ANNEX C

The Hardy Cross method for balancing pipe networks

1 Introduction

Calculating the flow in pipe networks is difficult because the volume flow rate Q is a function of the friction factor f and pipe length l. Dynamic losses due to fixtures, bends and junctions are usually reduced to equivalent lengths of pipe, and these lengths are related to the pipe's Reynolds number Re_d. Hence, it can be seen that the volume flow rate along any pipe in a network is related to Re_d. Unfortunately, this relationship is not only non-linear, but also discontinuous in the region of $Re_d = 2000$ to 2300 (laminar/turbulent transition).

The Hardy Cross method is an iterative method which resolves the flow rate in each path of the pipe network while at the same time satisfying continuity. Knowledge of the flow rate permits the Reynolds number to be calculated for each path allowing better equivalent lengths and friction factors. The method can be reduced to a number of simple steps. The Hardy Cross method usually converges very quickly on the solution and is very robust. It will still converge even if a few minor arithmetic errors are made. A good choice of initial values will reduce the number of iterations required.

2 Method

This section contains an outline of the steps involved on the Hardy Cross method:

i) Assume the best distribution of flow rates that will satisfy continuity;

ii) If not already provided calculate value of K, to satisfy $h_f = KQ^2$, where: $K = \dfrac{32.l.f}{\pi^2.g.d^5} \approx \dfrac{l.f}{3.d^5}$.

Using available data guess a suitable value of f and l where required;

iii) Adopt a sign convention for each loop in the circuit, e.g., clockwise is positive;

iv) Sum the losses for all n pipes in the loop, given by: $\sum_{i=1}^{n} (h_f)_i = \sum_{i=1}^{n} K_i Q^2{}_i$, note that h_f must be considered negative when the flow is against sign convention;

v) Calculate $2\sum_{i=1}^{n} |K_i Q_i|$;

vi) Calculate the flow rate correction ratio ΔQ for the loop, given by: $\Delta Q = \dfrac{-\sum_{i=1}^{n} K_i Q^2{}_i}{2\sum_{i=1}^{n} |K_i Q_i|}$;

vii) Amend all flow rates in the loop, observing the sign convention: $Q_{\mathrm{iAssumed}} + \Delta Q = Q_{i\mathrm{Improved}}$;

viii) Move to next loop and repeat steps (iv) to (vii) until all loops have been visited;

ix) Move to next iteration by repeating steps (iv) to (vii) until all values of ΔQ have fallen within acceptable limits or have reached equilibrium;

x) If required use the estimated flow rates to improve initial estimates of friction factor and dynamic losses. Check for onset of laminar flow in any branch.