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ANALYSIS OF PRESSURE SURGES IN THE WATER DISTRIBUTION NETWORK IN KANDY MUNICIPAL COUNCIL AREA

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INTRODUCTION

Surges in pipelines carrying liquids are usually caused by opening, closing or regulating *valves* or *pumps* starting and stopping. These *surges*, also called *hydraulic transients* may range in importance from a slight *pressure* or *velocity* change to sufficiently high *pressure* or vacuum to rupture the piping system, to damage pumping equipment and cause extensive shutdown time. *Water hammer*, a result of *hydraulic transients*, will occur when the total *surge pressure* exceeds approximately twice the value of the *static pressure* in the system when the fluid is at rest. The *velocity* of this wave may exceed 1000 m/s and the values of *pressure* may oscillate from very high to very low values. *Surge* protection analysis will be performed on critical sections of the piping system to verify design and *surge control* equipment selection. If excess *transient pressures* are predicted by the analysis, design and mechanical equipment application should be modified.

Transient pressures are most important when the rate of flow is changed rapidly, such as resulting from rapid valve closures or pump stoppages. Such disturbances, whether caused by design or accident, may create traveling *pressure* waves of large magnitudes. These *transient pressures* are superimposed on the *steady state* conditions present in the line at the time the transient occurs. The severity of *transient pressures* must be determined so that the water mains can be properly designed to withstand these additional loads (Wood, 2005).

Kandy city being the second largest city in *Sri Lanka* provides shelter to 125400 people according to census, 2011. Water works department of the *Kandy* Municipal Council is responsible in distributing purified water to the residents of the *Kandy* Municipal area. Water that gets treated at the *water treatment plant (WTP)*, *Gatambe* supplies 34000 m^3/day, to the city of *Kandy*. The water distribution system connected to the treatment plant, consists of three *pumping mains*. Purified water is pumped to three storage tanks situated in *Dangolla*, *Primrose* and *Wales Park*.

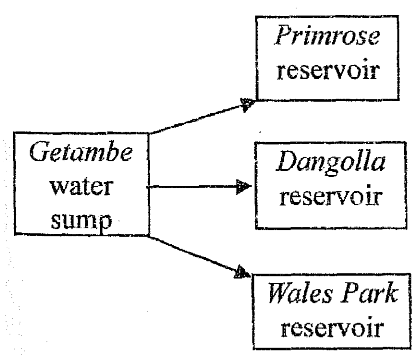

Figure 1: Distributions of *WTP*, *Gatambe*

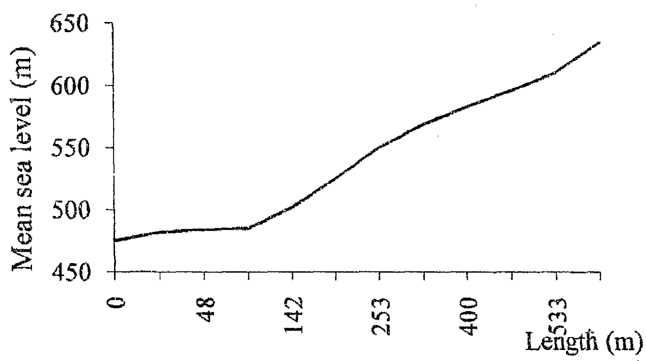

Figure 2: Longitudinal section of *WTP* to *Primrose reservoir* pipe main

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Kandy Municipal Council has invested significantly in the construction of the pumping system but has not properly protected the investment from *surge*. Although three *surge vessels* have been installed at the *pumping station* at *Gatambe*, none of them function properly. Due to the *malfunctions* of the installed *anti-surge devices*, pump failures, frequent damages to non - return valves and check valves have occurred. Disgruntled consumers are the main victims of *surge* related problems. *Kandy* Municipal Council is seriously suffering from costly repairs and reinstallation of devices connected to the system due to *surge* related problems. In order to protect the *pumping system* at *Gatambe*, a comprehensive study has been carried out to determine the size and location of the *surge* in *Primrose pumping main* and suggest suitable protection measures.

METHODOLOGY

To determine the *transient hydraulic conditions* at the pump and discharge line subsequent to a *power failure* at the pump, its characteristics, pump & motor *inertia* and *surge wave phenomenon* in the main must be considered. An extensive literature survey was carried out to obtain an in-depth knowledge of the problems that have been identified. Detailed surveys were carried out to find necessary data for analyzing.
Pump characteristic data depends upon the type of the pump. Power absorbed by the pump can be calculated using the characteristic equation of the pump, (Liyanage, 2005)

$$P_n = \frac{9.8 \times \gamma \times Q_n \times H_n}{\eta_n} \quad \text{.........} \quad (01)$$

where P_n = power absorbed by the pump (kW), γ = specific gravity of the liquid, Q_n = pump capacity (m^3s^{-1}), H_n = total pump head (m) and η_n = pump efficiency.

Torque of the pump is given by, (Liyanage, 2005)

$$M_n = \frac{974 \times P_n}{N_n} \quad \text{.........} \quad (02)$$

where, M_n = pump torque (kgm) and N_n = pump rotational speed (rpm).

Generally moment of inertia of the rotor of the motor GD_m^2 amounts to 90% of the total GD^2 and that of the rotating parts of the pump amount to 10% at most. The GD^2 of the motor differs considerably by the type and brand of the motor, but it can be roughly expressed by the following equation.

$$GD_m^2 = (0.013 \sim 0.005) \times P^{1.4} \times \text{No. of poles}^{0.75} \quad \text{.........} \quad (03)$$

where, P = motor out-put (kW) . Out of the range of the above coefficient, the larger part is for double squirrel cage type motors and smaller part is for wound rotor type motors. For the surge calculations it is safer when the above coefficient is smaller. (De Silva, 1998).

The velocity of propagation of pressure waves in a pipe line filled with liquid is defined by,

$$\alpha = \frac{1425}{\sqrt{\left[1 + \left(\frac{k}{E} \times \frac{D}{t}\right)\right]}} \quad \text{.........} \quad (04)$$

where, α = Pressure wave propagation velocity (m), k = bulk modulus of water (kgm^2), E = modulus of longitudinal elasticity of pipe material (kgm^2), D = internal diameter of the pipe (m) and t = thickness of the pipe (m).

Considering a pipe segment, the line constant is expressed by,

$$2\rho = \frac{\alpha \times V_n}{g \times H_n} \quad \text{.........} \quad (05)$$

where, 2ρ = line constant, V_n = flow velocity in pipe line (ms^{-1}), H_n = total pump head

(m) and g = acceleration due to gravity (ms^{-2}).

Interval of time for pressure wave travel time (μ) along the pipe line is given by,

$$\mu = \frac{2\,L}{\alpha} \quad \text{......} (06)$$

where, L = length of pipe line (m).

The head loss along the pipe segment is expressed by,

$$\text{Line loss} = \frac{H_l}{H_n} \times 100\% \quad \text{......} (07)$$

where, H_l = total head loss of the pipeline (m).

Pressure changes in a pumping main caused by sudden pump stop can be found by using numerical values obtained from the above equations and the simplified *water hammer charts* (Association of Agriculture Engineering Enterprises,1991). Out of the few methods available in analyzing the *transient hydraulic conditions* in a pumping main, graphical method has been selected for this study.

The minimum pressure gradient curve has been drawn for the *Primrose* main using the above mentioned numerical values and the simplified *water hammer charts*. By plotting the mirror image of the minimum pressure gradient curve, the maximum pressure gradient curve was found. By comparing the two curves with the existing pipe line profile, the point of maximum negative pressure and the location were found. *Water column separation* can be occurred if the value of the maximum pressure is greater than 10m. The life of the pipe main can be seriously affected by column separation. Suitable prevention measures should be taken to prevent any negative pressures. Therefore, necessary calculations have been carried out to select a *surge vessel* as a preventive measure for negative pressure in the *Primrose pumping main*.

olume of surge vessel has been found by using the following equation.

$$\frac{2\,C_0 \dfrac{+\Delta H_{max}}{H_0}}{Q_0\,L} = 15 \quad \text{......} (08)$$

Where, C_0 = volume of the surge vessel (m^3), $+\Delta H_{max}$= difference between the maximum positive pressure directly after the pump and hydraulic grade directly after the pump, H_0 = initial absolute pressure head in air chamber (m), Q_0 = pumping rate (m^3s^{-1}) and L = pipe length (m).

RESULTS AND DISCUSSION

Power absorbed by the pump	130 kW
Torque of the pump	85.5 kgm
Moment of inertia of the rotor of the motor	13.2 kgm^2
Pressure wave propagation velocity	1217 ms^{-1}
line constant	2.0
Interval of time for pressure wave travel time	0.98 s

Figure 3 shows the results that have been obtained considering the existing conditions of the *Primrose pumping main*. It is evident from figure 3, that at a point about 318.0 m away from the *pumping station*, a maximum negative pressure of 38.6 m is occurred. An *anti-surge device* should be installed to minimize the severity of the negative pressure. A trial and error method which is illustrated in figure 4 was used to obtain the most effective and economical *surge vessel* for the *Primrose pumping main.* After performing rigorous calculations it was found that the capacity of *surge vessel* for the *Primrose pumping main* should be of 650 l.

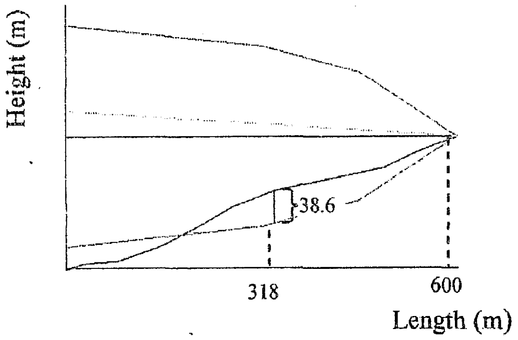

Figure 3: Water hammer study graph without anti-surge devices

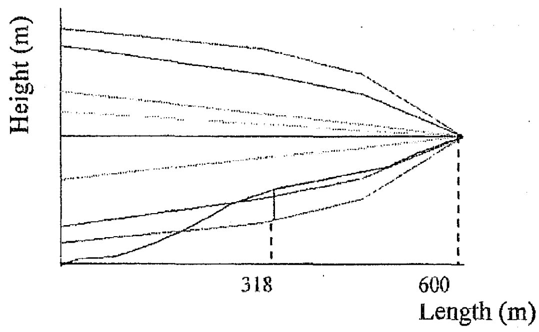

Figure 4: Water hammer study graph with anti-surge devices

LEGEND:
- Pipe line center line
- Maximum and minimum pressure gradient curves
- Hydraulic grade line
- Maximum and minimum pressure gradient curves No. 01
- Maximum and minimum pressure gradient curves No. 02

CONCLUSIONS/ RECOMMENDATIONS

To provide an uninterrupted water distribution to the residents and visitors of *Kandy* Municipal area, the negative pressure that occurs in *Primrose pumping main* should be minimized. The analysis was carried out using the graphical method based on the pump characteristics, pump & motor *inertia* and *surge wave phenomenon* in the main.
It was found that the maximum negative pressure of 38.6 m is occurred at a point about 318.0 m away from the *pumping station* in the *Primrose pumping main.* Although the capacity of the existing *surge vessel* installed in the *Primrose pumping main* is only 500 l, the authors found that the required capacity of the surge vessel should be 650 l to provide the consumer with an uninterrupted service.

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