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Towards creating a combined database for earthquake pedestrians' evacuation models

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ABSTRACT

Earthquake risk assessment at urban scale is actually based on site hazard, buildings vulnerability and exposition, but does not consider human behaviours during both the event and the evacuation. Nevertheless, human interactions in such conditions become one of the most influencing element for inhabitants safety. Hence, an important issue is understanding how people interact with other individuals and with the environment modified by the earthquake. The development of evacuation software in earthquake conditions needs investigations about these aspects. In fact, actual data about earthquake evacuation behaviours are very poor. This work starts from this request and proposes an innovative database for earthquake evacuation models according to literature suggestions. A wide number of videotapes concerning real events from all over the World is analysed in order to provide human behaviours and motion quantities, and to integrate previous results. The database firstly includes the step-by-step evacuation behaviours that are activated during the process. Secondly, motion quantities (speed, acceleration, and distance from obstacles) are provided. The analysis of real emergency conditions evidences particular phenomena. Main results demonstrate how people prefer moving with an average speed of about 2.3–3 m/s. Finally, fundamental diagrams of pedestrians' dynamics in earthquake emergency conditions show how, density values being equals, speeds and flows are higher than previous studies (in particular: fire evacuation and evacuation drill). These data can be used as input parameters for defining and developing new evacuation models, but also for existent models validation.

1. Introduction

Understanding human behaviours and defining behavioural rules in emergency conditions are essential issues in human safety assessment. Similar analyses introduce the importance of the "human" factor in the scenario and trace the bases for proposals about emergency management strategies. The most significant way to provide these results is the use of emergency and evacuation simulation software: their number has rapidly increased during the last years and demonstrates a wide range of powerful applications (Kuligowski and Peacock, 2005; Zheng et al., 2009; Helbing and Johansson, 2010), for different emergencies (Uno and Kashiyama, 2008; Zheng et al., 2009; Zhang and Yao, 2010; Hori, 2011; Song et al., 2013; D'Orazio et al., 2014a, 2014c) and in both indoor (Filippidis et al., 2006; Korhonen and Hostikka, 2010; Alizadeh, 2011; Chu et al., 2012; Pereira et al., 2013; Sarshar et al., 2013; D'Orazio et al., 2014d; Lovreglio et al., 2014) and outdoor (Hori, 2011; Nishino et al., 2012; Osaragi, 2012; D'Orazio et al., 2013; Murray-Tuite and Wolshon, 2013; Wijerathne et al., 2013) scenarios. In order to develop these software tools, qualitative and quantitative data on human behaviours are strongly and urgently needed. All the different emergency typologies (i.e.: fire, earthquake, flood, terrorist attack) require a series of investigations that include the definition of related emergency databases (Fahy and Proulx, 2001; Purser and Bensilum, 2001; Shi et al., 2009; Kobes et al., 2010a) and chronological evacuation schemes (Alexander, 1990; D'Orazio et al., 2014c). Qualitative investigations involve human behaviours and they are performed by analysing the step-by-step actions carried out by evacuating pedestrians, including their statistical significance (Purser and Bensilum, 2001; Helbing et al., 2002; Yang et al., 2011; D'Orazio et al., 2014c). These analyses lead to distinguish the evacuation phases (Alexander, 1990; Riad et al., 1999; Averill et al., 2005; Shen, 2006; Kobes et al., 2010a, 2010b; D'Orazio and Bernardini, 2014; D'Orazio et al., 2014c): a pre-movement phase and a motion phase (including building exiting and safe areas reaching) are generally evidenced. The quantitative motion analyses involve the determination of motion parameters (e.g.: walking speeds, individuals evacuation paths) and they are preferably

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Table 1
Suggested data that contribute to an evacuation characterization according to previous works (Fahy and Proulx, 2001; Schadschneider et al., 2009; Shi et al., 2009; D'Orazio et al., 2014c): these aspects should be considered if evacuation databases want to be provided. For each analysed data, its type (quantitative when involves physical quantities; qualitative when involve pure behavioural aspects) and a short description is provided.

Evacuation data	Type (main unit of measure)	Short description
Delay times	Quantitative (s)	Time of reaction to the event; pre-movement time characterization
Walking speeds	Quantitative (m/s)	In different conditions of crowdedness and path
Occupant characteristics	Quantitative and qualitative	Differences in actions, reactions, specific parameters
Evacuation behaviours	Qualitative	Series of actions during evacuations
Evacuation path obstruction	Quantitative (e.g.: density (people/m^2)) and qualitative	Influence of environmental conditions on queue delays or block egress
Exit and path choice decisions	Quantitative (e.g.: flow (people/(m s))) and qualitative	Influence of environmental conditions and other people positions on travel paths and travel times

performed through analyses on evacuation videotapes (Hoogendoorn, 2003; Liu et al., 2009; Hori, 2011; Yang et al., 2011; D'Orazio and Bernardini, 2014; D'Orazio et al., 2014c; Ronchi et al., 2014) by using different motion tracing techniques (Teknomo et al., 2001; Li et al., 2012; Boltes and Seyfried, 2014). Evacuation phases are generally characterized by different behaviours and numerical quantities (Alexander, 1990; Helbing and Johansson, 2010; Kobes et al., 2010a, 2010b; D'Orazio et al., 2014c). Table 1 resumes the main qualitative and quantitative data that have to be analysed according to previous works (Fahy and Proulx, 2001; Helbing et al., 2002; Shi et al., 2009; D'Orazio et al., 2014c): these quantities should contribute to the definition of evacuation databases.

Nowadays, most studies deal with human behaviour analysis in fire evacuations or big structure evacuations (Johnson et al., 1994; Muir et al., 1996; Riad et al., 1999; Shields and Boyce, 2000; Fahy and Proulx, 2001; Helbing et al., 2002; Averill et al., 2005; Chu et al., 2006; Shen, 2006; Mawson, 2007; Dederichs and Larusdottir, 2010; Nilsson et al., 2010): behavioural aspects and evacuation quantities, such as delay times and motion speeds, are deeply investigated. Analyses has been involved real accidents (Canter, 1980; Proulx, 2002a; Averill et al., 2005; Mcconnell et al., 2010), evacuation simulations in virtual reality (Ren et al., 2008; Vilar et al., 2012), evacuation experiments in different locations, such as retail stores (Shields and Boyce, 2000), hotels (Kobes et al., 2010a), cinemas and theatres (Nilsson and Johansson, 2009), schools (Zhang et al., 2008; D'Orazio and Bernardini, 2014), flats (Proulx, 1995), care homes (Gwynne et al., 2003b), means of transportations (Johnson et al., 1994; Gwynne et al., 2003a). Pre-movement phase and egress choices are also investigated in relation to social attachment, attachment to things and known exits positions (Mawson, 2007; Augustijn-Beckers et al., 2010; Kobes et al., 2010a, 2010b; D'Orazio et al., 2015). Disabled individuals' behaviours have also been collected in other experiments (Proulx, 2002b; Lena et al., 2010). Relations between pedestrians' flow rate, people density and motion speeds (Hankin and Wright, 1958; Predtechenskii and Milinskii, 1978; Mori and Tsukaguchi, 1987; Weidmann, 1993; Seyfried et al., 2005; Johansson and Helbing, 2008) are provided: these works usually involve both normal and evacuation experiments conditions, and different approaches in quantities measurement (Johansson and Helbing, 2008; Steffen and Seyfried, 2010; Courbon and Leclercq, 2011; Burghardt et al., 2013). Besides, retrieval of related fundamental diagrams of pedestrians' dynamics (Seyfried et al., 2005) allow quick models to be defined for describing motion process from a fluid dynamics point of view (Henderson, 1971; Seyfried et al., 2006; Johansson and Helbing, 2008; Steffen and Seyfried, 2010; Transportation Research Board, 2011) also in evacuation conditions (Lämmel et al., 2008; Kunwar et al., 2014).

On the contrary, a limited number of works investigates other kinds of emergencies, and, in particular, earthquake evacuations (James, 1968; Takuma, 1972; Boileau et al., 1978; Arnold et al., 1982; Turner et al., 1986; Alexander, 1990; Grünthal, 1998; Hori, 2011; Osaragi, 2012; Prati et al., 2012; D'Orazio et al., 2014a). Nevertheless, the importance of human behaviours in earthquake emergencies is generally evidenced (Takuma, 1972; Alexander, 1990; Ainuddin and Routray, 2012; Yang and Wu, 2012; Amini Hosseini et al., 2014; D'Orazio et al., 2014c; Mishima et al., 2014). During both the earthquake and the first post-event evacuation phase, people adopt different choices with the aim to remain in safe conditions, to avoid dangerous zones, to be close to other pedestrians, to gain safe areas. These phenomena are more influent in urban scenarios, where man-environment interactions are strongly influenced by environmental modifications due to the earthquake (Goretti and Sarli, 2006; Ferlito and Pizza, 2011; D'Orazio et al., 2014c). For this reason, tools for earthquake emergency and evacuation analysis is actually more and more needed and also the number of related simulator is increasing (Hashemi and Alesheikh, 2010; Hori, 2011; Liu et al., 2011; Ye et al., 2011; Osaragi, 2012; D'Orazio et al., 2014a). Traditional evaluations on site hazard (Klügel, 2008; Panza et al., 2012), buildings and infrastructure vulnerability (Palacios Molina, 2004; Federal Emergency Management Agency, 2009; Zanini et al., 2012) and exposure (Chen et al., 1997; Mouroux and Brun, 2006) will be soon merged with simulators analyses in order to develop a sort of integrated "risk maps" for pre-disaster interventions and disaster management. This means the adoption of an approach comparable to the fire safety engineering one (Shi et al., 2009). Acquiring and organizing data on humans behaviours and evacuation motion quantities represent the first bases for the development of simulations tools (D'Orazio et al., 2014a).

Despite of the request to gain these data, the amount of present studies is limited (James, 1968; Takuma, 1972; Boileau et al., 1978; Arnold et al., 1982; Turner et al., 1986; Alexander, 1990; Grünthal, 1998; Yang et al., 2011; Osaragi, 2012; Prati et al., 2012; Yang and Wu, 2012). These works could be evaluated by principally distinguishing the performed methodologies and the surrounding scenario. Table 2 provides their characterization by addressing their strengthens and weaknesses. Some additional references concerning other fundamental pedestrians' behavioural studies are included in order to evidence some interesting evaluation techniques. Only few works try to classify human behaviours and to organize a chronological scheme of the evacuation process (Alexander, 1990; D'Orazio et al., 2014c). They often extract data from questionnaires related to case studies (Miyamoto et al., 2011; Prati et al., 2012). The analysis of real earthquake evacuations is rarely performed (Helbing et al., 2002; Yang et al., 2011; Yang and Wu, 2012), even though it concerns potentially unbiased data (Yang et al., 2011; Yang and Wu, 2012). The importance of analyses on real earthquake is also underlined by the presence of differences between the real evacuation and the simulated ones (Yang et al., 2011). In general terms (D'Orazio et al., 2014c), results show that some behaviours are common to other kind of evacuations and some others are instead specific of earthquake evacuation. In particular, previous works evidence the existence of a lower limit in the perception of earthquake (Grünthal, 1998), the panic conditions characterization (Alexander, 1990; Grünthal,