Engineering Structures 140 (2017) 353–372

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Emilia 2012 earthquake and the need of accounting for multi-hazard design paradigm for strategic infrastructures

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ARTICLE INFO

Article history:
Received 22 February 2016
Revised 1 March 2017
Accepted 2 March 2017

Keywords:
Emilia earthquake
Multi-hazard
Water lifting plant
Combined probability
Seismic vulnerability
Response spectrum

ABSTRACT

This study provides some insights into the seismic events of Emilia 2012, with an emphasis on the emblematic case of the severely damaged water lifting plants in the area of the mainshocks of the earthquake. The examined case studies point out the extreme vulnerability of such strategic infrastructures from combined natural hazards, which in areas densely populated, can cause enormous costs in terms of human loss and goods destruction, and the need of revising existing design codes to include multi-hazard paradigms.

1. Introduction

This study focuses on the risk connected to seismic and hydrogeological hazards together with the relevant real cost for civil and environmental protection, as dramatically pointed out by the earthquake of region Emilia-Romagna in Northern Italy, which took place in May 2012. The analysis describes seismic, hydrogeological and other potentially catastrophic natural hazards as a life-threatening aleatory event, making an evaluation of the population and heritage at risk in the Italian country. This rather novel approach of evaluating combined risk scenarios has been the object of recent research and scientific communications [4,10,11,29,17,30,14,32,5]. Recently, experiments of implementing such innovative paradigm for risk assessment into environmental territorial planning and strategic infrastructure design have been carried out by several public governmental Agencies [7,24,16,12]. Indeed, the present study appears novel inasmuch it regards a geographic area which is, on the one hand, highly vulnerable from a seismic point of view due to high anthropization density, strong industrialization, and intense agricultural activities; and on the other hand, it is constantly under flooding risk, requiring to be protected through a reclamation hydraulic network [3].

This awareness of the fragility of the Italian territory and of the risk for natural catastrophes known to affect a significant percentage of the national territory is a well known social issue as reported for instance in the ANCE/CRESME Survey [2]. The latter document was commissioned by the ANCE (National Association of Building Contractors), by the National Geology Council and the National Register of Architects to the CRESME (Centre for Social and Economic Research on the Market and the Construction Industry) and drawn up by a committee of experts. The analysis therein aims at a survey on the "hydrogeological" instability, intended as "the set of phenomena related to the wasteful flow of water on the surface and within the soil, producing effects that can lead to loss of life, impairment of assets and man production activities and of the natural environment" [2], on seismic vulnerability; and related social costs for environmental protection.

In this paper, attention is given to the damage provoked by seismic actions onto water lifting plants and to the hydrogeological risk connected to the out-of-service of such facilities, a potential life threaten for population, production activities and the natural environment itself.

The paper addresses two case studies represented by two water lifting facilities preventing territories from flooding and granting safety to a densely populated region with high industrial and agricultural activity concentration, which were severely damaged by the earthquake. The safety assessment of seismic vulnerability of such structures in compliance with actual Italian design codes

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http://dx.doi.org/10.1016/j.engstruct.2017.03.004
0141-0296/

shows that these structures, designed according to obsolete criteria, are not in compliance with modern anti-seismic requirements, nor even able to withstand the dynamic action induced by the main shocks. A risk assessment is hence presented for combined seismic and flooding hazards, in accordance with modern criteria van Westen et al. [29], van Westen and Woldai [30], which even more evidently indicates lack of safety for the examined structural facilities. The presented study indicates the inland in the Po river area as a territory exposed to potentially life-threatening multi-hazard risk. This works aims at highlighting that natural hazards should be considered as a totality of possibly simultaneous or cascading occurrences, and hence, at making the point of a need to integrate into the current regulations a combined-hazard paradigm in design criteria and verification methods, in order to more accurately predict potentially dangerous actions on strategic and civil structures and to grant a higher level of safety.

The paper is organized as follows: first, in Section 2, a survey on the Italian territory seismic and hydrogeological natural hazard scenarios in relation to anthropization density is presented; secondly, a synthetic excursus on the seismic sequence which struck Emilia region is reported with emphasis on response spectra and soil properties. Section 3 presents the typical dewatering pump facilities located in the Emilia plain, as key components of the vast water reclamation network aimed at protecting the territory from flooding. Section 4 presents the two water lifting plants object of the present communication with their typical structural features and a description of the damages occurred through the seismic events. Section 5 reports the seismic-based vulnerability assessment for the above mentioned structures in accordance to Italian Norms. Moreover, a multi-hazard combined risk assessment is proposed, indicating the high fragility of the water reclamation basin geographic areas in case of heavy rainfalls. Conclusions are drawn in Section 6 pointing out the need in the Italian context of a new paradigm of design criteria for strategic structures.

2. Seismic and hydrogeological hazards: the Italian scenario

The ANCE/CRESME survey [2] reports on the average annual change in resident population of different age groups and on the contribution of foreigners to the growth of number of families in relation to natural catastrophes risk, see Figs. 1–4. Recent observations point out that demographic growth is concentrated in areas characterized by high levels of seismic and hydrogeological fragility; increasing human anthropization has led to a significant worsening of environmental criticalities. In addition to this, a parallel depopulation of inland areas typical of southern Italy and islands is gradually leading to the reduction of routine activities aimed at environmental protection and land securing, resulting in acceleration of land degradation phenomena. The analysis emphasizes the pressing need for environmental planning, supported by proper public investment and environmental protection policies able to ensure land protection and prevention.

This problem affects the entire country, as depicted in Fig. 2, and may be related to structural or occasional causes [2]:

- Progressive decline of the ‘‘maintenance” of the suburban territory, both as a decrease in production activities settlement and as a more sporadic routine maintenance of open land, resulting in impoverishment of the soils which become more vulnerable to extreme weather phenomena;
- Postponement of ordinary prevention activities from environmental hazards, due to funding shortages, and limited mainly to emergency occurrences;
- Progressive soil sealing connected to the forms of urbanization typical of the urban context;

The seismic risk of the Italian territory is probably the most relevant characterizing the country, as damage caused by earthquake can be devastating in terms of human loss as well as damage to facilities and goods; due to the potential catastrophic consequences on residential buildings and public edifices which by far consist of masonry historical buildings, designed in accordance with obsolete conceiving rules to bear only vertical actions. The ANCE/CRESME study, drawing information and data from the National Institute of Geophysics and Volcanology (INGV), estimates the number of earthquakes per year near 100. Italy is considered a country with a medium-to-high seismic activity, with earthquakes of magnitude between 5.0 and 6.0 and an average 5–6 earthquakes a year with a magnitude greater than 5.0. The most prone areas are located along the arc of the Apennines, in the eastern part of the Alps and in volcanic areas, as may be observed in Fig. 1.

The INGV seismic classification of the Italian territory sets Emilia Romagna region as seismic as of October 10, 2005 [22]. For each zone, the seismic hazard is provided in terms of ground shaking expected at a given location as a result of a given earthquake at a certain distance. The estimated value of expected shaking refers to the analysis of the historical seismicity of the area under consideration, as well as geo-physical analysis of the territory, and is delivered in terms of peak ground acceleration (PGA) or maximum horizontal acceleration on a rigid basis. The analysis of geological and seismic risks as separate entities, aims at estimating the share of national population and production activities exposed to combined natural hazards, see Figs. 3,4. The estimated percentage of the surface of the national territory subject to hydrogeological risk turns out to be approximately 10% (29.500 km^2) affecting 82% of the municipalities; while areas at high seismic risk are approximately 44% (131.000 km^2) of the inland territory, comprising 36% of the municipalities. An estimate indicating the population subject to both forms of risk reaches 27.6 million.

In the case of the plains of Emilia, the second largest drainage river basin in Europe, combined earthquake and flooding risk is more relevant, because almost all of this region is classified as seismically active and a considerable part of the territory surrouding the course of the Po river is under the average sea level. In order to focus on the case studies of Section 4, in the following we report the rainfall data recorded from the second half of the twentieth century by two rain gauges near the two mainshocks, and the data related to the seismic sequence recorded in May 2012.

2.1. Rainfall situation in the area struck by the 2012 Emilia earthquake

In Fig. 5 we collect the annual and monthly rainfall data, provided by the Regional Agency for prevention, environment and energy of Emilia-Romagna (http://www.arpae.it/), in the period ranging from 1951 to 2014, for the two rain gauges Ponte Bacchello (lat. N 44.9099 long. E 10.9881) and Moglia di Sermide (lat. N 45.0099 long. E 11.2813), highlighting *water cloudbursts*, which [20] amount to a minimum of 30 mm rain in a single hour, closely connected to the climatological definition of storm [26,1]. Analysis of the data shows that, on the average, rainfalls in this areas were more abundant in the recent past with more frequent storm events. It is to be noted that the long-term weather forecast in this area would indicate a reduction of the total precipitation and an increase of numerosity in extreme rainfall events. Interestingly, reports from ISPRA [13] indicate increased landslide risk in the areas struck by the earthquake, mainly due to banning sand and gravel mining from river beds, which in many cases causes water flow problems disfiguring the river ecosystem, and to illegal building practice largely condoned nowadays [15].