Guideline

Transient Analysis

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1. Introduction

1.1 Purpose

These guidelines have been prepared for use by engineers undertaking water hammer/transient analysis for pressure systems, owned and operated by Sydney Water.

This guideline aims to provide guidance to design engineers on Sydney Water's requirements and preferences with respect to undertaking transient analysis and reporting of results. The outcome must comply with, and support the design principles stipulated in the Sydney Water *Management Specification* (Doc. no. 1041412) to:

- ensure safe, reliable, and sustainable designs and assets
- design assets for lowest life cycle cost to achieve desired level of service and acceptable risk
- comply with legislation, regulations, licences, policies and Sydney Water's management systems, and
- provide continuous improvement and innovation.

To achieve these design principles, the execution of a transient analysis is considered an important tool in the design process. These guidelines have been curated to support and inform design decisions for the overall pipe system design process. This document is not intended to serve as a prescriptive modelling guide to be used in isolation from the rest of the design.

1.2 Scope

These guidelines:

- Provide a decision framework for undertaking a transient analysis and guidance on the level of the analysis required.
- Provide guidance on minimum requirements for transient analysis and reports that need to be prepared as part of the planning and design process for new assets (incl. upgrades to existing assets), or to investigate performance or operational issues pertaining to existing assets.
- Apply to the transient analysis, design and operation of pipes, pumps, valves and pressure vessels within Sydney Water's drinking water and recycled water supply pressure network, and wastewater pressure mains.
- Provide common design rules and general modelling methodologies.
- Include specific Sydney Water requirements with respect to modelling and control of transients (mitigation).
- Outline minimum requirements for design of mitigation measures to ensure that assets subject to transient events are designed, constructed and maintained for safe operation over its design life.

1.3 Competency

Transient analysis and reports, prepared on behalf of Sydney Water, must only be undertaken by suitably qualified and experienced practitioners who meet the competency requirements set out in the Sydney Water *Engineering Competency Standard* (Doc no. D0000833). Similarly, anyone engaged in quality assurance (QA) reviews, peer reviews or verification must also comply with this competency standard.

1.4 Reporting

Any transient analysis report prepared on behalf of Sydney Water may be used as part of a wider design process or operational investigation. Nevertheless, the report must contain all relevant background information, list all assumptions, and make all relevant interpretations and qualifications in order to form a coherent stand-alone document.

The report must contain all relevant information so that it can be reviewed by a third party as part of a QA process or referred to in the future. For example, for reference in investigation of future augmentations or to assist in resolution of operational matters.

2. Framework for undertaking transient analysis

The context within which engineering decisions and judgements are made to determine the parameters of a transient analysis are nuanced and unique to every pipe system under consideration. As a consequence, it is necessary to have a clear appreciation and understanding of the framework that underpins Sydney Water's concerns and requirements with respect to undertaking transient analysis to support the pipeline design process.

2.1 Investigation

It is not the intention of Sydney Water to mandate a comprehensive transient analysis to be undertaken on every pressure system.

However, unless specifically excluded or otherwise directed by Sydney Water, whenever work is carried out on a pressure system (i.e. new pressure system, refurbishment or augmentation of existing system, changes to critical/significant components of an existing system), a qualitative assessment by a competent engineer (H4 classification in accordance with the Engineering Competency Standard) must be undertaken to determine:

i. if a transient analysis of the system is warranted or not, and

ii. the level of transient analysis that must be undertaken.

For a simple low head- low flow pipeline, a simple first order calculation may indicate negligible pressure transients, whereas a complex pipe with high head and high flow may require a comprehensive transient analysis.

In the event it is determined that a transient analysis is not warranted, the decision must be documented in the design report. As a minimum, the design report must:

i. describe the scope of the project in terms of relevance to transients

ii. justify reasons for not undertaking a transient analysis

iii. document possible risks

iv. comprehensively demonstrate, by way of engineering judgement, risk analysis and/or first order calculations, that the absence of a transient analysis will not result in unacceptable risks to Sydney Water

v. make recommendations

Conversely, when a comprehensive transient analysis is determined necessary, competent engineering personnel must follow this guide for the transient analysis and reporting of the results. Upon conclusion of the investigation phase, a stand-alone scoping memorandum is required (see item 3.1.2 Complex network).

2.2 Potential effects of transient pressures

Damaging effects of unacceptable transient pressures that are of particular concern for Sydney Water are:

- high pressures (leading to pipe bursts or damage to pipes, fixtures and equipment)
- low pressures (imposing additional stresses within the wall of the pipe, compromising the integrity of jointing systems or the functioning of equipment e.g. sealing of air valves)
- excessive noise, vibration or resonance including damage to rotating equipment
- high flows, especially reverse flows (may loosen deposits and rust adversely affecting water quality)
- destructive cavitation or collapse of gas cavities (may damage equipment and pipe linings)
- transient forces leading to structural damage e.g. to buildings or valve chamber walls
- contamination (low pressures can lead to intrusion of contaminated water into the network), and
- unacceptable pressure oscillations at consumer taps.

Design limitations on very low or negative pressures within drinking water systems are typically more onerous than in wastewater systems (refer item 7 Design for pressure), as any ingress of contaminants into drinking water systems must be prevented in the interests of public health protection.

Repeated, long duration, high impact vacuum loadings can ultimately lead to failure modes such as ‘seal suck’, leading to leaking joints and internal corrosion of the pipeline if cement mortar linings spall off.

A large part of the Sydney Water’s supply network comprises old pipes which are especially susceptible to failure under fluctuating pressures, especially cast iron pipes. Any changes to old pressure systems with at - risk pipes (e.g. cast iron) is of concern to Sydney Water and must be approached with caution.

Wastewater overflows and leakage of pollutants to the environment is a major concern for Sydney Water in sewerage networks.

The failure of any pipe can have serious consequences, with the potential for damage to property, creation of safety hazards as well as adverse environmental and public health impacts. Not only should catastrophic failure of a pipe be prevented, but the system response to transient events can also create O&M issues such as air ingress/egress and odour emissions, ongoing maintenance associated with air valves, etc.

In summary, the impacts of unacceptable hydraulic transients are of concern to Sydney Water due to:

- health and safety reasons when sewage spills or leaks to the environment
- contamination of drinking water due to air, debris or groundwater intrusion
- long term costs due to premature aging and wear of valves, pipes and pumps
- fatigue failure in pipes and fittings
- service interruptions due to repair and maintenance of infrastructure
- meeting licence compliance standards and service standards
- loss of water through leakage (cost and environmental footprint) and
- collateral damage to private property and safety risks caused by main breaks.

Transient pressures well below the maximum pressure rating of a pipeline can have consequential impacts. Consequently, a reduction of transient pressures across the pressure system might be considered to improve system reliability. Where practicable, transient pressures should be mitigated to acceptable levels.

2.3 Causes of transient pressure

Causes of potentially damaging transient pressures typically include (but are not limited to):

- The system configuration, including:
  - high static head
  - long / flat pipeline profile
  - short vertical profile e.g. pumping into an elevated reservoir
- Operational scenarios and requirements, maintenance tasks and failures, including:
  - power failure leading to pump shutdown or valve opening/closing
  - pump starts and stops
  - valve opening or closing, including slamming of non-return valves or air valves
  - pipe filling or draining
  - incorrect manual operation of equipment
  - unauthorised pump or valve operations on private premises
  - ‘hunting’ of a control valve
  - mechanical failure of pumps, valves or other equipment (including fatigue)
  - fire hydrant testing
  - main breaks
  - excessive air in pipelines.

2.4 Analysis and design of mitigation measures

Design of pressure pipe systems must be based on robust assumptions to ensure there will be a high level of confidence regarding prediction of transient pressures. Transient investigations must consider, analyse and design for:

- catastrophic failure (e.g. pipe bursting, pipe collapse, runaway (reverse) pump speed, joint movement, extreme vibrations and excessive noise)
- benign failure (e.g. lining failures, pipe wall pitting, joint degradation and repeated excessive stresses imposed upon the system), leading to degradation of design life
- sensitivity of the system to changes in parameters of components and operations.

Particular attention must be paid to the following components or locations within the system to determine the impacts of hydraulic transients:

- Non-return valves at pumps as flow reverses from the downstream reservoir or surge vessels to the pump.
- Reservoir inlet valves, altitude valves at elevated tanks, or isolation and control valves if they can close rapidly.
- Local high points where vapor or air pockets may form and collapse.
- Surge-control devices if not properly designed, maintained or operated.

- Changes in pipeline profile or alignment where transient forces may be significant.

The design of any water system must include both normal and abnormal operations (see item 8 Definitions) and be safeguarded to handle adverse external events such as power failures, pipeline failures, and so on. The following causes of hydraulic transients must as a minimum be investigated, as applicable to the pipe or water system under consideration:

- controlled pump start-up or shutdown
- uncontrolled pump shutdown (e.g. power failure)
- valve opening or closing
- change in boundary pressures (e.g. losing overhead storage tank, adjustments in the water level at reservoirs, pressure changes in tanks, etc)
- rapid changes in demand conditions (e.g. hydrant flushing)
- changes in transmission conditions (e.g. main break)
- pipe filling or draining (reference to relevant SOPs)
- unprotected system when air valves or other surge control equipment malfunction.

The overall design must also give careful consideration to unusual design or abnormal operating conditions such as pigging operations, bypassing a reservoir, pump station or barometric loop, dual mains, variable inlet/suction conditions, flooded wells, operation of a scour valve during pump operation, etc.

2.5 Control of hydraulic transients

Various options to control hydraulic transients are available to the design engineer. The selected option(s) must be based on lowest life cycle cost with acceptable risk.

In some cases, the appropriate approach may be to accept and design for the unprotected system pressure envelope. Where hydraulic transients are very rare and insignificant, and/or the pipe system components are sufficiently robust, a ‘do nothing’ approach may be warranted.

In other cases, it may be prudent from a risk, operational or value perspective to implement measures to reduce high pressure transients or eliminate / reduce negative pressures (i.e. system improvements, flow controls, or mechanical protection).

Notwithstanding any preferences expressed by this guide, it remains the responsibility of the design engineer to undertake and/or advise Sydney Water of the necessary investigations, analysis and interpretation required to understand the nature of hydraulic transients, and to select the appropriate control and mitigation measures.

Different methods for control of hydraulic transients are discussed further in Section 5. However, within the transient analysis decision making framework, the following approaches may be considered:

- Select pipeline route to eliminate critical high points that may be subject to negative pressures.
- Reconsider the pipeline material to reduce celerity (e.g. a PE or PVC pipeline in lieu of MS or DI).
- Reduce transmission velocity (e.g. larger pipeline diameter).
- Reduce the speed of closure of a valve or stopping/starting of a pump (e.g. fly wheels, mechanical devices to control valve closure, VSDs, etc).
- Select and size equipment to reduce non-return valve slamming.

- Install pressure relief / vacuum relief valves, bursting discs to protect pipeline integrity.
- Install equipment to eliminate or reduce surge (e.g. pneumatic tanks, surge tanks, etc).

The strategy to control transients in a water system must be comprehensive and must consider the system in its totality. The strategy must provide the necessary system protection while providing value for money both in terms of capital expenditure and ongoing maintenance and operation, at the least acceptable risk.

As these approaches differ significantly in terms of the required civil and piping works, physical appearance and hydraulic characteristics, the strategies must be evaluated for:

- long-term reliability
- operational complexity and flexibility
- cost of construction
- operation and maintenance costs.

2.6 Validation of transient pressures

Where appropriate, or specifically requested by Sydney Water for investigation or model validation purposes during commissioning, monitoring of transients in a pressure system requires the use of high frequency monitoring equipment, typically recording pressure variations at 20 to 500 times a second. Any discrepancies found between modelled results and field test results must be incorporated into an updated model.

The design engineer must make an informed decision on the appropriate recording intervals that would be appropriate for the particular scenario. For comparison, consider a 100 Hz logger for a steel pipe at c = 1000m/s, that means that a 100 Hz logger will take a measurement roughly every 10m (for PE pipe of c ~ 300m/s, that then becomes a measurement of every 3m). Logging many hours would record millions of data points, making it very difficult to review the data.

Any monitoring must be done in consultation with the Reliability Engineering Group within the Engineering and Technical Support (ET&S) Group.

3. Transient models

3.1 Scope

The scope of a transient model is closely related to the purpose of a transient analysis (refer Item 2.1). Broadly, Sydney Water considers the following scenarios:

1. Isolated pressure main with hydraulicly well-defined boundaries e.g. single pressure main, pumping from one reservoir to another, or from a wet well to a discharge maintenance hole, with no other connections.
2. Complex network with one or more significant cross connections and no easily identifiable hydraulic boundaries.

Prior to building the model and based on having a clear understanding of the purpose for the transient analysis, the model extent must be clearly defined and scoped. The following requirements apply.

3.1.1 Isolated pressure main

For an isolated pressure main, a scope definition by way of a short paragraph in the Design Report will suffice.

Transient analysis is one component of the entire pipeline design process and cannot be undertaken in isolation from the other components that make up a pipeline. It is required that the final transient analysis incorporates accurate parameters of hydraulicly significant components within the system. For instance, the transient analysis of a rising main must be based on the final pump selection, and not modelled as an arbitrary node with variable pressure.

The transient analysis must accurately reflect different components of the pipeline to give accurate results and present an accurate pressure envelope.

3.1.2 Complex network

For a complex network, the scope and extent of the model constitutes a critical input into the transient analysis and requires judicious investigation and selection of hydraulic boundaries. It is not the intention of this guide to require, neither is it practical, for an analysis to include every single pipe within the system. Network boundaries must be selected to include hydraulicly significant components and/or boundaries. This is a complex and nuanced undertaking and must be done with a very clear understanding of the operation of the system. It is highly recommended to obtain input from the Sydney Water Planning team, Operations and Maintenance teams, and the Specialist Engineering team to scope the model.

For a complex network, a stand-alone scoping memorandum is required. The scoping memorandum must be attached to the final Design Report. As a minimum, the scoping memorandum must address the following:

- description of the system
- schematic of network – layout
- description of the operation of the system and configuration of the system
- defined hydraulic boundaries
- significant connections
- connections deemed insignificant for the purpose of the transient analysis

- discussion on events which may initiate transient conditions
- risks associated with the selected hydraulic boundaries and boundary conditions (risks with exclusions)
- recommendations on model extent

3.2 Approved software packages

Unless otherwise approved by Sydney Water, a comprehensive transient analysis must be undertaken on a representative network model of the transfer or distribution system (new or existing – water, wastewater or recycled water) to properly locate and size the most effective combination of transient pressure control and mitigation devices.

Sydney Water holds Bentley Hammer and Hytran licenses. Unless otherwise agreed with Sydney Water, models must be provided in Bentley Hammer so that it can be saved and used by Sydney Water in the future.

Situations where traditional water hammer software are not appropriate, specialist applications such as CFD simulation software with the appropriate capability may be used.

3.3 Transient modelling procedures

The typical steps in the modelling procedure are likely to include (but are not limited to):

- network layout and system configuration
- pressure criteria adoption
- data entry and boundary conditions: reservoirs, pumps, pipe and junction data
- celerity calculations
- listing of all analysis scenarios
- setting of calculation options: run time, vapour pressure, output data frequency, path profiles, time steps, etc
- setup analysis case (e.g. pump failure without surge protection – input pump data, inertia, etc)
- calculating initial steady state conditions and transient pressures
- reviewing results
- specifying outputs & profiles (cavity formation and collapses, air vapour volumes, etc)
- visualising simulated results
- generating reports (transient histories, etc)
- evaluating results (results sensitivity with air valve types/locations and failure, measures to prevent column separation, ramp times for VSDs, time delays, etc)
- testing of transient mitigation options (surge protection measures)
- reporting summary, qualifications, recommendations and conclusions.

3.4 Network data

Network data describes all physical components of the pressure system and defines how those elements are interconnected. Networks are made up of nodes and links. Nodes represent water system features at specific locations and links define relationships between nodes.

For existing systems, network data can be exported from Sydney Water's network model (Infoworks) to use as the base on which to build the transient model.

One of the limitations of the Sydney Water Infoworks model is that pipe levels may be based on ground levels and do not accurately represent pipe elevations. Usually, the modeller will apply a standard depth and then do a sanity check of the WAE drawings to ensure critical high and low points are captured correctly. The location of existing air valves to be introduced into the transient model is done using WAE drawings. The location and properties of these air valves must be validated by field confirmation. Detailed inspection may be required to confirm air valve type and check if it is functional.

3.5 Skeletonisation

Skeletonisation is defined as the process of reducing the network model by removing pipes and/or components not considered essential to the analysis. Judicious skeletonisation of a water system is allowed with the specific requirement that any element that may have a material impact on the resultant transient pressures, must be included. The degree or level of skeletonisation will depend on the purpose of the model, its intended use, and the size and complexity of the overall network. Data scrubbing, branch trimming and series pipe merging (or node removal) should be undertaken with care to avoid causing network disconnections or loss of functionality in the model.

The theory of Hydraulic Equivalency (i.e. of defining an equivalent pipe to replace two or more pipes in parallel or in series while preserving their carrying capacity) does not hold for transient analysis and is limited to steady-state modelling applications. The theory is predicated on steady-state equilibrium and ignores the interaction of transient pressure waves in the different pipe properties of a distribution system.

The design engineer must determine the extent of the skeletonisation required and provide detailed substantiation/justification in the modelling report for the culled components.

3.6 Network demands

Network demands and its distribution throughout the network are key inputs into the transient model. Not to be confused with 'demand modelling' which is a steady state modelling activity, network demand modelling (eg. InfoWorks) provides the current and future steady state flow conditions for input into the transient analysis.

As with the model links and nodes, the network demand may be obtained from the Sydney Water InfoWorks network model, in consultation with the System and Asset Planning (SAP) team and Asset Analytics team.

3.7 Transient model configuration

The model configuration must:

- be based on a steady-state model for a range of hydraulic operating conditions
- be scaled and not drawn schematically
- be based on the Darcy-Weisbach friction formula, and
- adopt simulation runs that are long enough to catch any return waves to superimpose on the direction of water flow.

3.8 Scale of transient model

The scale of the model must be determined by:

- the importance of the model and its intended use
- the level of skeletonisation appropriate to the model, and
- the scale of the system being analysed.

As a minimum, but subject to engineering judgement:

1. For analysis of systems from pump or valve boundary conditions to other system boundary conditions (e.g. reservoirs, tanks or other pumps/ valves), models with the following discretisations:
   i. a maximum discretisation of 10 m is applicable for systems with pipelines > 1 km and ≤ 5 km in length, and
   ii. a maximum discretisation of 50 m is applicable for systems with pipelines > 5 km in length.
2. For analysis of partial systems (e.g. pipework within 1,000 m of and/or inside a pumping station or valve station), artificial boundary conditions shall be set up to replicate system pressures accurately before a transient event and models with the following discretisations:
   i. a maximum discretisation of 1m is applicable for systems with pipelines ≤ 100 m in length, and
   ii. a maximum discretisation of 5m is applicable for systems with pipelines > 100 m and < 1,000 m in length.

A sensitivity analysis must be undertaken to evaluate the effect of changes in maximum model discretisation lengths and confirm that the discretisation adopted does not introduce problematic levels of numerical dispersion in the model predictions.

3.9 Model parameters

Model parameters must be obtained from authoritative textbooks or equipment suppliers. Appropriate sensitivity analysis is required to cater for unknowns or uncertainties. General observations are provided in the following sections on a selection of model parameters.

3.9.1 Wave celerity (wave speed)

Most software packages have built-in wave celerity calculators. Pipeline restraint conditions should be determined as either unrestrained or partially/fully restrained before use in the wave speed equation:

1. Unrestrained – typically socketed or slip-on collar joints for metallic, plastic or MS or DI cement lined pipes with flexible joints sealed with O-Rings; and
2. Restrained – typically fully welded or concrete encased joints for metallic, plastic or cement pipes with rigid joints.

3.9.2 Pipe material characteristics

Sydney Water has a large variety of different pipe materials within its water and wastewater systems. In the absence of specific information, the following ranges of Modulus of Elasticity and Poisson ratio values (for restrained pipes) may be used (Table 1).

Table 1: Modulus of Elasticity and Poisson Ratio

Pipe Material	Modulus of Elasticity (GPa)	Poisson ratio
Mild steel (MS)	200 – 207	0.30
Cast Iron (CI)	80 – 170	0.25 – 0.27
Ductile Iron (DI)	172	0.28 – 0.30
Asbestos Cement (AC)	23 – 24	0.20 – 0.30
Polyethylene (PE)	0.80 – 1.10	0.40 – 0.50
Unplasticised polyvinyl chloride (uPVC)	2.40 – 3.50	0.45 – 0.46
Fibreglass	50	0.35
Concrete	14 – 30	0.10 – 0.15
Reinforced concrete	30 – 60	0.25

(Ref: American Water Works Association. (2017). *M32 - Computer Modeling of Water Distribution Systems*. Denver: Library of Congress.)

Caution must be exercised when analysing an existing system because, depending on the installation date, the relevant standards for older pipelines (including internal pipe diameters and pressure ratings), may be different compared with the corresponding new standard.

AC pipes can be subject to leaching of cement due to internal and/or external conditions. Care should be taken with wall thickness assumptions and the effective pressure rating of old AC pipes.

Similarly, assumptions with respect to the condition of cement linings in old CICL pipes should be treated with caution. Sensitivity testing may be appropriate depending on the age and known condition of the pipes.

3.9.3 Pump parameters

Pump data should be obtained directly from the supplier. Inertia should include pump, motor, coupling and water in the volute.

Modern design and construction techniques have resulted in lighter pumps, resulting in lower inertia. Inertia data from suppliers is always best and preferred, but not always available.

In the absence of manufacturer supplied information, pump and motor inertias may be calculated as follows.

The moment of inertia for larger and older pumps is given by:

$$I_{pump} = 0.03768 \times \left[\frac{P}{\left(\frac{N}{1000}\right)^3} \right]^{0.9556} \qquad \text{Eq. 1}$$

The moment of inertia for small, lightweight pumps is given by:

$$I_{pump} = 0.03407 \times \left[\frac{P}{\left(\frac{N}{1000}\right)^3} \right]^{0.844} \qquad \text{Eq. 2}$$

The moment of inertia for motors is given by:

$$I_{motor} = 0.0043 \times \left[\frac{P}{\left(\frac{N}{1000}\right)^3} \right]^{1.48} \qquad \text{Eq. 3}$$

Where

I = moment of inertia (kg.m^2)

P = shaft power of pump operating at its best efficiency point (kW)

N = rotational speed (rpm)

(Ref: American Water Works Association. (2017). *M32 - Computer Modeling of Water Distribution Systems*. Denver: Library of Congress.)

Caution must be taken when calculating the moment of inertia. Different modelling software or suppliers sometimes provide inertia data or calculate inertia using different methods and units i.e. Nm^2 or kg.m^2.

3.9.4 Flywheels

In the absence of manufacturer supplied information, the moment of inertia of flywheels may be calculated as follows:

$$I = kmr^2 \qquad \text{Eq. 4}$$

Where

I = moment of inertia (kg.m^2)

k = inertial constant – depends on the shape of the flywheel (typically k = 1 for wheel loaded at rim like a bicycle tire, k = 0.5 for flat solid disc of uniform thickness)

m = mass of rotating element (kg)

r = radius from centre of rotating mass to centre of rotation (m)

3.9.5 Valve parameters

Valves must be modelled and analysed using the characteristic valve properties as supplied by the manufacturer. Data sheets must be attached in an appendix to the design report.

4. Transient analysis

4.1 System operations

A fundamental basis for any transient model is a clear understanding of the operation of the system. Any transient analysis must first determine the normal and abnormal operating scenarios (see item 8 Definitions) of the system taking account of the possible causes of unacceptable hydraulic transients. This must be done in consultation with the System and Asset Planning Group, and Operation and Maintenance teams. The designer must clearly determine the operating scenarios under which the transient model will be evaluated, and the strategies implemented to mitigate unacceptable pressures. For an existing system, the Sydney Water steady state InfoWorks model is used as a basis of the transient model. The steady state model needs to be calibrated against existing operational data to ensure the steady state condition is valid before proceeding with the transient analysis.

The following modelling scenarios should be considered, as a minimum, depending on the system being gravity fed, or a pumping system:

- Pumped system
  - power failure
  - controlled and uncontrolled pump start-up
  - controlled and uncontrolled pump shut down
  - rapid valve closure, or rapid valve opening
  - mechanical device failure e.g. air valves not operating.
- Gravity system
  - rapid valve closure, or rapid valve opening
  - mechanical device failure e.g. air valves not operating.

In addition to the modelling scenarios listed above, and during the investigation phase, the design engineer must determine all possible scenarios that may introduce unacceptable transient pressures. The design engineer must then consider non-standard operations as well as potential inadvertent, improper or unauthorised operations, e.g. human error. The objective in this regard is to identify potentially catastrophic operational scenarios and mitigation measures to ensure a fail-safe design.

For example, valving on a large transfer main might be designed with two forms of control, auto and manual. A standard operating procedure might ensure safe system operation under auto control; however, improper manual operation might introduce unacceptably high pressures, or vacuum conditions, that could result in a pipeline burst or collapse. In this case, some other fail-safe mitigation measures might be considered, for instance, as an emergency last resort the operation of a bursting disc (rupture disc).

Consequently, consideration should be given to the consequences of malfunction of surge control devices, particularly in high risk situations.

It remains the responsibility of the design engineer to consider all possible scenarios and carry out detailed analysis of any possible scenario which may have an impact on the transient performance of the system. This should be undertaken in consultation with relevant stakeholders (e.g. commissioning teams, and operational and maintenance teams).

4.2 Checklist and indicative table of contents

A transient modelling checklist and an indicative transient analysis report table of contents are provided in Appendix A and Appendix B respectively.

In broad terms, it is expected that transient analysis reports will include, as a minimum:

- Brief description of the wider context of the project.
- Description of the proposed infrastructure and its range of operating modes.
- Background on any interfaces with existing operational infrastructure.
- Comment on potential future system augmentations.
- Brief description of model and its limitations (quoting version number).
- Model inputs and assumptions with reference to data sheets attached in appendices.
- Sensitivity analysis.
- Reference to Sydney Water stipulated requirements and deviations from standards. Deviations must be accepted prior to submitting the final report.
- Discussion of operational modes and selection of cases for modelling.
- Clear definition of steady state HGL (considering maximum and minimum system curves).
- Assessment of unprotected and protected system configurations.
- Maximum and minimum pressure envelope presented in terms of net positive and negative pressures.
- Comment on a range of abatement measures not just one selected solution (why other options were rejected).
- Model scenarios for air valves closed or blocked and malfunction of mitigation devices.
- Comment on infrequent versus regular operations and significance to design and operations.
- Model and present results for a range of control options (design max/min, prevention of column separation, etc).
- Discussion of results and any appropriate sensitivity testing.
- Conclusions and recommendations.
- Appendices

5. Transient control measures

5.1 Planning control measures

The best option to control transient pressures is to eliminate, as far as reasonably practicable, the possible causes of transient pressures. This may include options such as:

- reduce the flow velocity
- use a pipe material with lower modulus of elasticity/celerity
- increase the pressure rating of the pipe
- re-route/regrade the pipe to avoid high points or points which may induce or exacerbate transient pressures.

All these options should be considered on the basis of risk and cost benefit analysis, taking account of capital costs as well as operational and maintenance costs.

5.2 Mechanical and electrical equipment

Transient control measures may also include a wide range of mechanical and electrical equipment, including soft starters or variable speed drives, flywheels, control valves, relief valves, non-return valves, hydropneumatic tanks, surge tanks and bursting discs. Such equipment must comply with the relevant Sydney Water technical specifications and Australian Standards.

It is Sydney Water's preference to limit the use of mechanical and electrical devices for the control and/or mitigation of transient pressures as far as reasonably practicable.

General observations are provided in the following sections on a selection of common mechanical and electrical transient control measures.

5.2.1 Soft starters and variable speed drives (VSDs)

Soft starters and VSDs are often required on pumping systems to reduce impacts on the power supply. In some instances, the primary purpose of VSDs may be to meet some process requirement, for instance, levelling out flow into a wastewater treatment plant or maintaining constant pressure in water supply network. Nevertheless, in normal operation both soft starters and VSDs can be used to reduce transient pressures by controlling pump starts and stops.

Typically, soft staters have adjustable but limited ramp up and down time settings, usually 10 to 30 seconds, which in some cases may not be enough to control water hammer. VSDs have infinite ramp up and down curves and can maintain pressure transients within limits. However, the length of time pumps can operate below the pump's minimum continuous operating flow during start and stop needs to be considered, especially for wastewater pumps which have a tendency of ragging up at low speeds.

Soft starters and VSDs are both ineffective in power failure scenarios.

5.2.2 Flywheels

Flywheels are sometimes used to mitigate surge in power failure scenarios. They are suited to dry well or above ground pumping installations but not submersible pumps. They are often considered on long pipelines with low static heads where surge vessels would be excessively large. They may also be suitable for bi-directional pumping stations.

Although flywheels provide excellent surge mitigation under specific conditions, caution must be exercised when using flywheels. Considerations include:

- Flywheels require significantly higher starting currents.
- Flywheels can make fine speed control of pumps more challenging (by making the pumps 'heavier', they become less responsive to quick speed changes to maintain a setpoint pressure).
- Flywheels will necessitate longer start and stop times. In wastewater applications, it may not be possible to arrest the motion of the pumps fast enough to avoid ragging. In water pumps, the use of flywheels could require a larger storage/buffer volume to allow for the fact that the time that passes between requiring pumping and obtaining pumped flows could be longer than normally expected.
- Flywheels may have significant installation implications. The addition of flywheels has broader implications for space clearances around the pump for its guarding, supporting plinths, etc.

5.2.3 Non-return valves and valve slam

Non-return valves are usually located on pump discharges for the prevention of reverse flow. They can also be used in other circumstances for the purposes of transient control, for instance, on one-way surge tanks or as sectional non-return valves on pressure mains. In the latter case, non-return valves are located some distance from the pumping station to 'shorten' the length of the main and hence reduce transient flow.

Several types of non-return valves are available. The type of valve should be carefully selected to ensure that its operational characteristics (such as closing time) are appropriate for the transient flow reversals that can occur in the system. The type of valve must also be suitable for the type of service such as wastewater.

Non-return valves must be modelled with data from the supplier to confirm that:

- they operate as per design during transient events
- excessively high transients, noise and vibration are not generated due to the valve slamming upon closing.

Non-return valve slam is defined as the sudden closure of a non-return valve while reverse flow is occurring. The non-return valve design must consider flow deceleration and match this to the characteristics of the valve to reduce slam.

Non-return valves must be designed to eliminate or minimise valve slam by either closing rapidly before reverse flow is fully established or closing very slowly once reverse flow has developed. A rapidly closing valve is preferred above a slow closing valve as the latter usually require a hydraulic damper which may fail or require excessive maintenance. Hence, a slow closing valve may only be considered if no other option is available.

The non-return valve should have the following characteristics:

- the disc should have low inertia
- the hinge pin should have low friction
- the travel of the disc should be short
- the closing motion should be assisted with springs or weights.

5.2.4 Pump station bypass non-return valve loops

Pump station bypass non-return valve loops can be used in scenarios where there are adequately high suction water levels. After a power failure, such a bypass loop can slow the reduction in flow by supplying water to the pipeline in the down surge period. The elevated water in the pump suction can drive water into the pipeline as negative pressures develop. This can be effective in downhill or flat pipelines. However, no upsurge relief is provided as no backflow can occur through the non-return valve.

5.2.5 Control valves

5.2.5.1 Pump Delivery Control Valves (DCVs)

Pump delivery control valves can be used to throttle the flow from a pump on start and stop. In general, pump control valves are favoured over VSD starters on pumps for drinking water applications to control the start up and shut down as they have no impact on pumping efficiency when fully open. However, like soft starter and VSDs, DCVs are ineffective in power failure scenarios.

5.2.5.2 Pressure/surge relief valves (SRVs) and surge anticipating valves (SAVs)

Fast acting pressure relief valves are not a preferred primary surge mitigation measure and must only be considered as a backup or secondary measure. Pressure relief valves may only be considered when no other feasible or cost-effective measure is possible, and with formal approval by Sydney Water. The design must present a strategy to deal with discharge from the valves within the environmental context.

Generally, fast acting relief valves and surge anticipating valves cannot be used in wastewater systems. In scenarios where a relief valve needs to be installed, the outlet of the valve must be routed to a suitable drain point. Reaction loads due to sudden release of water must be countered to properly restrain the valve to prevent damage in the branch connection to the header.

These types of valves can limit high pressures but won’t prevent vapour cavities or eliminate low pressures.

5.2.5.3 Pressure reducing valves (PRV)

Pressure reducing valves are commonly used within water reticulation networks to maintain customer service pressures within acceptable limits. PRVs can have a damping effect on transient pressures but they do not prevent the transmission of transient pressures and cannot be relied upon for surge suppression purposes.

5.2.6 Air valves

Air valves are required in water and wastewater systems to enable filling and emptying of mains, and to expel accumulated air/gas that might otherwise reduce the hydraulic performance of the system. Different types of air valves are required for water and wastewater applications.

Sydney Water does not allow the use of air release and vacuum relief valves as the primary means of pressure relief. Air release and vacuum relief valves may be used as secondary means of transient pressure mitigation.

An air valve at a high point may prevent vapour formation at the valve itself but other vapour pockets and sub-atmospheric conditions may persist elsewhere along the main (high pressures may not be significantly reduced in some cases). If air is admitted into a system and not expelled then velocities can be increased due to the change in flow area, potentially affecting the performance of pumps.

Due attention must be given to the sizing of air valves as adverse effects can occur due to lack of capacity to expel or admit air. Incorrectly sized air valves can lead to valve slam, valve chatter, excessive noise and reverberation. In some cases, silencers may be required.

Different makes of air valve require greater or lesser positive seating pressures to prevent leakage. It is noted the AS 4956 (Air valves for water) and AS 4883 (Air valves for sewerage) standards for air valves requires a minimum seating pressure of 50kPa. Designers need to refer to Sydney Water's *Technical Specification - Mechanical*.

Air valves require frequent maintenance and can malfunction and/or be closed from time to time for operational purposes. Therefore, transient simulations must always include a case of all air valves being closed. This is a requirement whether the valves are designed to fail open or not as they can be isolated for maintenance or be blocked.

Designers must also consider environmental factors related to the release or ingress of air, including volume of air and frequency as well as odour, health and noise issues.

5.2.7 Surge tanks

Open surge tanks, also sometimes referred to as standpipes, can be used where air exposure is not a concern (e.g. raw water pipelines and roofed drinking water tanks). In some cases, they can also be used on wastewater systems, provided the air surface is vented back to the wet well or an appropriate odour control strategy is employed. Typically, these tanks require topping up with water after each transient event.

Two-way surge tanks are unsuitable in cases where the standpipe is prohibitively tall. However, a non-return valve used in conjunction with a surge tank, known as a one-way surge tank, can be used to reduce the height of the tank but then it has no effectiveness in mitigating high pressures.

For water supply systems, designers must consider the volumetric turnover of water stored in surge tanks, including the frequency of turnover to meet minimum water quality standards. Overflow from the tank also needs to be considered in case of non-return valve leaking or sticking open.

Transient modelling must establish the necessary maximum and minimum tank water levels and volumetric requirements of the tanks in conjunction with sizing of valving, minimum opening flow, varying degrees of valve percentage open over the range of differential operating pressures and sizing of pipework.

5.2.8 Hydropneumatic tanks (surge vessels)

Surge vessels are also known as hydropneumatic tanks, pressure accumulators, compressor tanks and gas accumulators. Some of these tanks use compressors to charge with air ('air-over-water' vessels). Others have a membrane and are pre-charged with nitrogen or air, known as bladder type surge tanks. Commercial package designs are available for both water and wastewater applications.

Surge vessels can be effective in eliminating vapour cavity formation. After a pump stop or a valve closure when the water column keeps moving gas pressure allows water in the pressure vessel to flow into the system to prevent negative pressure. Likewise, limited reverse flow into the surge vessel is controlled by the compressible gas/air. In this way pressure vessels can eliminate high pressure spikes resulting from collapse of vapour cavities.

Typically, operating fluid levels are maintained between a minimum of 50% and a maximum of 70% of the total volume of the vessel(s) under all operating scenarios other than a surge event. During a surge event the fluid levels must be maintained between 20% and 90% of the vessel(s) volume provided this does not result in overpressure conditions or the escape of air. Modelling must demonstrate that these criteria are met.

Surge vessels must be able to withstand the maximum and minimum anticipated transient pressures when one duty vessel is out of service (e.g. due to maintenance or control system failure). Surge vessels must also be designed to withstand the maximum shutoff head in the pumping system.

The requirements for surge vessels on water systems apply also to wastewater systems except that any pressure relief provided should be directed to a suitable discharge location. Surge vessels with bladders are preferred to avoid the use of compressors, but they are not available in large sizes. Regardless, all surge vessels must be periodically re-filled due to compressed air/gas loss due to leakage or absorption.

The polytropic index for air and/or nitrogen contained in any surge vessel must be taken as 1.2 within the following equation used to determine the relative water / wastewater to gas proportions in surge vessels over the range of applicable steady state and transient pressures:

$$C = PV^n \qquad \text{Eq. 5}$$

in which

P = absolute pressure,

V = volume of gas,

n = polytropic index = 1.2 and

C = a constant

When a significant volume is required, two smaller gas vessels should be considered to provide redundancy whenever one unit has to be maintained, or in case one loses its gas volume and is ineffective during a transient. The following appurtenances require careful design for ‘air-over-water’ vessels:

- There should be min. two air compressors (1 duty + 1 standby), each equipped with an air receiver to store enough air at the required pressure to supply the vessel for short times after a power failure. Compressors should be capable of running from generators during an extended power failure.
- Level-control probes should be set for high and low level, high and low alarm. Avoid setting high- and low-level probes too close to the normal operating range to avoid spurious warnings. This can cause operators to ignore more serious low or high-level alarms.

5.2.9 Bursting discs

Bursting discs can be provided as a backup fail-safe measure to protect the integrity of a pipeline system in a possible catastrophic, but very rare event. They are not considered to be a primary transient pressure control device.

6. Operation and maintenance considerations

6.1 Design considerations

Key operation and maintenance issues that require consideration in the design of pressure systems include:

- Ensuring that transient analysis considers the full range of operational scenarios.
- Minimising the use of transient mitigation measures that require high operational or maintenance inputs (e.g. minimise number of air valves where possible).
- Mitigation measures to avoid regular vacuum wherever possible (especially on water supply systems due to water quality risks).
- Ensuring pressure systems are fail-safe under scenarios of equipment malfunction (e.g. air valves, AICVs, SRVs, etc).
- Ensuring system is fail-safe under standard and special operating procedures as well as potential inadvertent improper operation.
- Consideration of historical operational experience in cases where new infrastructure interfaces with existing systems.
- System risks and life-cycle costs.

6.2 Standard and special operating procedures

Any surge mitigation strategy must address appropriate re-start procedures after a transient event, ranging from automatic re-start capability to the need (at times) for manual intervention. Procedures to be considered would include:

- Determination of state of system after a surge event (possibility of a major failure or malfunction of a piece of equipment).
- Need for pump reset time.
- Minimum times required for air valves to operate and allow full recharge of pipeline.

Following a power failure or emergency shutdown, pumps should be restarted only after transient pressures have had sufficient time to decay and air has been removed from the pipes as much as possible. A transient decay analysis can be simulated, and a timer should be used to prevent a premature pump restart. Should significant air still remain in the water system, a fast restart of a pump may increase hydraulic transients.

The air trapped at local high points must always be released during both normal and emergency pumping operations. During line filling, air at local high points must be vented in the proper order and pump flow must be limited to 0.3 m/s to avoid severe hydraulic transients and possible pipe breaks.

7. Design for pressure

This guide only considers transient analysis and implications for pipeline design in terms of pressure only. It does not provide guidance on the overall structural design of pipelines. The structural design of a pipeline must be undertaken as a specific design action with input from the transient analysis results.

7.1 Design pressure

The design pressure of the system must be the maximum of the static, steady state and transient events, for all operating scenarios i.e. existing and future.

For water/ recycled water reticulation networks, the minimum design pressure must be 1200 kPa as per the *WSA03 Water Supply Code of Australia (Sydney Water edition)*. A reduced design pressure may be considered for transfer and distribution mains, subject to all operating scenarios being considered in consultation with all relevant stakeholders.

In the event that the calculated transient pressure is less than 200 kPa above the steady state, a minimum allowance of 200 kPa above the steady state must be made.

The design engineer must determine all operating pressures and design accordingly. In some instances, transient pressures may not be the governing factor in calculating the design pressure (e.g. static case of pumping against a closed valve may be the governing operating scenario).

7.2 Maximum pressure limits

7.2.1 Metallic pipes

For metallic pipes, differentiation is made between uncontrolled infrequent transient events (e.g. water hammer resulting from power failure) and controlled frequent cyclical pressure transients (e.g. pump start/stop) in determining the Design Pressure.

For DI pipes and fittings complying with AS/NZS 2280, and metallic flanges complying with AS/NZS 4087, the Design Pressure must not exceed the Pressure Class rating (PN) or Allowable Operating Pressure (AOP). The Design Pressure must include frequent transient events (refer Figure 1).

Under infrequent transient events, the internal pressure must not exceed the Maximum Allowable Operating Pressure (MAOP), which is 1.20 times the AOP. Derating of metallic pipes, fittings and flanges due to fatigue, temperature or other phenomenon is typically not required in conventional water/ wastewater systems.

For MS pipes complying with AS 1579, the maximum allowable stress in the steel pipe wall at the Design Pressure must not exceed 72% of the minimum yield stress (MYS). Under infrequent transient conditions, the allowable stress can be raised to 90% of MYS.

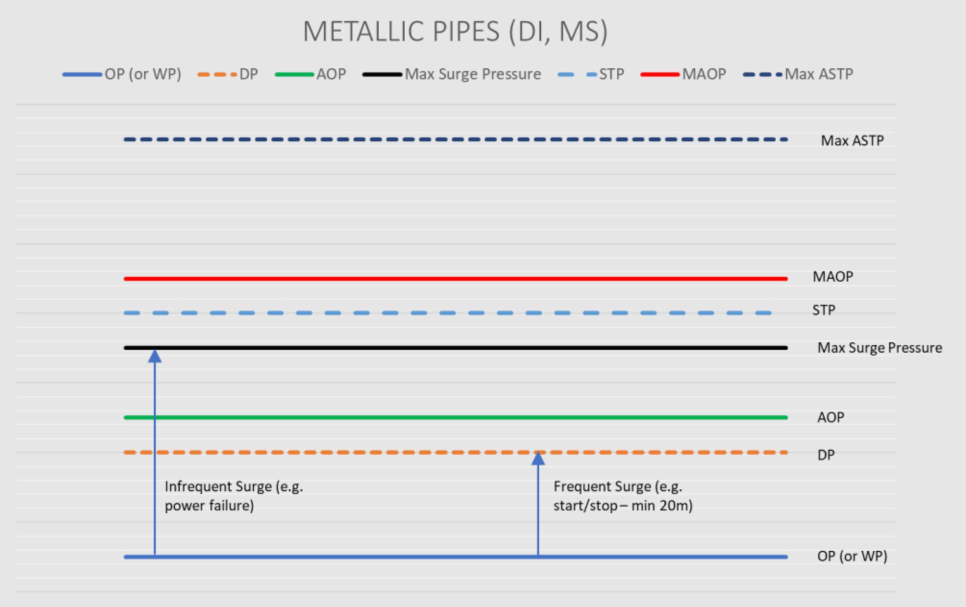

Figure Definitions:

Max ASTP: Max Allowable Site Test Pressure =
(1.25 x AOP)

MAOP: Max Allowable Operating Pressure
DI - (1.20 x AOP)
MS - 90% of MYS

STP: Site Test Pressure =
(1.0 – 1.25) x DP ≤ ASTP

Max Surge Pressure: ≤ MAOP

AOP: Allowable Operating Pressure (kPa)
DI – Pressure Classification PN = AOP/100
MS - 72% of MYS

DP: Design Pressure (≤AOP)

WP (or OP): Operating Pressure or Steady State Working Pressure

Figure 1: Relationship between Operating and Allowable pressure - Metallic Pipes

7.2.2 Plastic pipes

Various plastic pipes may be used in Sydney Water networks including oPVC, mPVC, GRP and PE pipes, complying with various requirements of Sydney Water's *EPS 500 – Engineering Product Specification for Standard Pipes and Fittings for Networks.*

Unlike metal pipes, no differentiation is made between infrequent and frequent transient events for pressure design of plastic pipes. The Design Pressure must include all infrequent and frequent transient events. For plastic pipes, the Design Pressure must not exceed the calculated Maximum Allowable Operating Pressure (MAOP).

The MAOP for plastic pipes is generally the reduced pressure rating of the pipe (PN) after application of any derating factors due to fatigue or temperature, and application of design factors for PE pipes.

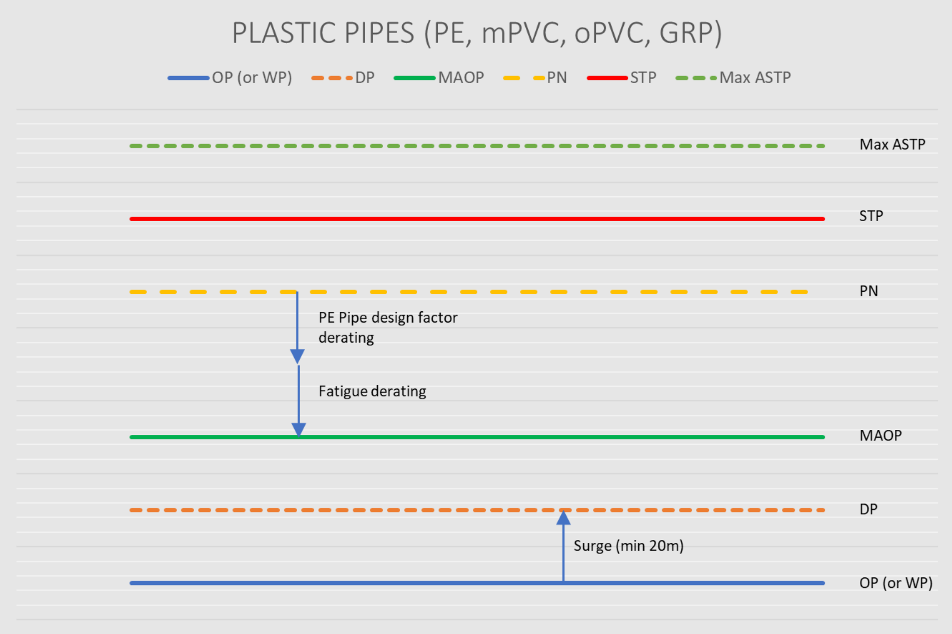

Figure Definitions:

Max ASTP: Max Allowable Site Test Pressure = (1.25 x PN)

STP: Site Test Pressure = (1.0 – 1.25) x DP

PN: Nominal Pressure Classification

MAOP: Max Allowable Operating Pressure

DP: Design Pressure (≤ MAOP)

WP (or OP): Operating Pressure or Steady Sate Working Pressure

Figure 2: Relationship between Operating and Allowable pressure - Plastic Pipes

7.2.3 Fatigue

In addition to a transient analysis, a fatigue analysis must be undertaken for plastic pipes to ensure that the typical system operating pressures and/or transient pressures do not lead to premature failure. The transient analysis report must include a section on fatigue analysis.

It is important to differentiate between a transient event which is rapid short duration loading, and fatigue which is associated with cyclical loading where the stress oscillates rapidly about a mean level. Plastic pipes subjected to cyclical loading are susceptible to fatigue failure. Design engineers are required to include a fatigue de-rating factor in the design of thermoplastic pipes such as PVC, GRP and PE.

A common cyclical loading arising from frequent transients is the normal pump stop/start cycles in a pumping station, particularly sewage pump stations. The transients generated from these cycles may not exceed the safe working pressure of the pipe but may generate fatigue failure in the long term.

7.2.4 Derating for PE pipes

The pressure rating of PE pipes must also be reduced through application of design factors in accordance with AS/NZS 4130 and the *Sydney Water Technical Specification - Civil.*

7.2.5 Existing systems

Reduced pressure limits apply to new pressure transients introduced to existing systems. Increase in transient pressures for existing systems must be limited to 50 kPa over the current pressure envelope. For sensitive systems (e.g. old pipe networks with brittle CICL and AC pipes, or areas of high pipe break / leakage etc.) the pressure must be maintained within the current pressure envelope. This must be determined in consultation with the Sydney Water Operation and Maintenance teams.

7.3 Minimum pressure limits

It is desirable to have positive pressure in the system under all operating scenarios to ensure air, groundwater and possible contaminants won't be drawn into the pipeline. It is also desirable to have at least 50 kPa of positive pressure to ensure air valves do not leak. This is of a particular concern in sewerage systems due to both pollution of the environment and sewage fouling the valve seal which may then leak under higher pressures as well.

A positive pressure of 50 kPa must be maintained in the system during normal operation (i.e. including frequent controlled transient events like pump start and stopping).

A drinking or recycled water supply system must never have sub-atmospheres pressures, under any scenario due to water quality risks.

In wastewater systems occasional sub-atmospheric or negative pressures (abnormal operation) may be acceptable, provided the pipeline can structurally withstand the negative pressures.

7.4 Maximum and minimum transient pressures

Pressure criteria for the design of transient pressures are as follows:

Table 2: Pressure Criteria

	Normal Operation (incl. frequent controlled surge)		Abnormal Operation (incl. infrequent uncontrolled surge)	
	Drinking Water/ Recycled Water	Sewer	Drinking Water/ Recycled Water	Sewer
Maximum pressure *Metal Pipes*	1.3 x WP (< AOP)	1.3 x WP (< AOP)	1.5 - 2 x WP (< MAOP)	1.5 - 2 x WP (< MAOP)
Maximum pressure *Plastic pipes*	1.3 x WP (< MAOP)	1.3 x WP (< MAOP)	1.5 - 2 x WP (< MAOP)	1.5 - 2 x WP (< MAOP)
Minimum Pressure	50 kPa	50 kPa	20 kPa	-100 kPa*

- WP - Steady state working pressure (not including surge)
- * Full Vacuum

Notwithstanding the pressure requirements of Table 2, where innovation, excessive costs, unacceptable risks or a specific site condition makes compliance not feasible or reasonably practicable, the design engineer must present an alternate solution which is fit for purpose. Where the design solution deviates from the requirements, Sydney Water's Deviation from Standards Procedure must be followed.

8. Definitions

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>Competent engineer</td><td>Suitably qualified and experienced engineer with the ability to apply knowledge and skills to achieve the intended design, construction, testing or monitoring task. For engineering tasks related to design, engineering personnel who meet requirements of the Sydney Water Engineering Competency Standard.</td></tr>
<tr><td>Water hammer, surge or transient pressures</td><td>Three synonymous terms referring to the investigation of pressure changes in pipelines, typically caused by sudden changes in flow velocity (e.g. pump stop/start, valve opening/closing). These terms are used interchangeably within these guidelines.</td></tr>
<tr><td>Normal operating conditions</td><td>Conditions consistent with the design intent for daily operation of the system. In the context of this guideline, normal operating conditions (not exhaustive list of examples):
For a pumping station, represents regular pump starts and stops under controlled power and within the range and limits of the design intent (includes higher pressures than steady state and lower pressures than normal operation).
For a pressure gravity main, represents controlled slow opening and closure of valves in accordance with design intent.</td></tr>
<tr><td>Abnormal operating conditions</td><td>Conditions consistent with uncontrolled and irregular operation outside the design intent and daily operation of the system. In the context of this guideline, abnormal conditions:
For a pumping station, represents power failure to the pump station and uncontrolled shut down of the pumps resulting in rapid pressure increases and decreases.
For a pressure gravity main, represents an uncontrolled rapid opening or closure of a valve resulting in rapid pressure increases and decreases.</td></tr>
</table>

9. Acronyms

Acronym	Definition
AICV	Automatic Inlet Control Valve
AOP	Allowable Operating Pressure
ASTP	Allowable Site Test Pressure
AV	Air Valve
CICL	Cast Iron Cement Lined Pipe
DCV	Delivery Control Valve
DI	Ductile Iron Pipe
DICL	Ductile Iron Cement Lined Pipe
DN	Nominal diameter
GRP	Glass Reinforced Plastic
HGL	Hydraulic Grade Line
MAOP	Maximum Allowable Operating Pressure
MS	Mild Steel Pipe
O & M	Operation and Maintenance
PE	Polyethylene Pipe
PN	Nominal Pressure Rating
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride Pipe
SAV	Surge Anticipation Valve
SOP	Standard Operating Procedure
SRV	Surge Relief Valve
uPVC	Unplasticised Polyvinyl Chloride
VSD	Variable Speed Drive
WAE	Work as Executed
WSAA	Water Services Association of Australia

10. Ownership

Role	Title
Group	Engineering and Technical Support
Owner	Engineering Manager
Author	Gary de Leeuw (Principal Civil Engineer)

11. Change history

Version	Issue Date	Approved by	Brief description of change and consultation
1	September 2022	Norbert Schaeper, Engineering Manager	New document

Appendix 1 Transient analysis and reporting checklist

The checklist should be used by all designers and modellers preparing transient analysis investigations for Sydney Water assets. The checklist must be completed by the verifier and submitted with the transient analysis report at 100% completion as a proof of verification. Design verification must be done as part of the design process before submitting the report to Sydney Water.

The checklist should be included or referenced in Sydney Water's contract documents for design only and design and construction of pressure pipes. It may also be used as a quick guide by the Sydney Water reviewers, project managers, project engineers and commissioning engineers.

Transient Analysis Checklist

Project Name:		**Project/ Case No:**	
Location:		**Delivery Contractor:**	
Designer:		**Design Verifier:**	
Date:		**Competency Compliance**	

ITEM	REQUIREMENTS	Y	N	N/A	DESCRIPTION (for example)
1	Reference to earlier background studies and/or designs including a brief summary				Needs specification, planning report or operational incident report
2	Description of both the wider regional scheme and the specific project				Plans, profiles, basic components, sizes, demands/flows, key environmental constraints, future augmentations
3	Specific objectives of investigation				Maximum surge pressure for pipe class and structural calculations (establish test pressure), measures to meet minimum pressure design criteria (e.g. no vacuum under normal operations)
4	Discussions with operations staff regarding interfaces to existing infrastructure including O&M history, key operational issues and range of potential operating modes				Age of existing infrastructure, history of main breaks/leakage, noise or vibration issues, air valve leakage or noise, special operational considerations
5	Summary of design criteria				
6	Definition of steady state HGL				
7	Description of model and any limitations relevant to this project				
8	Summary of operating modes and selection of modelling scenarios for pump stop/start, etc. List infrequent and potentially inadvertent, improper, or unauthorised operating modes				
9	Outcome of unprotected mode worse case				Column separation, extensive low pressures and high pressures, potential for valve slam, etc
10	Consideration of system configuration and basic design options as mitigation. Discussion of air ingress/egress.				Reduce design head/ velocity, modify pipeline route or profile, materials or diameter, air controls/venting

Transient Analysis

11	Modelling of mitigation cases				
12	Steady state HGL				
13	Maximum and minimum pressure envelopes				
14	Component malfunction operating scenarios				
15	Comment on frequency and duration of transient outcomes, incl. valve slam analysis (if relevant)				
16	Sensitivity testing				
17	Conclusions and recommendations				
18	Deliverables – Report, Electronic model with…input/ output files…				
20	Data sheets included in Appendix				

Appendix 2 Transient analysis indicative table of contents

QA Record, Version and Date	
Table of Contents	
Abbreviations / Glossary	
Executive Summary	Key findings and recommendation
Introduction	Description of project, location, context etc
Objectives	Might include provision of inputs to pipe material selection and design pressure envelope, surge mitigation objectives, etc
Project Background	Proposed system, relevant background to project, design constraints, demands/loads, route(s) and profile(s), system configuration
Existing Infrastructure	Reference to any interfaces with existing infrastructure including Needs Specifications, WAE drawings, discussions with operators regarding system performance / validation and available monitoring and/or special requirements
Description of Model	Basic description of model and limitations
Input Data and Assumptions	Key system elements, sources of data and assumptions for model inputs
Modelling Scenarios	Description of critical cases including the “no mitigation – unprotected” case and options to prevent or limit cavitation
Modelling Results	Graphical presentation of results, interpretation of any apparent anomalies and sensitivity testing where appropriate
Discussion of Results	Observations, clarifications and conclusions
Recommendations	Design recommendations including any need for further investigations.
Appendices	Data sheets, detailed model input summaries, references, etc