Hydraulic transient events cause abrupt disturbance in the equilibrium state of pressurized water distribution system. They are initiated when a sudden operational breakdown happens like pump shut-off, rapid valve closing and opening etc. And they cause evolution and propagation of intense pressure waves. As a result, these events can lead to water column separation by producing significant negative pressure waves, which may cause catastrophic pipe failure and other problems. Therefore transient protection devices should be installed in the system to prevent any accidental or unintentional transient. Surge analysis helps us to identify possibility of transient and to design protection equipments. In context of Dhaka, frequent pump shut-off can be quite serious threat to the stability of newly installed network, if adequate protection measures are not taken. This paper provides a basic understanding of transient event, causes and consequences, major parameters, and suitable protection measures in context of Dhaka.

1 INTRODUCTION

For development of a sustainable infrastructure for a complex megacity like Dhaka, one of the most essential requirements is the proper utilization of operation and maintenance in potable water distribution system. The existing water supply and distribution system is mainly groundwater based with a combination of very complex pipe network and a huge amount of production tube wells. In addition, there are quite a number of control devices (like gate valves, air valves, non-return valves etc) for operation of pumping and flow. All these components require appropriate design and efficient synchronization in their operation for a hydraulically sound water management.

Traditionally a pressurized water distribution system is planned and designed based on some steady state assumptions and conditions in order to deliver water in adequate quantity, of acceptable quality and at sufficient pressure to the consumer. And this approach often facilitates the system in real field to experience the hydraulic behavior as expected too, as long as steady condition is maintained. But if the system experiences any single unsteady event at any moment, whole system behavior may become unbalanced instantly. Normally, these events do not exist in the network and are generated mostly in case of some sudden operational disorder of control devices within the system. For example, one of the most common operational disturbances is power failure. And these disturbances initiate abrupt unsteady condition in pressure-flow state which gives rise to hydraulic transients. Transients consist of pressure waves that very quickly move through the system. These would be of little interest if the transient waves were small and inconsequential. However, in certain situations, transients can have catastrophic consequences. Excessive pressure surge can be produced in the water mains. Therefore the network elements should have adequate capacity to withstand those transient forces. And for this reason, it is very important to analyze possibility, extent and consequences of transient events extensively in design of water distribution system; and appropriate protective measures should be taken in operation.

The network pattern of Dhaka is very complex. It comprises both grid and branch system and very densely oriented. Over five hundred production tube wells are being operated to supply and distribute potable water. Unfortunately their production is insufficient compared to actual total demand of the city. Moreover those

pumps cannot maintain the system completely pressurized due to presence of huge amount of leakage. Sometimes people have to use suction pump to draw water from distribution lines.

Within this complex network, as control devices, there are mainly three types of valve like isolation valve, non return valve and air release valve. All these control components are basically operated to regulate the flow and maintenance work. But in practice, there is no comprehensive hydraulic basis for their design and operation here. In addition, the network does not have any technically sound surge protection devices. The whole system is manually operated and its performance is completely dependent on skill and experience of the operator.

This paper aims to investigate possible transient events in context of water distribution network system of Dhaka. But before that, a clear conception about physical behavior and mechanism of transient event is necessary. With that, actual hydraulic and operational behaviors of pipe network need to be understood. In this study, detail features of the types of transient events which are (or can be) most critical, major parameters affecting them, their causes and consequences and suitable protective measures against them would be explained. And this paper will cover only those transient phenomena which are relevant to Dhaka. In addition, based on some simplified assumptions, the paper will outline most common transient event i.e. pump shut-off that occurs frequently in Dhaka, for a selected region, performing software based hydraulic transient modeling analysis.

2 HYDRAULIC TRANSIENTS: CAUSES AND CHARACTERISTICS

Usually system flow control operations are performed as part of the routine operation of a water distribution system. Examples of system flow control operations include opening and closing valves, starting and stopping pumps, and discharging water in response to fire emergencies. These operations cause hydraulic transient phenomena, especially if they are performed too quickly. However, some unintentional events can also initiate transient situation like sudden power failure, pipeline breakage etc.

Among all the common transient events in pressurized system, pump shut-off appears to be most critical. And this event occurs when the energy supply is interrupted suddenly (i.e. power failure). The non-return valve associated with valve is closed almost instantly. By the same time, a negative pressure wave is developed in the conduit near to the pump. The dead end pipes closed to pump are at most vulnerable situation in this case because they experience the extreme suction. At this stage, depending on magnitude of the wave, water column separation can take place. With that, continuous undulation undergoes until the surge is neutralized by damping effect. However at extreme level, this may lead to catastrophic failure of pipes or joints if they fail to bear the excess pressure.

Another most common transient inducer is closing and opening of valves. Sudden closure or opening may produce considerable surge waves in the conduit resulting in development of transient pressure. However this can be avoided by controlling the valves more slowly. And most likely this situation occurs when the operator has no idea about controlling them or has done it unintentionally.

Fire hydrants are more accountable for hydraulic transients sometimes in a pipe network, because they introduce an unsteady flow very quickly in the equilibrium state of a system. Although fire incidents are infrequent in nature, a sudden need of fire flow through hydrants can initiate significant transient pressure in the water mains.

There are several other causes for occurrence of hydraulic transient like pipeline breakage, storage tank operation, air intrusion etc. All these events lead to potential disturbance in the system. The principle components of the disturbance are changes in pressure and flow which cause evolution and propagation of intense pressure waves throughout the whole distribution system. When the system is non-pressurized or remains under atmospheric condition, this transient behavior usually remains smooth and unnoticed. But in the pressurized water distribution system, transients can introduce huge pressure forces and rapid fluid accelerations in addition with steady state condition.

However, development of pressure waves depends on the existing situation of pipe network and other devices also. Presence of surge protection devices like air valves can alleviate pressure surge. But, if the network is compact with no or very little leakage and with no surge protection device, then the magnitude of pressure surge can be significantly high. On the other hand, like Dhaka, where exists excessive leakage in the system, transient pressures may not be noticed. Because those leakages may act as air pocket against formation of cavitations. But in such case, frequent transient event can accelerate formation of leakage and cause water quality problem. In addition, there are numbers of isolation valves present in the network for operation and maintenance work although their efficiency is not always satisfactory. They are quite old and

are manually operated device. Usually their control is a slow process and therefore they are less susceptible to occurrence of transients.

Another important parameter is pipe roughness. New pipes produce pressure waves with higher magnitude than that of older pipes. Because frictional resistance (roughness) in old pipes tightens propagation of pressure waves and thereby makes impact relatively low. Related to roughness, an important concern is the layout of new pipe network in a cluster like pattern. Under small packages, always there has been some pipe rehabilitation program ongoing in Dhaka. This can lead to a differential transient behavior between adjacent pipe regions.

3 FACTORS AFFECTING TRANSIENT BEHAVIOR

Transient is very much affected by the formation of pipe layout and mechanical properties of network elements, pumps and of other control devices. In a pressurized water distribution system, regions that susceptible to transients are at high elevation zones, locations with either low or high static pressures, dead end pipes and at regions far removed from overhead storage. Hydraulic disturbance resulting from these transients sustains until the system stabilizes to a new steady state condition. Following factors have major influence on characteristics of transient behavior.

3.1 *Pump inertia*

A pump's moment of inertia plays a critical role in surge events. The higher the moment of inertia, the longer the pump will continue to rotate after shut-off. A higher moment of inertia minimizes pressure drops before the reflecting wave raises the pressure again. And in this way, effective damping can be obtained.

3.2 *Valve opening and closing*

During operation, any abrupt control in valve closing or opening can produce surge pressure. Therefore handling and control operation of valves are quite significant from transient point of view.

3.3 *Pipeline profile and length*

Pipe profile has a direct effect on minimum transient pressure if water column separation takes place, because profile is associated with initial hydraulic energy. On the other hand, Pipe length influences on the reflection time and the inertia of water inside the pipe. The longer the pipe is, longer the time it takes for the wave to reflect at the outlet and return to the starting point. In addition, longer pipes convey larger mass of water which affects the moment of inertia of the water column.

3.4 *Dead end pipes*

In most distribution systems, loops are formed to ensure system reliability and flexibility. However the network pattern of Dhaka is a mixture of loop and branch system. And in the areas which have branch system, significant numbers of dead end pipes are common (for example, in Khilket, Badda, Manikdi etc). Dead end pipes are more sensitive in the event of water column separation or of negative transient pressure. The intensity of negative surge at the dead ends is higher than any other location. Therefore resultant surge behavior is very much affected by the quantity and the layout pattern of dead ends.

3.5 *Pipe cover setting*

Due to the pressure changes created by disturbance, there will be oscillations of the pipe in the ground. Therefore the filling around the pipe will have a great effect on the wear of the pipe. Sharp stones, for example, can tear the pipe exterior. For submerged pipes, consideration must also be given to the depth of the pipe because the pipe wall is subject to the difference in pressure between the pressure inside the pipe and the external pressure from the surrounding water. If the pressure from the surrounding water is greater than the pressure inside the pipe, there is a risk of collapse or buckling.

3.6 Air valve

Usually air valves are provided in a network to dissipate air bubbles away. Dissolved air may exist in the fluid and propagate toward the higher elevation zones of profile, forming air bubbles. Therefore these valves are provided at high points in the network. However depending on the characteristics and position of the valves, transient event can be initiated. For example, if only air inlet valve (which only allows air to enter the system) is used, air bubbles that exist in the pipe cannot go out thereby may cause water column separation. On the other hand, if only air release valves are used, cavitations may be threatening for the system, as there pressure may fall below vapor pressure of the fluid. However, double orifice air valve permits air to pass in both way i.e. flow in and flow out. In Dhaka, most portions of the network are equipped with only air release valve. Therefore in case of pressure fall, the system may be vulnerable to low transient pressure.

3.7 Reticulation pipeline and house connection pipe

Ideally, the transient prediction in a water distribution system considers a compact fluid conveyor network with or without surge protection devices like surge tanks, air valves etc. Beyond that, there are some certain variable parameters exist in a system which can affect the transient behavior also. For example, in the event of a sudden pump shut-off, negative surge wave evolves. At the same, water column separation or vacuum may form at the far end pipes. In such case, house connection (HC) pipes may act as air pocket if their delivery ends are not closed instantly. And air can enter in the pipe then as a result of sudden suction. Next it will accumulate in the reticulation pipe from all the HC pipes. Finally it will intrude in the distribution pipe to mitigate the suction effect to an extent. However, the true behavior of transient is very complex and also very hard to predict when the system undergoes this condition.

4 BASIC FACTORS AFFECTING SURGE PRESSURE

The magnitude of surge pressure in a transient event depends on mechanical and hydraulic properties of the conduit and the fluid. During operational disturbance, surge wave is produced which depends on the velocity and volume of flow, elastic strength of fluid and pipe material, pipe wall thickness, pipe diameter, pipe roughness and on characteristic time of wave propagation. The resultant pressure induced on pipe wall is a combination of static pressure and the surge pressure then. However, the intensity of surge pressure varies depending on the type of hydraulic disturbance also. During transient analysis, designers are most concerned with negative surge so that water column separation cannot take place. Therefore, first priority goes to analyze pump shut-off case which is most sensitive in this issue. However, positive transient should also be analyzed so that it does not exceed pipe capacity resulting in collapsing or bending of pipelines.

5 CONSEQUENCES OF HYDRAULIC TRANSIENT

Extreme transient pressure can have significant destructive effect on the distribution network as well as on the control devices. The worst consequence may result as failure or rupture of pipelines and valves. Pipelines may collapse due to sub-pressure or rupture due to overpressure, but are generally more susceptible to sub-pressure than overpressure. In addition, fracture may occur at joints and bents may form in weaker sections. Figure 1 shows a typical valve rupture due to transient pressure. Sometimes surge pressure contributes to formation and expansion of leakages in the network. It can also be responsible for corrosion resulting in reduction of pipe wall thickness.



Figure 1. Check valve rupture due to transient pressure [Source: Internet]

Even if a pipeline does not collapse, water column separation (sudden vaporous cavitations) could occur if the pressure in the pipeline is reduced to the vapor pressure of the liquid. With vaporous cavitations, a vapor pocket forms and then collapses when the pipeline pressure increases due to more flow entering the region than leaving it. Collapse of the vapor pocket can cause a dramatic high-pressure transient if the water column rejoins very rapidly, which can in turn cause the pipeline to rupture. Vaporous cavitations can also result in pipe flexure that damages pipe linings.

During period of surge undulation, hydraulic vibration is formed which affect on pipe wall and pipe supporting masses. Prolonged vibration can have severe deteriorating effect on the stability of pipe lining and durability of pipes.

Another very important concern is water quality. Transient events can generate high intensities of fluid shear which may result in re-suspension of settled particle and in bio-film detachment. Those particles will mix up with the water then. In addition, negative pressure or suction may induce intrusion of contaminated substance through leakage.

However, some surge protection device may also cause water quality if properly not designed and operated. For example, increasing overhead storage for surge protection like bladder tank may cause water age problem if it has longer residence time. Therefore in design of an efficient water distribution system, the engineer must carefully consider all the potential dangers and allocate appropriate surge protection devices to eliminate the consequences of hydraulic transients.

6 SURGE PROTECTIONS

Transient event is a random dynamic state of hydraulic condition in a system. Moreover, it is associated with unsteady flow. And the surge behavior of a system is completely unique irrespective of any other similar system. Therefore it is quite impossible to make accurate prediction on surge behavior and set up surge protection strategy accordingly. Although cannot be avoided completely, certain protection measures can be taken to mitigate impact of surge to a desirable extent effectively.

Some strategies involve design and operational control only. As for example, it is always preferable to design a pipe layout avoiding topographic undulation as much as possible. In addition, pipe diameter and wall thickness should be adequate enough to bear surge pressure. Again, slow-operating practice in control of valves and hydrants is very much useful to avoid local transient. Another effective surge control practice is to use higher inertia pumps. Pumps with higher inertia helps to control transients because they continue to move water through the pump for a longer time as they slowly decelerate. This behavior slows transient generation and can reduce the overall transient experience in a system.

As the next level of surge protection strategy, in addition with operational control, some special devices are installed. Usually they are placed at transient sensitive regions in a system i.e. at or near locations where the surge disturbance is initiated (see Figure 2). Surge tank or pressure vessel is one of the most effective surge protection devices, which is used to control minimum transient pressure followed by pump-shut-off due to power failure. Therefore they are installed at or near the pump station. There are several types of pressure vessel like closed tank, bladder tank, hybrid tank, one way surge tank etc. The main function of pressure vessel is to use its stored water to prevent formation of vacuum or water column separation. At steady state, water in the vessel remains at or above atmospheric pressure depending on the characteristics of the tank. And at the moment of application, water is released from the tank at that pressure. However, water in the tank should be altered at regular interval to avoid water age problem.

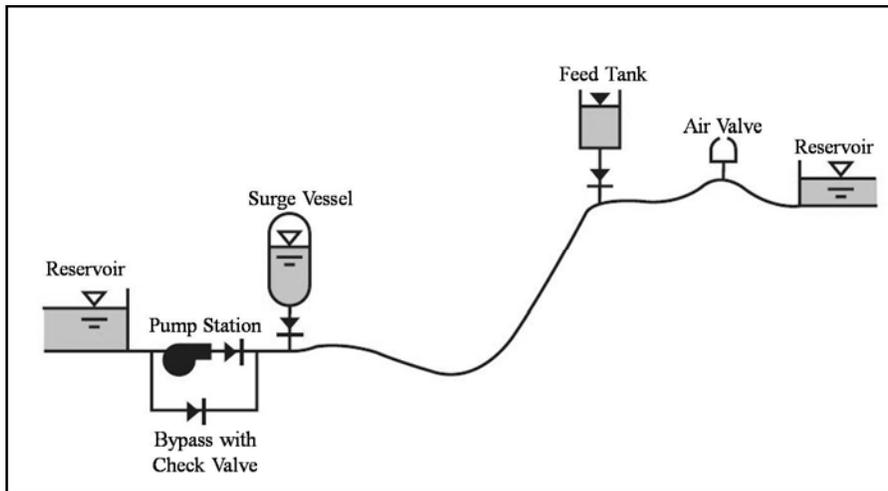


Figure 2. Typical locations for different surge protection devices

In a water distribution system, it is a common practice to install different types of air valves. Air valves can be different types depending on their functional behavior. They can be either air inlet valve, air release valve or can be both. Air inlet valves permit air only to enter in the conduit and therefore useful in case of cavitations. On the other hand, air release valves allow air to release from the pipe. They are usually installed at high points in a network where there is a probability of column separation followed by air accumulation. However air valves have both of the above facilities i.e. they permit air both to enter or release. These air valves reduce intensity of transient pressure significantly and therefore are very effective in case of transient events. But excessive use of air valves may cause water quality problem, especially in situation like Dhaka because it's very contaminated here. Therefore choice of air valve in terms of quantity and layout needs to be properly investigated.

Another effective surge protection device is the surge-relief valve. A surge-relief valve ejects water out to prevent excessive pressure surges. Therefore it is effective to control positive transient pressure. The valve is set at a preset value of pressure, and when the system pressure exceeds that, valve is automatically activated.

In some special cases like low-head pumping system with positive suction head, use of a bypass line with pump may be effective in mitigating transient pressure followed by pump shut-off. However this condition is not applicable for production tube wells of Dhaka.

In all the above choices, there are no universally applicable guidelines for eliminating transient pressure. Any surge protection devices or surge protection strategies must be chosen accordingly. And the final choice should be set after a detail study and analyses of the system behavior from all technical and economic points of view.

7 CASE STUDY: PUMP SHUT-OFF

In context of Dhaka, pump shut-off is the most common operational disturbance followed by power failure. Therefore there is always a possibility of developing negative surge pressure as well as of water column separation. To investigate the case, an ideal surge analysis is performed in this study for northern portion of

Banani area (see Figure 3) using computer aided transient modeling tool. For simplification, the area is assumed to be isolated at first. The sources of supply are two production tube wells here. Also no leakages are assumed within the network. The existing network information is taken from the MIS (Management-Information-System) database of Institute of Water Modelling (IWM), Dhaka.



Figure 3. Study area (Banani-north)

[Source: Google Earth-Pro]

The simulation was carried out in special three scenarios. They are, without surge protection device, with air valves (both way) and with pressure vessel. Some standard properties were set for all the network elements and the simulation was carried out for 60 seconds. The simulation was set in such way that the two pumps shut down simultaneously just after 10 seconds. The analysis shows that minimum surge pressure is developed at the dead end pipes near the pumps. Following Figure 4 and Figure 5 show the surge pressure and flow variation respectively in the pipe which was affected mostly by the surge.

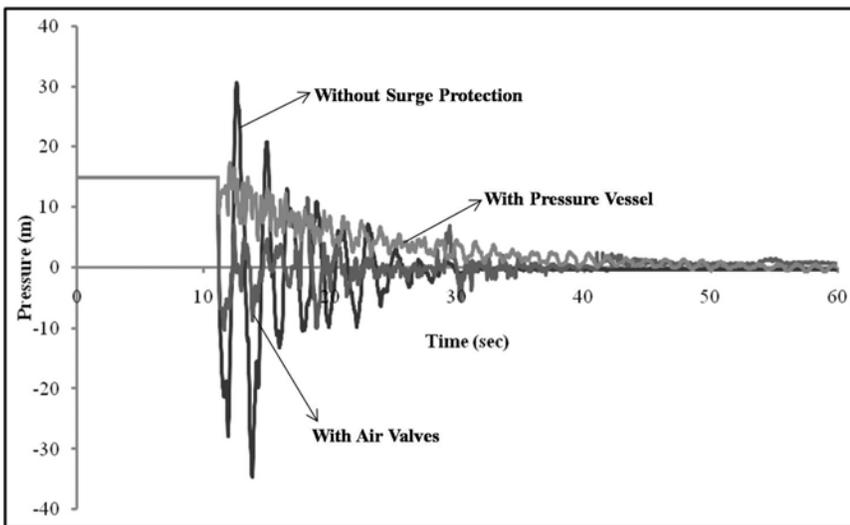


Figure 4. Surge pressure in a dead end pipe due to pump shut-off

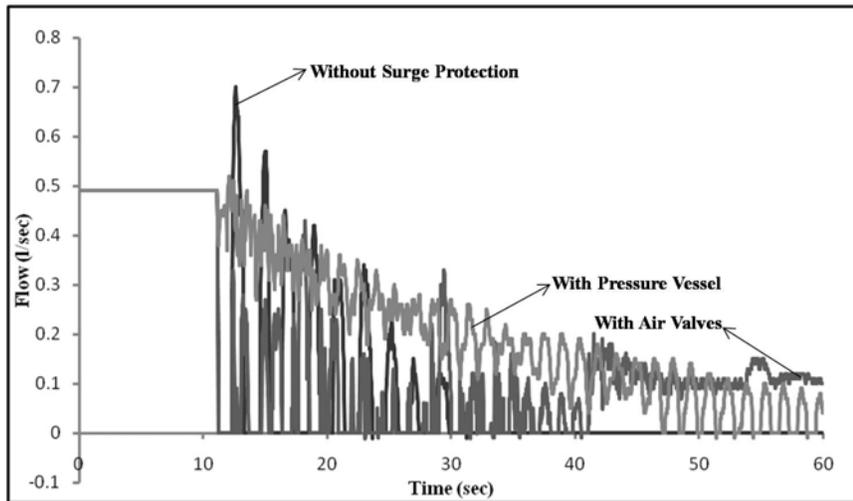


Figure 5. Flow Variation in a dead end pipe due to pump shut-off

These figures illustrate that without transient protection, surge pressure can certainly fall below water vapor pressure resulting in formation of column separation. But if surge tank is used, then it can be avoided. However with application of air valves, the intensity of surge can be reduced to considerable extent also. In addition, Figure 7 illustrates disturbance in flow for different scenarios which can result in hydraulic vibration. With application of surge tank of adequate size, the intensity of vibration can be neutralized to desirable limit.

The case study is intended mainly to understand the transient behavior. Actual results may vary depending on the field operating conditions of pumps, pipes, valves, flow, network pattern and the type of hydraulic disturbance. Therefore to obtain actual surge behavior, accurate physical and mechanical parameters should be applied in modeling.

8 CONCLUSION AND RECOMMENDATIONS

Hydraulic transients are unavoidable in a pressurized water distribution system. Though the current system is not pressurized, cities like Dhaka are bound to become pressurized in the future. Besides, a number of operational disturbances occur frequently in the network of Dhaka. And these transient events are quite vulnerable to the stability and durability of a newly established pipe network; if adequate protection measures are not provided. Especially the pump shut-off followed by power failure must be analyzed to prevent cavitations or water column separation in the network. However it may not be possible and/or feasible to predict always precisely, the worst case performance under all transient conditions. But comprehensive study and transient modeling can help to understand the true transient behavior and to take appropriate surge protection strategy to keep the impact of surge under tolerable limit. It is therefore recommended that transient analysis must be carried out in the design of a hydraulically sound water distribution system. And adequate surge protection devices should be installed. For this purpose, appropriate transient modeling tool needs to be applied.

REFERENCES

- Boulos, P.F. et al. 2005. Hydraulic Transient Guidelines for Protecting Water Distribution Systems. *Jour. AWWA* (97:5:111).
 Chawdhry, H.M. 1988. *Applied Hydraulic Transients*. New York: Van Nostrand Reinhold.
 DWSSDP. 2011. 1st Quarterly Progress Report. Dhaka. DWASA.
 IWM. 2006. MIS Report. IWM. Dhaka.
 Jung, B.S. et al. 2007. The need for comprehensive transient analysis of distribution systems. *Jour. AWWA* (99:1:112).
 Karney, B.W. & McInnis, D. 1990. Transient Analysis of Water Distribution Systems. *Jour. AWWA* (82:7:62).
 Martin, C.S. 1999. *Hydraulic Transient Design for Pipeline Systems*. New York: McGraw-Hill.
 Walski, T.M. et al. 2004. *Advanced Water Distribution Modeling and Management*. Waterbury: Bentley Institute Press.
 Wylie, B.E. & Streeter, V.L. 1983. *Fluid Transients*. Mich: FEB Press. Ann Arbor.