**Nomenclature alphabetical order**

2\(a\)     Patch length (mm)

2\(a'\)    Critical patch length (mm)

2\(b\)     Patch width (mm)

2\(b'\)    Critical patch width (mm)

\(A\)      Area of flow (mm\(^2\))

\(c\)      Patch depth (mm)

\(c'\)     Critical patch depth (mm)

\(c_{A\text{Ce}}\) External deterioration rate for AC pipes (mm/y)

\(c_{A\text{Ci}}\) Internal deterioration rate for AC pipes (mm/y)

\(c_d\)    Discharge coefficient

\(c_l\)    Coefficient for strength reduction

\(c_{lc}\) Coefficient for creep modulus reduction

\(c_{lf}\) Coefficient for fatigue strength reduction

\(c_s\)    Intercept parameter for long-term corrosion of metallic pipes (mm)

\(C\)      Compression modulus (GPa)

\(C_f\)    Fatigue constant for host pipe under cyclic surge pressure

\(C_{HW}\) Hazen Williams roughness coefficient

\(C_n\)    Total cash flow for each year ($) 

\(C_{n}(t)\) Nominal cash flow ($) at time \(t\)

\(C_{\text{nothing}}\) Cost of do nothing option ($) 

\(C_r(t)\)  Real cash flow ($) at time \(t\)

\(CRF\)    Creep retention factor of the liner

\(d\)      Initial hole (defect) size (mm)

\(d_f\)    Future hole (defect) size (mm)
\( D \)  Pipe internal diameter (mm)
\( D_0 \)  Pipe external diameter (mm)
\( D_L \)  Liner external diameter (mm)
\( D_{Li} \)  Liner internal diameter (mm)
\( D_M \)  Mean diameter of the host pipe (mm)
\( DN \)  Pipe nominal diameter (mm)
\( E_a \)  Young’s modulus of the adhesive (GPa)
\( E_A \)  Short-term tensile or compressive modulus of the liner in the axial direction (GPa)
\( E_{fa} \)  Short-term flexural modulus of elasticity (axial) of the liner (GPa)
\( E_{fal} \)  Flexural creep modulus (axial) of the liner (GPa)
\( E_{fh} \)  Short-term flexural modulus of elasticity (hoop) of the liner (GPa)
\( E_{fhl} \)  Flexural creep modulus (hoop) of the liner (GPa)
\( E_L \)  Short-term modulus of elasticity of the liner (GPa)
\( E_{i,dry} \)  Dry creep modulus of the liner (GPa)
\( E_{i,wet} \)  Wet creep modulus of the liner (GPa)
\( E_p \)  Modulus of elasticity of host pipe material (GPa)
\( E_s \)  Soil modulus (MPa)
\( E_t \)  Short-term tensile modulus of elasticity of the liner (GPa)
\( E_{ta} \)  Short-term tensile modulus of elasticity (axial) of the liner (GPa)
\( E_{tal} \)  Tensile creep modulus (axial) of the liner (GPa)
\( E_{th} \)  Short-term tensile modulus of elasticity (hoop) of the liner (GPa)
\( E_{thl} \)  Tensile creep modulus (hoop) of the liner (GPa)
\( E_{tl} \)  Tensile creep modulus of the liner (GPa)
\( f \)  Friction coefficient of the interface of the host pipe and liner
$g$  Acceleration due to gravity (m/s²)

$h$  Pressure head (m)

$H$  Burial depth (mm)

$H_w$  Groundwater depth (mm)

$i$  Discount rate (%) 

$IN$  Inflation rate (%) 

$I_o$  Initial investment ($)

$k$  Lateral earth pressure coefficient 

$k_1$  Patch factor 

$k_2$  Aspect ratio 

$K$  Enhancement factor 

$K_{IC}$  Fracture toughness of host pipe material (MPa m¹/²)

$L$  Installation length of the liner (m)

$L_{cost}$  Cost of the liner ($/m$)

$L_{mis}$  Miscellaneous liner cost ($)

$L_c$  Critical crack length (mm)

$L_p$  Length of the pipe (m)

$L_{ps}$  Length of the pipe spool (m)

$m_f$  Fatigue constant for host pipe under cyclic surge pressure

$MAOP$  Maximum allowable operational pressure (MPa)

$n_f$  Cyclic surge factor

$n_{PC}$  Number of recurring cyclic surge pressure cycles per day

$n_{TPC}$  Total number of surge pressure cycles for the service life of pipe/lined pipe

$N$  Safety factor for host pipe

$N_i$  Factor of safety for liner imperfections
NPV  Net present value ($)

\( P \)  Operating pressure (MPa)

\( P_G \)  Groundwater load (MPa)

\( P_{GC} \)  Groundwater load capacity (MPa)

\( PN \)  Nominal pressure (bar)

\( P_N \)  External pressure on the liner (MPa)

\( P_T \)  Test pressure (MPa)

\( P_c \)  Recurring cyclic surge pressure (MPa)

\( P_{max} \)  Maximum allowable pressure (MPa)

\( P_{min} \)  Minimum internal pressure (MPa)

\( P_s \)  Surge pressure (MPa)

\( P_v \)  Vacuum pressure (MPa)

\( q \)  Host pipe ovality (%)

\( q_t \)  Total external pressure on pipes (MPa)

\( q_{tc} \)  Liner capacity for total external pressure (MPa)

\( Q \)  Leak rate (L/s)

\( r_s \)  Minimum corrosion rate (long-term) of metallic pipes (mm/y)

\( r_{sh} \)  Lateral extension rate for metallic pipes (mm/y)

\( r_{sv} \)  Radial corrosion rate for metallic pipes (mm/y)

\( R_{cost} \)  Cost of replace option ($/m)

\( R_h \)  Hydraulic radius (m)

\( R_{mis} \)  Miscellaneous replace cost ($)

\( R_w \)  Water buoyancy factor (unitless)

\( S \)  Slope of the energy grade line, or head loss per unit length of pipe (m/m)

\( SCF \)  Stress concentration factor
$SCF$ Critical stress concentration factor

$t$ Time (years)

t$_h$ Time (hours)

$T$ Pipe wall thickness allowing for uniform corrosion (mm)

$T_{ext}$ Estimated external uniform corrosion (mm)

$T_f$ AC pipe remaining wall thickness at failure (mm)

$T_{int}$ Estimated internal uniform corrosion (mm)

$L$ Liner thickness (mm)

$T_n$ Pipe nominal wall thickness (mm)

$u_g$ Existing gap width of host pipe (mm)

$u_{gp}$ Gap formed due to axial movement or pulling force (mm)

$V$ Flow velocity (m/s)

$W$ Traffic load (kN)

$W_s$ Live load (MPa)

$x_l$ Coefficient for strength reduction

$x_{lc}$ Coefficient for creep modulus reduction

$x_{lf}$ Coefficient for fatigue strength reduction

$y_f$ Predicted year for failure of an AC pipe (mm)

$\alpha$ Coefficient of thermal expansion/contraction (mm/mm/°C)

$\beta$ Fraction of liner service life when out of service

$\gamma_s$ Soil unit weight (kN/m$^3$)

$\gamma_w$ Unit weight of water (kN/m$^3$)

$\Delta T$ Temperature change (°C)

$\theta$ Rotation angle (°)
\( \nu_L \) Poisson’s ratio of the liner

\( \nu_p \) Poisson’s ratio of host pipe material

\( \sigma_A \) Short-term tensile or compressive strength of the liner in the axial direction (GPa)

\( \sigma_{ad} \) Adhesion strength of the liner to host pipe substrate (MPa)

\( \sigma_{fa} \) Short-term flexural strength (axial) of the liner (MPa)

\( \sigma_{fal} \) Long-term flexural strength (axial) of the liner (MPa)

\( \sigma_{fh} \) Short-term flexural strength (hoop) of the liner (MPa)

\( \sigma_{fhl} \) Long-term flexural strength (hoop) of the liner (MPa)

\( \sigma_{max} \) Maximum stress in the liner (MPa)

\( \sigma_p \) Tensile stress in the host pipe (for AC pipe) (MPa)

\( \sigma_{t,AC} \) Ultimate tensile strength of AC (MPa)

\( \sigma_t \) Tensile strength of the liner (MPa)

\( \sigma_{t,AC} \) Ultimate tensile strength of host pipe material (MPa)

\( \sigma_{ta} \) Short-term tensile strength (axial) of the liner (MPa)

\( \sigma_{tal,r} \) Tensile rupture strength (axial) of the liner (MPa)

\( \sigma_{th} \) Short-term tensile strength (hoop) of the liner (MPa)

\( \sigma_{thl,r} \) Tensile rupture strength (hoop) of the liner (MPa)

\( \sigma_{thl} \) Long-term strength (hoop) of the liner and is the lesser value of either: the tensile rupture strength (hoop), \( \sigma_{thl,r} \) (MPa) or fatigue strength (hoop), \( \sigma_{thl,f} \) (MPa)

\( \sigma_{thl,f} \) Fatigue strength (hoop) of the liner (MPa)

\( \sigma_y \) Yield strength of steel (MPa)

\( \tau \) Transition period between short-term and long-term corrosion (y)

\( \phi \) Soil friction angle (°)

\( \phi_c \) Wet creep reduction factor
$\phi_s$  Wet strength reduction factor