

1 *Type of the Paper (Article, Review, Communication, etc.)*

2 **Checking Procedure of the Trieste (Italy) Subsea** 3 **Pipeline by Transient Tests. Preliminary Results**

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12 **Abstract:** The subsea transmission main (TM) of Trieste, Italy plays a crucial role in the water supply
13 system managed by AcegasApsAmga SpA (Hera Group). With the aim of implementing a
14 systematic inspection procedure – at present divers are used for periodic surveys –
15 AcegasApsAmga SpA decided to proceed with transient test-based techniques (TTBTs). In this
16 paper the results of preliminary transient tests generated by means of the existing devices – the first
17 option to be considered within TTBTs – are discussed and possible alternatives are highlighted.

18 **Keywords:** subsea pipeline; fault detection; transient-test based techniques.

19 **1. Introduction**

20 AcegasApsAmga SpA, of the Hera Group, manages the water systems of Padova and Trieste, in
21 the north east part of Italy.

22 Within the water supply system of Trieste, with its very important port, the subsea transmission
23 main (TM) plays a crucial role. In fact, it supplies not only the city but also the Carsico plateau. Such
24 an iron DN1300 pipe has a length of about 19 km and conveys a discharge equal to about 750 L/s with
25 a steady-state pressure equal to 7-10 bars according to the elevation. Since at present the inspection
26 of the Trieste TM is executed by divers, there is the need of implementing a systematic, and possibly
27 not too expensive, fault detection procedure.

28 In the last decades several technologies have been proposed for fault (e.g., leak) detection in
29 water distribution networks (WDNs). On the contrary, there are some limitations for TMs for which
30 the present most common fault detection technologies are of in-line type with tethered and free-
31 swimming sensors or acoustic correlators placed inside the pipelines (see, as an example,
32 www.puretechltd.com). A further option is the continuous monitoring at measurement sections
33 situated quite close to each other, i.e., at a distance of a few hundred meters (see, for example,
34 www.echologics.com). Because of the large length of the Trieste TM and its clear inaccessibility along
35 the route, the use of the transient test-based techniques (TTBTs) has been explored.

36 When TTBTs are used, pressure waves are generated to explore the system. It is worth noting
37 that TTBTs can be used to detect not only leaks but also other types of faults, such as partial blockages,
38 partially closed in-line valves, pipe wall deterioration, and illegal branches. In fact, any of such
39 anomalies gives rise to a reflected pressure wave whose characteristics allows understanding its
40 "nature" and detecting its location and size [1-4].

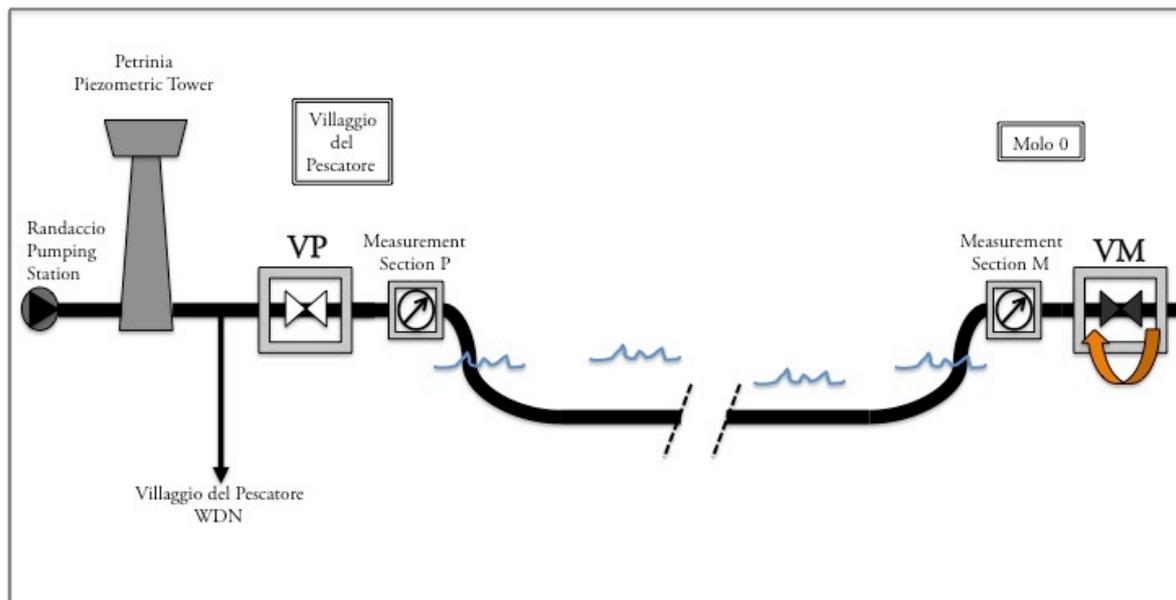
41 Within TTBTs, the choice of the suitable procedure for generating pressure waves, that
42 guarantees the diagnosis of the system without compromising its integrity, is one of the most
43 important decision to take. According to literature [e.g., 5-8], the choice of the transient test procedure
44 is strongly linked to the characteristics of the system and operating conditions. However, the first
45 and most obvious option is to generate transients by means of the installed devices, e.g. by

46 maneuvering (closing) valves and pumps (the so-called “explorative” tests). It is worth noting that
 47 even if such a preliminary phase may be quite time consuming, definitely it is essential. In fact, it
 48 allows understanding the transient response of the system and then designing the most appropriate
 49 type of test. Once it has been ascertained that such transients are not suitable (in other words, because
 50 of the characteristics of the generated pressure waves they do not allow detecting possible faults),
 51 alternative methods for pressure wave generation must be implemented.

52 In this paper the results of some “explorative” (preliminary) tests executed in the Trieste TM are
 53 reported and discussed in the view of the assessment of a reliable and safe fault-detection test
 54 procedure.

55 2. Explorative transient tests

56 The layout of the investigated system is reported in Fig. 1. The Randaccio pumping station
 57 supply the TM which is protected against water-hammer overpressure by means of the Petrinia
 58 piezometric tower. The small WDN of the “Villaggio del Pescatore” is supplied by the TM through a
 59 dedicated branch. At present, two valves are installed in land: the first (VP) at about the inlet section
 60 and the second (VM) at about the downstream end section. Preliminarily, it has been excluded the
 61 option of maneuvering the VP valve since it is too close to reflecting boundaries (i.e., the Petrinia
 62 piezometric tower and the “Villaggio del Pescatore” WDN). As a consequence, possible “explorative”
 63 transients could be those due to: (i) switching-off the pumps at the Randaccio pumping station, and
 64 (ii) totally closing the downstream end valve VM. The pressure time-history during transient tests
 65 (hereafter referred to as the *pressure signal, H*) has been acquired by means of piezoresistive
 66 transducers (Fig. 2a) – with a frequency acquisition of 1000 Hz – at two measurement sections:
 67 section P (Fig. 2b), just downstream of the VP valve, and section M (Fig. 2c), just upstream of the VM
 68 valve. It is worth noting that within TTBTs there is no need of measuring the discharge during the tests.
 69



70
 71 **Figure 1.** Schematic of the Trieste subsea transmission main (TM) managed by AcegasApsAmga SpA
 72 (Hera Group).

73 2.1. Transient generated by the pump switching-off at the Randaccio pumping station

74 At the Randaccio pumping station, the first pump switching-off causes a very slow pressure
 75 reduction that starts at section P at $t = 39$ min, 34 s (Fig. 3). According to the characteristics of the
 76 system and, very important, the place where such a transient is generated, the acquired pressure
 77 signals are not suitable for fault detection. Precisely, the following aspects must be taken into account:

78 (i) the Petrinia piezometric tower is situated between the section where the pressure waves are
 79 injected into the system and the system itself (as a consequence, it behaves as a sort of filter with the
 80 inertia of the mass of the water in the tower playing a very important role); (ii) the pump switching-
 81 off is a slow maneuver because of the inertia of the pumps (as a consequence, the generated pressure
 82 waves are not sharp enough [9] for a reliable fault detection [10]); and (iii) the "Villaggio del
 83 Pescatore" WDN, even if with a limited size, inevitably corrupts the pressure signal (in other words,
 84 the pressure waves generated in such a WDN make very arduous the understanding of the pressure
 85 signals). For the objection that the abovementioned negative aspects were absolutely predictable, it
 86 can be replied that the pump switching-off is a very simple and routine test. Nonetheless, it
 87 contributes to the knowledge of the transient behavior of the system.
 88



(a)

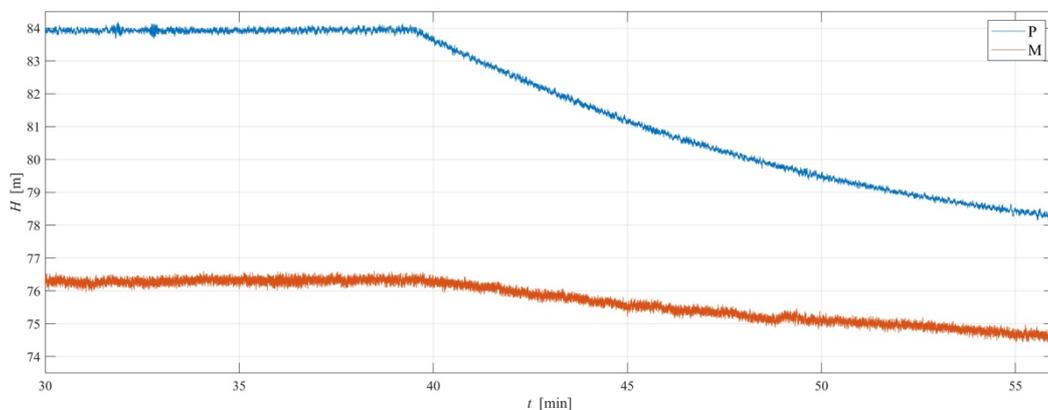


(b)



(c)

89
 90 **Figure 2.** Trieste subsea TM: a) pressure transducers installed at the measurement sections: b) P, downstream
 91 of the VP valve; c) M, upstream of the VM valve.



92
 93 **Figure 3.** Trieste subsea TM: pressure signals acquired at the measurement sections during transients
 94 generated by switching-off the pumps at the Randaccio pumping station.

95 *2.2. Transient generated by the closure of the VM valve*

96 Before totally closing the VM valve (Fig. 4), the discharge in the TM has been significantly
97 reduced for the following reasons: (i) to generate a safe pressure variation (i.e., few meters of water
98 column); and (ii) to make the closure as fast as possible in order to obtain sharp pressure waves [10].
99 With this aim, preliminarily the pumps at the Randaccio pumping station have been switched-off
100 (Fig. 3) and then the VM valve has been slowly and manually partially closed. After the pump
101 switching-off, the flow direction reversed and the TM was supplied by the Trieste WDN downstream
102 of "Molo 0". In fact, the manual partial closure of the VM valve causes a pressure decrease at $t = 65$
103 min, 11 s. Moreover, within the executed "transient sequence" (1st step: pump switching-off; 2nd step:
104 slow partial closure of the VM valve; 3rd step: fast complete closure of the VM valve), according to
105 the actual flow direction, the effects of the final maneuver (i.e., the fast closure of the VM valve)
106 happening at $t = 82$ min, 30 s, were those of a maneuver executed at the initial section of the TM. As
107 designed, the maximum value of the pressure oscillations is quite small and equal to about 2.7 m (see
108 the upper box in Fig. 5) and then the designed "transient sequence" is surely safe. However,
109 notwithstanding the preliminary partial closure of the VM valve, the final manual closure was not
110 fast enough since it was manual. Such a feature implies that single pressure waves cannot be detected
111 in the pressure signals and then the executed transient is not reliable for fault detection. However, in
112 terms of the transient response of the system, useful information were obtained about: (i) the pressure
113 decay after the completion of the maneuver, and (ii) the pressure wave speed, a . Precisely,
114 notwithstanding the large values of both the length and diameter of the TM [11], a very slow decay
115 of the pressure signal has been observed. In fact, as clearly highlighted in Fig. 5, the duration of the
116 pressure oscillations due to the fast closure of VM valve is larger than 48 min. Based on the pressure
117 waves arrival times at the measurement sections, the value $a = 1159$ m/s has been obtained. It is worth
118 noting that the knowledge of the value of the pressure wave speed is of a crucial importance for
119 designing safely any maneuver.



120
121 **Figure 4.** Trieste subsea TM: the VM valve at "Molo 0".

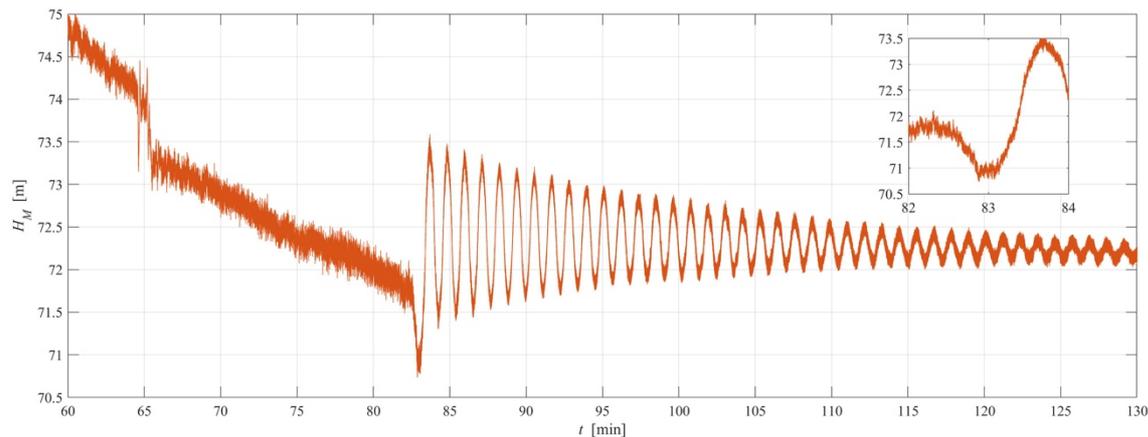


Figure 5. Trieste subsea TM: pressure signals acquired at the measurement sections during transients generated by the closure of the VM valve at “Molo 0”. In the upper box a magnification of the first characteristic period of the pressure signal after the total closure of the valve VM is reported.

5. Conclusions

At present, the inspection of the Trieste subsea TM is executed by divers. To reduce costs and increase the frequency of the inspections, AcegasApsAmga SpA of the Hera Group, who manages the system, decided implementing a systematic fault detection procedure. Because of the large length of the TM and its inaccessibility along the route, the option constituted by the transient test-based techniques (TTBTs) has been explored. Within TTBTs, preliminary tests concerned the pump switching-off at the Randaccio pumping station and the closure of the valve installed at the downstream end section of the TM. Such tests, even if useless for fault detection, provided a better insight into the transient response of the system.

In the continuation of the analysis, the following alternative solutions for generating a reliable transient for fault detection will be examined: (i) maneuvering a small-diameter side discharge valve, and (ii) connecting the Portable Pressure Wave Maker (PPWM) device refined at the Water Engineering Laboratory (WEL) of the University of Perugia [5].

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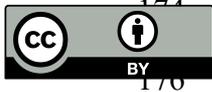
Author Contributions: All the Authors conceived, designed and performed the experiments; S. Meniconi, C. Capponi, M. Cifrodelli, and B. Brunone analyzed the data and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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