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Evaluating the structural priorities for the seismic vulnerability of civilian and industrial wastewater treatment plants

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ABSTRACT

Wastewater disposal systems are complex systems composed by several interconnected elements. In the aftermath of dramatic natural events, such as the earthquake, the failure of any of these elements can result in the deterioration of the environment as well as in the risk for the exposed population, due to leakage of untreated or un-properly treated wastewater on soil and/or its discharge into superficial waters.

This paper presents a multi-disciplinary methodology for the evaluation of the seismic vulnerability of municipal or industrial wastewater treatment plants, based on damage observation of available earthquake reports. Specific fragility curves and threshold values expressed in terms of Peak Ground Acceleration (PGA) are presented and compared with existing functions. The methodology fully comply requirements of most relevant and effective risk analysis tools or for land-use planning and can be adopted for the definition of structural priorities of plants.

1. Introduction

Past and recent strongest earthquakes (e.g. Loma Prieta 1989, Kobe 1995, Tohoku, 2011) affected dramatically either civil or industrial infrastructures. Wastewater Treatment Plants (WWTPs) also suffered severe damages, ranging from the temporary shutdown of the installation due to power outage to more significant structural failure. In some cases, the earthquake produced the collapse of the infrastructure, followed by the uncontrolled release of harmful and/or hazardous materials on soil and superficial waters, with undesirable consequences due to the decay of the environmental quality, public health and safety (Tang, 2000; Zare et al., 2010; Tang et al., 2011). A significant example is the case of the seismic sequence in Christchurch (New Zealand) on February 22nd and June 13rd, 2011. There, untreated municipal wastewater was massively discharged into Avon River, Heathcote River, Avon-Heathcote Estuary and sea. Two years later, the Environment Canterbury Regional Council still recommended avoiding the dermal contact with superficial water (ECRC, 2013). Eventually, the assessment of the seismic hazard and more in general the analysis of vulnerability of WWTPs is highly recommended in order to proactively predict, prevent and mitigate the most relevant consequences for the workers and for the population (Krausmann et al., 2011; Salzano et al., 2013). To this aim, structural priorities and other management options are needed (Kameda, 2000; Tugnoli et al., 2012). The obtained vulnerability functions can be adopted in existing tools for quantitative risk assessment and land use planning, which must include natural events as earthquake (Fabbrocino et al., 2005; Campedel et al., 2008).

Quite clearly, the effects of the earthquake on WWTP are quite difficult to be evaluated due to the complexity of WWTPs, which are composed by nodes (e.g. tanks) and links (pipes) with large differences in the seismic response. Furthermore, WWTPs are often part of the wider and more complex disposal system, which include other vulnerable lifelines as power supply and transportation systems. This complexity is shown in Fig. 1. There, WWTP is only an intermediate component of a highly hierarchical system.

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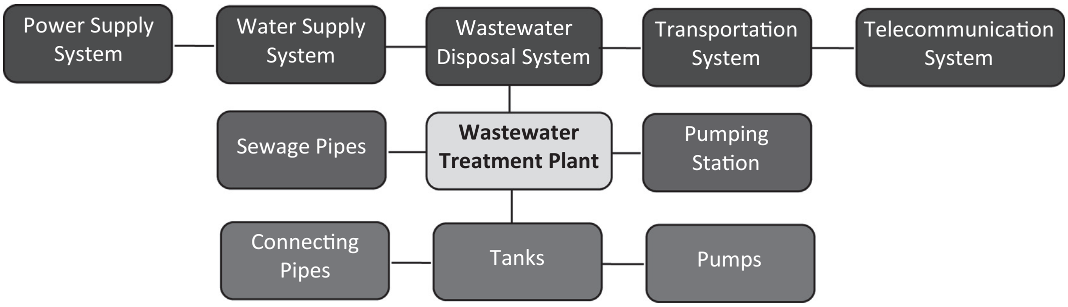

Fig. 1. Hierarchical system of lifelines.

In this work, a procedure for the assessment of seismic vulnerability of municipal and industrial treatment plants has been developed, taking into account the following assumptions:

- municipal and industrial WWTPs are similar from the physical and structural viewpoint: they are usually designed and built up according to the same construction technologies and structural analysis criteria (Hiks, 2007);
- municipal WWTPs do not deal with hazardous materials as in the case of the industrial systems (Metcalf and Eddy Inc., 2002);
- industrial operations may be interrupted if the installation is affected by the earthquake, however with additional economic consequences due to business interruption other than and repairing actions;
- municipal WWTPs cannot cope with the natural disaster: before returning to service, untreated or partially treated wastewater is unavoidably released into superficial waters or on soil, because the public sewage systems cannot be interrupted.

In this framework, a description of the main operational units of WWTPs and a characterisation of the earthquake hazard is needed, as in the following section.

1.1. Wastewater treatment plants

Municipal and industrial treatment processes have the aim of removing pollutants from the wastewater by means of physical, chemical and biological processes. The process may take place in open or closed tanks, which can be buried, semi-buried, ground or elevated (aboveground). In the tanks, physical (baffles) and mechanical devices (scrapers) are typically installed. In addition, they are interconnected by pressurised pipes or free surface channels, according to the specific treatment system. Additional elements include storage tanks for chemicals (e.g., chlorine, biogas), dewatered sludge tanks compressor units, and others.

Fig. 2 shows the main components of WWTP in more details. There, units 3 and 4 are adopted for the preliminary treatment of wastewater, for the removal of coarse and floating solids as well as grit. Hence, in unit 6, a primary (settleable, solid removal) and a secondary treatment (unsettleable, solid removal by biological conversion into settleable solids) is performed. These treatments are followed by disinfection (unit 18) before being discharged into the receiving water bodies. When the effluent quality from secondary treatment is unacceptable if compared to quality standards established by law or regulation, a third level of treatment by means of advanced processes (e.g. advanced oxidation, micro/ultra/nano-filtration by membranes, activated carbon filtration) is commonly used. Other units and more details information are described extensively elsewhere (Metcalf and Eddy Inc., 2002; Hiks, 2007).

1.2. Earthquake characterisation

The design of civil and industrial structures in seismic areas is commonly based, among others, on the estimation of the level of shaking induced by an expected earthquake selected on a probabilistic basis. A typical measurement of the seismic scale is the Magnitude (Local Magnitude or Moment Magnitude), which is a unique value that is related to the quantitative estimation of the released energy. In the past, however, the seismic scale was measured based on its intensity, which is related to the damaging effects of the earthquake as in the Modified Mercalli Scale (MMI or Macroseismic Intensity). Quite obviously, this is not an objective scale, because it is not based on a unique site-independent parameter but on the observation of the damages.

More recently, the presence of seismic network stations has led to the use of instrumental and objective parameters for the description of earthquakes. For the simplified (pseudo-static) earthquake engineering analyses, synthetic parameters are often preferred rather than whole time histories of the seismic motion (in terms of acceleration, velocity or displacement) (see e.g. Kramer, 1996 for details). In this framework, the most significant parameter for structural analyses has been recognised in the Peak Ground Acceleration (PGA), which is the peak of the horizontal component of an acceleration time history. In fact, for aboveground civil engineering structure, the PGA is directly related to the structural damage, due to the importance of inertial effects in the seismic loadings.

Quite clearly, the PGA is a synthetic description of the seismic motion and do not give a complete description of the ground motion, which should be also characterised by frequency content and signal duration. However, despite of this limitation, this parameter is frequently adopted as reference for designing earthquake-resistant structures.

2. Methodology

The methodology proposed in this work is based on an observational method, and is composed by four steps as follows: damage data collection; damage state definition; risk state definition; and fragility curves plotting. Each of these steps is discussed in the following sections.

2.1. Damage data collection

An earthquake can affect either directly or indirectly the WWTP. That is, tsunamis, flooding and power shortage are indirect causes of failure for WWTPs produced by an earthquake. Direct causes include breaks and deformations of structural elements (e.g. pipes or tank walls) as well as detachments and breaks of non-structural elements (e.g. sludge scrapers, baffles, aerators, mechanical

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