Designing for Surge & Fatigue

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1. INTRODUCTION

All pipelines are subjected to pressure variations during their lifetimes. Some of these pipelines, e.g. rising mains, will experience significant and regular pressure surges, while others may be subjected only to minor diurnal pressure variations.

Rapid pressure fluctuations and surges generally result from events such as pump start-up and shutdown, or rapid closing or opening of valves, including "slamming" of air valves as can happen during venting of bulk air from pipelines.

For the purposes of the CoP, a pressure surge is defined as a rapid, short-term pressure variation. Surges are characterised by rapid, high-pressure rise rates, with minimal time spent at the peak pressure. Surge events usually consist of a number of diminishing pressure waves that cease within a few minutes.

The frequency and magnitude of the pressure transients affects the choice of pipe pressure class. Ensure that the following aspects are considered when designing for surges and fatigue:

- That the maximum and minimum pressures are within acceptable limits for the pipe and fittings for all surge events (including infrequent events such as power failure, emergency shut-down, rapid closure of fire hydrants);
- Consider the potential for fatigue and select the pipe pressure class accordingly, to allow for frequent repetitive pressure variations;
- The pipe and the quality of installation and their influence on the fatigue resistance of the pipe.

The following sections provide a methodology for dealing with surge and fatigue, so that pipes are adequately designed to provide the 100 year design life that is required.

The PIPA Guidelines may also be used, specifically the following:

- POP010A – Polyethylene Pressure Pipes Design for Dynamic Stresses
- POP101 – PVC Pressure Pipes Design for Dynamic Stresses

These may be found at http://www.pipa.com.au/Guidelines.html.

2. PRESSURE SURGE EVENTS

A surge analysis is required to check whether damaging pressure surges (or surges that could cause customer complaint) could occur in a system. The level of detail of the surge analysis should be appropriate to the pipeline. For example, a reticulation pipeline may require only consideration of rapid closure of fire hydrants and conservative selection of pipe pressure rating.

Pipelines that may be subjected to more severe surge effects e.g. rising mains, areas close to control valves (reservoir inlet valves and pressure reducing valves) and where specified by the Council, require a more detailed level of analysis, or the selection of pipe materials that are highly resistant to surge and fatigue issues.

The source(s) of significant pressure surges in a water system should be identified and included in any surge analysis. Mitigating measures may be needed to minimise any surges generated, and any surge control devices must be designed accordingly. As a minimum, such a surge analysis should consider:

- Identified causative scenarios (e.g. power failure, pump trip, component failure, air valve operation, rapid closure of valves);
- The highest pressure along the pipeline;
- The lowest pressure along the pipeline;
- Vacuum and air relief requirements along the pipeline under all conditions.

Note that non-slam air valves may be required on plastic pipelines, to minimise the risk of severe surges being generated by the movement of trapped air, and to minimise the potential for instantaneous “slamming” shut of a conventional air valve.

If, during the design phase, it is found that the minimum pressure in the mains could fall below atmospheric pressure during pressure surge events or drain down, mitigating measures must be designed to eliminate or minimise these effects. If negative pressures are a possibility, buckling of the pipe must be considered and a safety factor of at least 2.0 applied.

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3. FATIGUE

Consideration of the effect of fatigue is particularly relevant to plastic pipes that are subjected to a large number of pressure cycles. Fatigue considerations can generally be ignored for ferrous pipe materials, e.g. ductile iron and concrete-lined steel. The important factors are the magnitude and frequency of the pressure fluctuations.

For fatigue loading situations, the maximum pressure reached in the pressure cycle must not exceed the nominal pressure rating of the pipe.

Fatigue does not need to be considered if the number of pressure cycles during the pipe's designed lifetime does not exceed the values below

Table 1 Critical number of surges in pipe lifetime

Pipe Material	Critical Number of Cycles in Lifetime
PVC-U, PVC-O	100,000
PE 80B, PE 100	300,000

The procedure for fatigue design is:

- confirm the design lifetime of pipeline (The pipeline design life must be taken as 100 years unless specified otherwise by the Council);
- estimate the likely number of pressure cycles during design life;
- calculate the range of pressure surges;
- calculate the fatigue load factor;
- determine the equivalent operating pressure;
- select the pipe PN rating.

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4. NUMBER OF PRESSURE CYCLES

Calculate the expected number of cycles during the pipe's lifetime, based on realistic estimates of the number of pressure cycles per day or per hour. If the primary pressure variation is followed by a smaller number of pressure fluctuations on each cycle, as shown in Figure 1, the calculated number of cycles should be doubled.

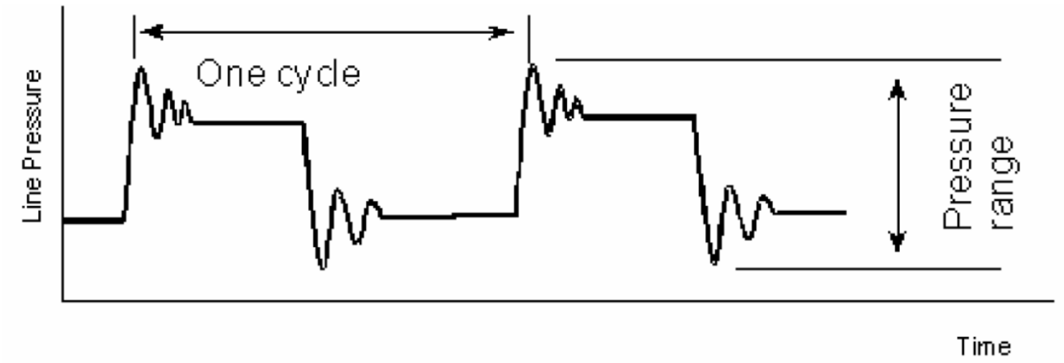

Figure 1 Pressure cycle and pressure range (from POP101 Figure 1)

The table below shows the number of pressure cycles over 100 years for various numbers of cycles per day and hour.

Table 2 Pressure cycles in 100 years for various numbers per hour and per day

Cycles Per Hour	Cycles Per Day	Total Number of Cycles in 100 Years
0.04	1	36,000
0.5	12	440,000
1	24	880,000
10	240	8,800,000
60	1440	52,500,000
120	2880	105,000,000

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5. RANGE OF PRESSURE SURGES

Calculate the pressure range of the regular pressure variations by surge analysis. Figure 1 shows a typical cyclic pressure pattern. Where pumps are controlled by variable speed drives, select a pressure cycle that is most representative of the expected pipeline operation over its design life.

The effects of infrequent or accidental conditions, e.g. power or surge protection device failures may be ignored, provided the peak surge pressure does not exceed the values derived from Table 19.

Note that the pressure range will vary along the pipeline. Economies may be possible on some pipelines by dividing the pipeline into sections and evaluating the fatigue design for each, subject to the approval of the Council.

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6. FATIGUE LOAD FACTOR

The fatigue load factors for plastic pipes are as shown below in Table 3 and Table 4

Table 3 Fatigue Load Factors for PE80B and PE100 (from POP010A Table 1)

Total Cycles	Cycles per day for 100 year life	PE80B	PE100
36,500	1	1.00	1.00
100,000	3	1.00	1.00
300,000	8	1.00	1.00
500,000	14	0.95	0.95
1,000,000	27	0.88	0.88
5,000,000	137	0.74	0.74
10,000,000	274	0.68	0.68
50,000,000	1370	0.57	0.57

Table 4 Fatigue Load Factors for PVC (from POP101 Table 1)

Total Cycles	Cycles per day for 100 year life	PVC-U	PVC-M	PVC-O
26,400	1	1.00	1.00	1.00
100,000	3	1.00	0.67	0.75
200,000	5.5	0.81	0.54	0.66
500,000	14	0.62	0.41	0.56
1,000,000	27	0.50	0.33	0.49
2,500,000	82	0.38	0.25	0.41
5,000,000	137	0.38	0.25	0.41
10,000,000	274	0.38	0.25	0.41

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7. EQUIVALENT OPERATING PRESSURE

Calculate this using the following equation:

Equation 1 Equivalent operating pressure

$$P_{eo} = \frac{\Delta P}{FLF}$$

where:	P_{eo}	= Equivalent operating pressure (bar)
	ΔP	= Cyclic pressure range (bar) (refer Figure 5)
	FLF	= Fatigue Load Factor (refer Figure 6)

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8. PIPE PRESSURE RATING

The specified pipe pressure rating (PN) must exceed both the equivalent operating pressure, P_{eo} and the maximum operating pressure for the system.