Managing debris clearance from road transportation networks after earthquakes

Managing Debris Clearance from Road Transportation Networks After Earthquakes

Alessandro Cardoni,[1] Sebastiano Marasco,[2] Marco Domaneschi,[3] and Gian Paolo Cimellaro[4]

[1]Ph.D. Candidate, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy; e-mail: alessandro.cardoni@polito.it
[2]Post-doctorate Researcher, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy; e-mail: sebastiano.marasco@polito.it
[3]Assistant Professor, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy; e-mail: marco.domaneschi@polito.it
[4]Professor, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy; tel.: +39 011 090 4801; e-mail: gianpaolo.cimellaro@polito.it

ABSTRACT

This research proposes a framework that allows to define a debris removal strategy from a road transportation network after a seismic event. The case study is a virtual large-scale city consisting of many interdependent infrastructures. Once the debris generated by the collapse of buildings have been estimated, blocked roads are identified. Cleanup operations are then prioritized based on road importance and travel time. The goal is to first verify that evacuation routes and important paths connecting strategic facilities such as hospitals, shelters, fire stations, etc. are available. In case some roads within these paths are blocked, alternative routes are considered. If the pre-event travel time does not significantly increase, clearing equipment and resources could be managed accordingly and directed towards other areas. The objective of this work is to help emergency managers to successfully improve disaster response avoiding delays during rescue and recovery operations.

INTRODUCTION

Over the last decade, the development of efficient disaster management strategies has become crucial due to the increasing number of natural disasters. When a disaster strikes urban communities, the quantity of generated debris might be overwhelming. Therefore, proper debris management operations should be planned. Clearing debris from roads is one of the first steps to ensure a rapid response and recovering.

Some of the decision variables that must be evaluated when assessing transportation operations are: (i) amount of debris; (ii) infrastructure; (iii) region (rural, coastal, etc.); (iv) land use; (v) type of debris material (Reinhart and McCreanor 1999). Depending on these parameters, specific strategies can be developed.

(Brown et al. 2011) presented a comprehensive review on disaster waste management. They identified three management phases: emergency (few days – two weeks), recovery (up to 5 years), rebuild (in the order of ten years). In addition, they discussed key aspects such as temporary storage sites, coordination, planning, and social aspects. Pre-disaster identification of temporary storage is crucial to avoid delays and environmental damage. However, the expense of moving waste twice (to temporary sites and then to recycling and disposal facilities) and of acquiring land can be limiting. Moreover, there is limited understanding of the impact of disaster waste management on community recovery. Social aspects such as identifying possible public health threats, psychological implications of the speed of debris removal, and involving the community in decision making, should be taken into account. Planning and coordination are essential for efficient actions.

Unfortunately, many past disasters have shown little or no coordination between public authorities, in both developed and developing countries, leading to extremely long operations. Plans are mostly developed after a disaster has struck, with limited decision-making options. Generally, plans based around key decisions are more effective than prescriptive operational plans. (Zhang et al. 2019) pointed out that after the work done by Brown et al. (2011), only few research gaps have been addressed and there have been no clear changes or developments.

Özdamar et al. (2014) proposed a heuristic that generates road debris cleanup plans assuming a certain blockage intensity of roads. The method is based on the idea of minimizing network inaccessibility, making e location reachable using the shortest distance. The goal is to minimize the cumulative inaccessibility in a certain time by efficiently allocating clearing equipment in each district.

One of the limitations of the existing methodologies is that waste quantities are estimated by mathematical models and satellite/aerial imagery, but the accuracy is limited. Al-Jarjees and Al-Ahmady (2020) used satellite images to identify destroyed areas and on-site measurements of the height of the debris for 50 sample locations. They also assumed a maximum distance between the debris and the temporary storage sites of 2km. Çelik et al. (2015) presented a stochastic solution to the debris clearance problem to mitigate the lack of information. They assumed that debris quantities are stochastic, and the location of blocked roads is known. The idea is to determine an optimal sequence of roads to clear in a given period of time using Markov decision process.

In this paper, a framework that allows to define a debris removal strategy from a road transportation network after a seismic event is proposed. An existing virtual city hybrid model that has been previously implemented into a numerical platform is the case study. It includes many interdependent infrastructures and their interdependencies. The objective of this work is to help emergency managers to successfully improve disaster response avoiding delays during rescue and recovery operations.

DEBRIS ESTIMATION

In this research, network models are used to analyze the seismic response of a virtual city named Ideal City. This virtual environment is inspired by the city of Turin in Italy and it is meant to represent a typical European city. Detailed information about how the city was modeled and simulation methods can be found in (Marasco et al. 2020).

Ideal City's building portfolio comprises four different sectors including housing (residential building, hotel, shelter), education (school, university, library), business (shopping centers, retail stores, heavy industries), and public services (hospital, police station, churches, etc.). The building database consists of about 23,420 masonry and reinforced concrete structures, each categorized by several parameters such as year of construction, number of storeys, footprint area, mechanical characteristics of the materials, etc.

A large-scale simulation methodology was developed to perform nonlinear time history analyses and determine the damage state of each structure. Damage states were obtained from maximum inter-storey drifts. As a result, after the simulation, buildings could be categorized in five levels of damage: none, slight, moderate, extensive, and complete.

The seismic scenario was defined through epicenter location, moment magnitude, and acceleration time history. Geometrical attenuation at any building location has been estimated based on Ambraseys ground motion model (Ambraseys et al. 1996). In this application the 2016 Central Italy earthquake record was used. The damage state map of part of the city is illustrated in Figure 1.

Figure 1. Building damage state.

Ideal City's road transportation infrastructure was modeled through graph theory principles. Roads were characterized by their middle axis, start, and end point. Overall, the obtained graph consists of about 14,000 nodes and 18,000 edges connecting them. Typically, road graphs are directed, because of one-way streets. However, in this application the network was modelled as an undirected graph since it was assumed that in case of emergency directionality is not respected to accelerate evacuation and rescue operations. The graph is mathematically described by an adjacency matrix which allows to quickly update the topology once blocked roads are identified. Another parameter that was collected and included in a second dimension of the adjacency matrix is the road width. This information is fundamental to determine which roads are blocked.

To estimate the debris extension a machine learning (ML) approach was used. First, a database of pictures showing damaged buildings and the corresponding debris extensions was generated. 310 pictures from 25 worldwide different earthquakes were analyzed. The features of the database are: construction material (masonry or reinforced concrete), number of storeys, height of the structure, year of construction, magnitude of the event, distance from epicenter. The extension of the debris was defined in terms of distance between the building footprint and the debris footprint. Eight ML algorithms were tested and compared. The accuracy was evaluated through the mean squared error and R-squared. At the end of the evaluation process, the random forest algorithm was found to provide the best outcomes. Figure 2 shows the results of the implementation of the algorithm in Ideal City' building portfolio.

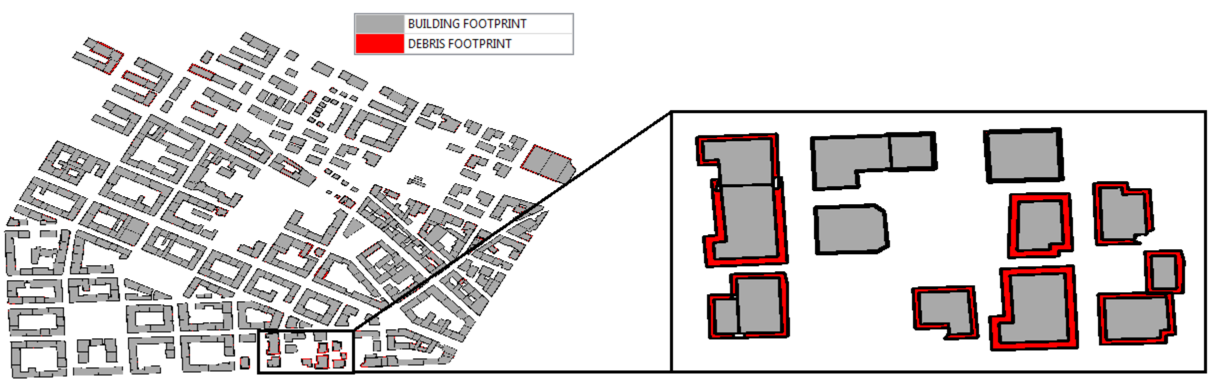

Figure 2. Extension of debris after the seismic event.

Therefore, for each building it was estimated and visualized its debris footprint. This information was then used to identify blocked roads by comparing debris extensions and road widths. It was assumed that if a debris footprint covers more than 50% of its width, that road needs to be cleared from debris. Figure 3 shows the blocked roads for the same part of the city.

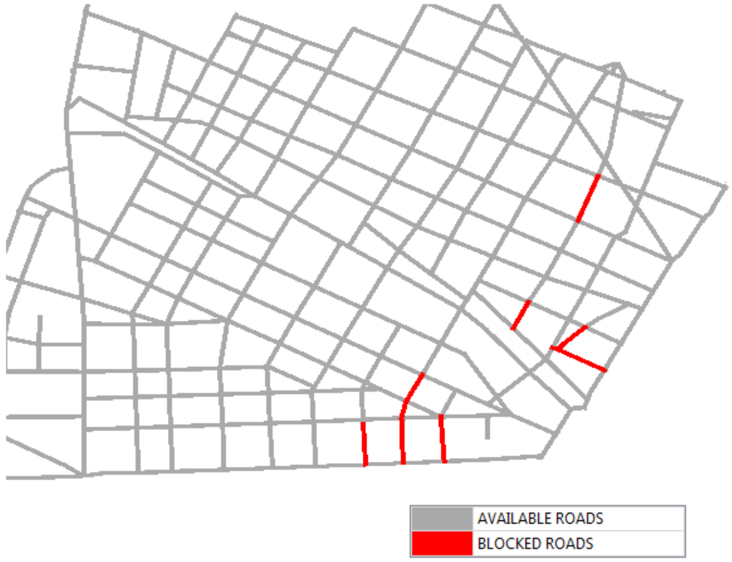

Figure 3. Blocked roads after the seismic event.

DEBRIS MANAGEMENT FRAMEWORK

Hypothesis:
Location of temporary storage sites → definition of main roads/rescue routes (shortest distance) → damage and debris estimation → compare the shortest paths (or travel time) post-disaster to normal conditions → allocate clearing equipment to most critical situations → calculate cleanup time based on the distance to the temporary storage sites (it requires to know the volume of debris)

Strategic locations were selected for temporary storage sites as shown in Figure 4. the main criteria for the selection of these areas were: (i) easy access thanks to large roads; (ii) even distribution within the city to minimize the travel time of clearing equipment; (iii) abandoned or industrial areas to mitigate the impact on the built environment; (iv) minimum distance to residential buildings of 500m.

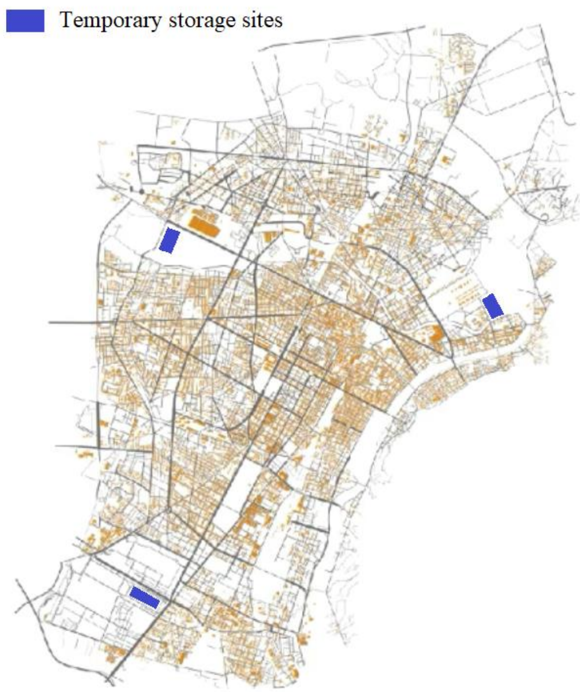

Figure 4. Locations of the debris temporary storage sites.

The locations of the hospitals were considered to define the main roads that need to be cleared first (Figure 5).

Figure 5. Location of the hospitals.

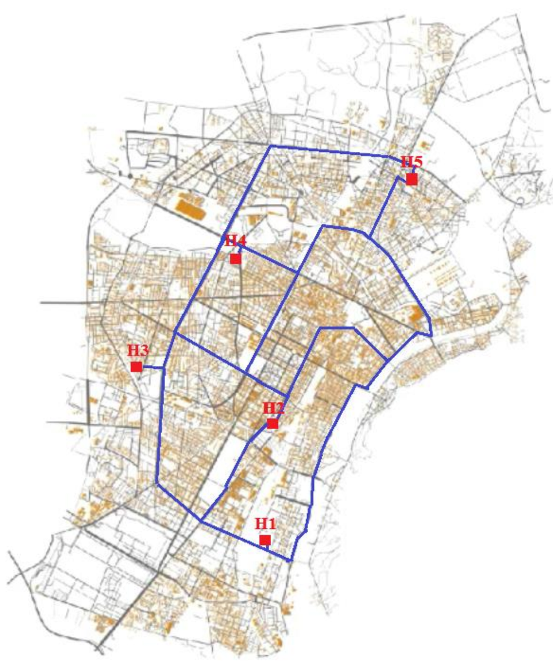

Figure 6. Main routes connecting the hospitals. Forse meglio toglierla e scrivere soltanto che vanno calcolate tramite shortest path

CONCLUSION

In this paper a framework for the debris management at the urban level was presented.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Research Council under the Grant Agreement n◦ ERC_IDEal reSCUE_637842 of the project IDEAL RESCUE—Integrated DEsign and control of Sustainable CommUnities during Emergencies.

REFERENCES

Al-Jarjees, S. D., and Al-Ahmady, K. K. (2020). "Planning the optimal debris removal of destroyed buildings in the Midan region in the Old City of Mosul." *Waste Management & Research*, 38(4), 472-480.

Ambraseys, N. N., Simpson, K. u., and Bommer, J. J. (1996). "Prediction of horizontal response spectra in Europe." *Earthquake Engineering & Structural Dynamics*, 25(4), 371-400.

Brown, C., Milke, M., and Seville, E. (2011). "Disaster waste management: A review article." *Waste management*, 31(6), 1085-1098.

Çelik, M., Ergun, Ö., and Keskinocak, P. (2015). "The post-disaster debris clearance problem under incomplete information." *Operations Research*, 63(1), 65-85.

Marasco, S., Cardoni, A., Noori, A. Z., Kammouh, O., Domaneschi, M., and Cimellarof, G. P. (2020). "Integrated platform to assess seismic resilience at the community level." *Sustainable Cities and Society*, 102506.

Özdamar, L., Aksu, D. T., and Ergüneş, B. (2014). "Coordinating debris cleanup operations in post disaster road networks." *Socio-Economic Planning Sciences*, 48(4), 249-262.

Reinhart, D. R., and McCreanor, P. T. (1999). "Disaster debris management–planning tools."

Zhang, F., Cao, C., Li, C., Liu, Y., and Huisingh, D. (2019). "A systematic review of recent developments in disaster waste management." *Journal of Cleaner Production*, 235, 822-840.