

Project	La Esperanza gravity supply	Date	16 Oct 2026
Element	Steel gravity main GM-1	Author	Eng. Ana Pérez

1 · Purpose and scope

Using the Michaud formula, one of the classical water hammer formulas, this report determines the surge head and the pressure envelopes of the steel gravity main GM-1 of the La Esperanza gravity supply, fed from a reservoir, for the closure of the valve at its end in 30 s. Geometry and levels come from the project, the pipe dimensions from the Author, the steel modulus from typical values, and the flow and maneuver conditions from the design discharge and the actuator setting, as listed in the input data.

2 · Input data

Parameter	Symbol	Value	Unit	Source
Pipeline length	L	2 000	m	Project longitudinal profile
Internal diameter	D	300	mm	Input by the Author
Wall thickness	e	8	mm	Input by the Author
Modulus of elasticity of the material	E	206	GPa	Typical value for steel
Steady-state velocity	v_0	1.5	m/s	Design discharge of the main
Valve closure time	T	30	s	Valve closure time (actuator setting)
Static level (water elevation in the highest reservoir)	Z_s	100	m	Maximum level of the head reservoir
Pressure rating of the pipe	PN	25	bar	Pipe pressure class

Pipeline centerline profile:

Point	Station	Elevation
Start (reservoir)	0+000.00	95 m
Intermediate point	0+800.00	60 m
End (valve)	2+000.00	20 m

3 · Assumptions

- Pressure wave speed by the Korteweg formula for a thin-walled elastic pipe with expansion joints along its length (no axial restraint, $c_1 = 1$).
- Gravity main of uniform characteristics (constant diameter, wall thickness and material) between the upstream reservoir, at constant level, where the wave is reflected, and the valve, located at distance L.
- Friction during the transient and protection devices (air vessels, surge tanks, relief valves) are not considered.
- Gradual maneuver ($T > t_c$): Michaud formula, which assumes a linear reduction of the velocity during the maneuver.
- Fluid: water, with density $\rho = 1\,000\text{ kg/m}^3$ and bulk modulus $K = 2.1\text{ GPa}$.
- Envelopes along the pipeline about the static line, at elevation $Z_s = 100\text{ m}$: the surge head is maximum at the valve and zero at the reservoir. The critical length $L_c = a \cdot T/2$, measured from the reservoir, separates the reach with the full surge head from the reach with a linear distribution down to the reservoir (triangle if $L \leq L_c$, trapezoid if $L > L_c$).
- Gauge pressures at each point: hydraulic grade elevation minus centerline elevation.

- The maximum and minimum hydraulic grade line (HGL) elevations are the envelope given by the classical formulas, obtained by superposing the surge head on the static line, without modeling cavitation; the physical meaning of the minimum pressure is bounded by the check against the vapor pressure.
- Criteria adopted: maximum pressure not exceeding the pressure rating of the pipe, PN = 25 bar; minimum pressure not below -0.98 bar, the vapor pressure of water (column separation).
- Acceleration due to gravity $g = 9.81 \text{ m/s}^2$.

4 · Methodology

Pressure wave speed (Korteweg) and critical time of the pipeline:

$$a = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1 + \frac{KD}{Ee}}} \quad t_c = \frac{2L}{a}$$

The surge head depends on the duration of the maneuver relative to the critical time: rapid maneuver ($T \leq t_c$), Joukowsky formula; gradual maneuver ($T > t_c$), Michaud formula:

$$\Delta H = \frac{a v_0}{g} \quad \Delta H = \frac{2L v_0}{g T}$$

Distribution of the surge head along the pipeline, with d the distance from the reservoir, and envelopes about the static line at each station x :

$$L_c = \frac{a T}{2} \quad \Delta H(d) = \frac{a v_0}{g} \min\left(1; \frac{d}{L_c}\right)$$

$$H_{\max}(x) = Z_s + \Delta H(x) \quad H_{\min}(x) = Z_s - \Delta H(x)$$

5 · Calculations

With the inputs expressed in SI: $D = 300 \text{ mm} = 0.300 \text{ m}$; $e = 8 \text{ mm} = 0.0080 \text{ m}$; $E = 206 \text{ GPa} = 2.06 \cdot 10^{11} \text{ Pa}$; $\text{PN} = 25 \text{ bar} = 254.929 \text{ m H}_2\text{O}$.

Pressure wave speed and critical time:

$$a = \frac{\sqrt{\frac{2.1 \cdot 10^9}{1\,000}}}{\sqrt{1 + \frac{2.1 \cdot 10^9 \cdot 0.300}{2.06 \cdot 10^{11} \cdot 0.0080}}} = 1\,232.57 \text{ m/s}$$

$$t_c = \frac{2 \cdot 2\,000}{1\,232.57} = 3.245 \text{ s}$$

Since $T = 30 \text{ s} > t_c = 3.245 \text{ s}$, the maneuver is gradual and the Michaud formula applies:

$$\Delta H = \frac{2 \cdot 2\,000 \cdot 1.5}{9.81 \cdot 30} = 20.39 \text{ m}$$

Critical length, measured from the reservoir:

$$L_c = \frac{1\,232.57 \cdot 30}{2} = 18\,488.5 \text{ m}$$

$L \leq L_c$: triangular distribution, from the surge head at the valve to zero at the reservoir.

6 · Results

Quantity	Value	Quantity	Value
Maneuver type	Gradual (Michaud)	Critical length, $L_c = a \cdot T/2$	18 488.5 m
Pressure wave speed, a	1 232.57 m/s	Maximum pressure in the pipeline	9.84 bar (station 2+000.00)
Critical time, $t_c = 2L/a$	3.245 s	Minimum pressure in the pipeline	0.49 bar (station 0+000.00)
Surge head, ΔH	20.39 m H₂O		

Envelopes at the profile points:

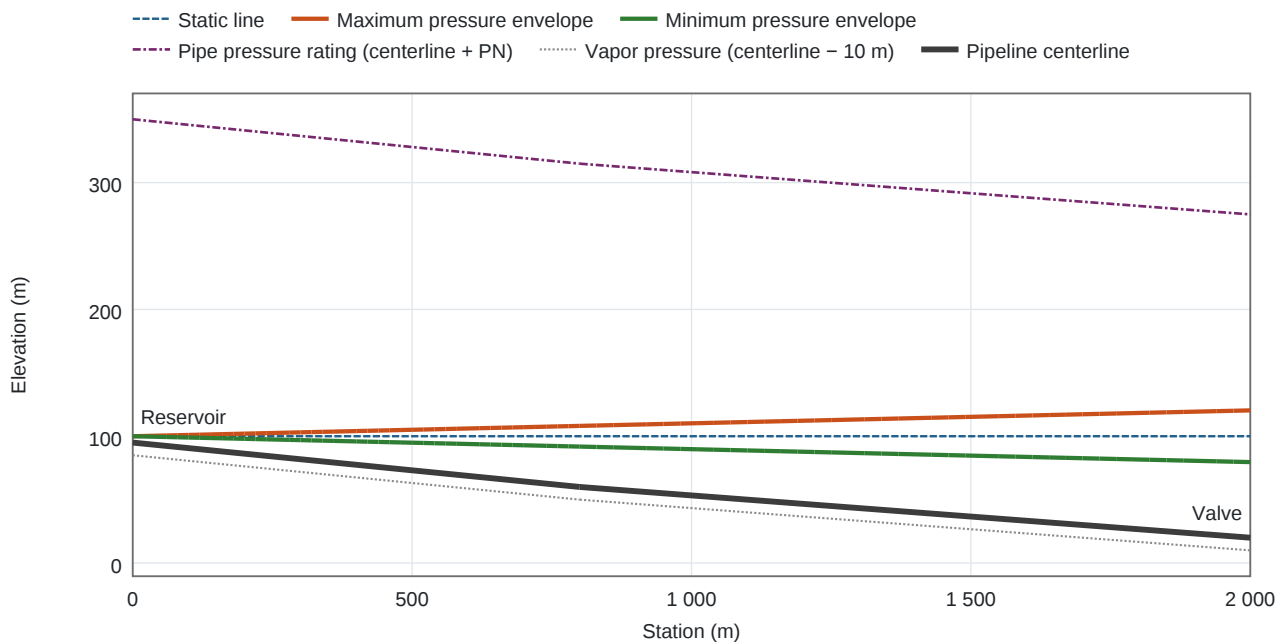
Station (m)	Centerline elev. (m)	ΔH (m H ₂ O)	Max. HGL (m)	Min. HGL (m)	Max. pressure (bar)	Min. pressure (bar)
0+000.00	95.00	0.00	100.00	100.00	0.49	0.49
0+800.00	60.00	8.15	108.15	91.85	4.72	3.12
2+000.00	20.00	20.39	120.39	79.61	9.84	5.85

7 · Pressure checks

Criterion	Limit	Calculated value	Result
Maximum pressure against the pressure rating	≤ 25 bar	9.84 bar (station 2+000.00)	✓ SATISFIED
Minimum pressure against the vapor pressure of water	≥ -0.98 bar	0.49 bar (station 0+000.00)	✓ SATISFIED

The pressure wave speed is 1 232.57 m/s, governed by the properties of water and the deformability of the steel pipe, since a stiffer wall yields a faster wave. The wave's round trip along the pipeline sets a critical time of 3.245 s. The closure time of 30 s given by the Author exceeds it, so the maneuver is gradual and the Michaud formula applies. The duration of the closure attenuates the surge head, which is 20.39 m H₂O. The critical length of 18 488.5 m exceeds the 2 000 m of the pipeline, so the whole main lies within the attenuated reach. The maximum pressure of 9.84 bar occurs at the valve end (station 2+000.00), and the pressure-rating check is satisfied with a 60.6 % margin. The minimum pressure of 0.49 bar occurs at the reservoir (station 0+000.00), above the -0.98 bar limit, so the vapor-pressure criterion is satisfied.

8 · Pipeline profile and pressure envelopes



Actual elevations; vertical scale exaggerated relative to the horizontal. In red, the reaches where the maximum envelope exceeds the pipe pressure rating or the minimum envelope falls below the vapor pressure.

9 · Conclusion

The closure of the valve on the steel gravity main GM-1 produces a surge head of 20.39 m H₂O. The envelopes give a maximum pressure of 9.84 bar at station 2+000.00 and a minimum pressure of 0.49 bar at station 0+000.00. Both the pressure-rating check and the vapor-pressure criterion are satisfied. The pipeline therefore withstands the maneuver considered under the adopted assumptions. These values result from the classical water hammer formulas for the maneuver considered.

10 · References

- Chaudhry, M. H. (2014). *Applied Hydraulic Transients* (3rd ed.). Springer. — Pressure wave speed, Joukowsky equation and critical time of the pipeline.
- Wylie, E. B., and Streeter, V. L. (1993). *Fluid Transients in Systems*. Prentice Hall. — Korteweg formula, restraint coefficient c_1 and moduli of elasticity of materials.
- Mendiluce Rosich, E. (1987). *El golpe de ariete en impulsiones* (2nd ed.). Bellisco. — Pump stoppage time, Michaud formula for gradual maneuvers, and pressure envelopes in short and long rising mains.

Calculations, checks and report drafting carried out with HidraSoftware Calculators, based on the data and criteria defined by the Author, under whose professional responsibility this document is issued.