Achievements of and Challenges to the Hong Kong Landslide Risk Management

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ABSTRACT: Landslide is one of the common natural hazards in Hong Kong. With the Government and public's concerted efforts, landslide risk in Hong Kong has been drastically reduced since the establishment of a comprehensive slope safety system in 1977. However, given Hong Kong's climatic and geographical conditions and the current state of technology, occurrence of serious landslides that could potentially cause multiple fatalities remains a distinct possibility, particularly during extreme rainfall events.

1. LANDSLIDE RISK IN HONG KONG

1.1 Introduction

Landslide is one of the most common natural hazards in Hong Kong. The city has a high and intense rainfall, with an annual average precipitation of 2,300 mm, about 80% of which falls between May and September. Steep hilly terrain, heavy summer rain and the dense development have made the city prone to landslide risk.

Hong Kong has a population of 7 million and a total land area of about 1,100 square kilometres, with about 60 percent of the territory being natural terrain. As a result of the rapid population increase since the end of World War II and economic growth, the housing and land shortages have unavoidably driven the development towards the hillsides. Prior to 1977, there was a lack of geotechnical standards for land development and insufficient geotechnical control of slope formation works both in the public and private sectors. The stability of many slopes formed in this period, and earlier, is therefore in doubt.

1.2 Landslide history

Hong Kong has 60,000 sizeable man-made slopes with 40,000 government slopes and 20,000 private slopes. On average, about 300 landslides are reported to the Government each year.

Hong Kong has a long disastrous landslide history that can be traced back to 1889 in the early colonial days (Figure 1). In the past 60 some years since 1948, more than 480 people have lost their life in landslide incidents, mostly associated with failures in man-made cut slopes, fill slopes and retaining walls prior to 1977. The landslide fatalities and other economic losses have had heavy impact on the community. Table 1 summarized the landslide fatalities between 1948 and 1977.

Figure 1 Landslide occurred in May 1889 in Glenealy, Central

Table 1 Landslide fatalities in Hong Kong between 1948 and 1977

Year	Total no. of fatality	Cumulative no. of fatality
1948 - 1952	32	32
1953 - 1957	51	83
1958 - 1962	52	135
1963 - 1967	83	218
1968 - 1972	176	394
1972 - 1977	29	423

As a result of the landslide disasters at Po Shan Road and in Sau Mau Ping in 1972, which killed 67 and 71 persons respectively, as well as the second landslide disaster in Sau Mau Ping in 1976 which caused 18 fatalities, the Government established in 1977 the Geotechnical Engineering Office (GEO) (formerly named as the Geotechnical Control Office before 1991). The main objective of GEO is to implement geotechnical control on new developments and to contain the landslide risk through landslide risk management. This paper highlights the key strategies in the Hong Kong landslide risk management framework, summarizes the achievements in slope safety works, and identifies the challenges ahead.

2. LANDSLIDE RISK MANAGEMENT

2.1 Hong Kong Slope Safety System

It is the Hong Kong Government's objective and vision on landslide risk management to meet Hong Kong's need for the highest standards of slope safety. To achieve this, a comprehensive Slope Safety System has been developed, with the overall target of minimizing landslide risk to the whole community.

There are 3 key strategies in reducing the landslide risk (Figure 2):

I. Containing risk arising from new developments
II. Reducing risk by implementing landslip prevention and mitigation measures to systematically contain the overall landslide risks of the existing man-made slopes and natural hillside catchments
III. Reducing risk by minimizing the possible consequences of landslides

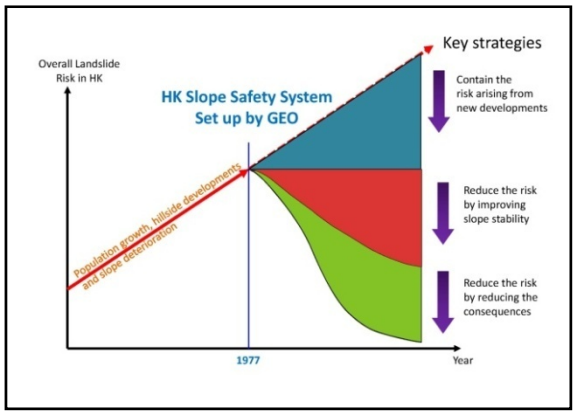

Figure 2 Key strategies in reducing landslide risk

2.1.1 Containing risks arising from new developments

Territory-wide geotechnical control has been put in place since the establishment of GEO in 1977 to audit the adequacy of the design and the supervision of the construction of new slopes, in both private and Government projects. The GEO also provides geotechnical input to land use planning, in which the potential impact of natural terrain landslide hazards is taken into account in planning new developments at the early stages, as part of the risk management strategy.

2.1.2 Reducing risk by implementing landslip prevention and mitigation measures

There are about 60,000 man-made slopes registered in the Catalogue of Slopes maintained by the GEO, of which about 40,000 are Government slopes and about 20,000 are private slopes (Figure 3). There are about 2,700 natural hillside catchments with known hazards and close to existing buildings or important transport corridors.

GEO commenced the Landslip Preventive Measures Programme (LPMP) since 1977 to upgrade substandard man-made slopes in existence in accordance with a risk-based priority ranking system, as well as to mitigate natural hillside landslide hazards on a "react-to-known-hazard" basis. As a result of the Kwun Lung Lau landslide incident (5 fatalities) in 1994, the programme was accelerated under the 5-year Accelerated LPM Project launched in 1995, and completed in 2010 in the 10-year Extended LPM Project launched in 2000.

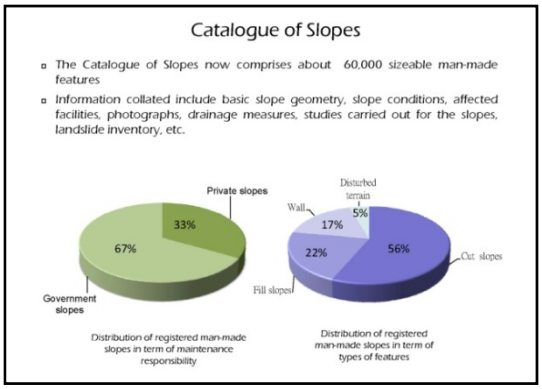

Figure 3 Catalogue of Slopes

GEO has launched a rolling Landslip Prevention and Mitigation Programme (LPMitP) in 2010 to dovetail with the LPMP. The programme is to systematically deal with the landslide risk associated with the man-made slopes and natural terrain catchments, and to contain the overall landslide risk at a level within the As Low as Reasonably Practicable (ALARP) zone (Figure 4).

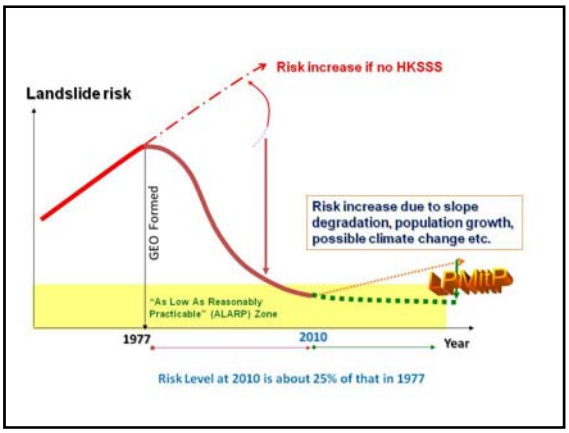

Figure 4 Landslide Risk Trend

The targeted annual output of the LPMitP comprises the following:

(a) upgrading 150 government man-made slopes;
(b) conducting safety-screening studies for 100 private man-made slopes; and
(c) implementing risk mitigation works for 30 natural hillside catchments.

Other than GEO, there are 7 slope maintenance departments responsible for improving the stability of government man-made slopes not covered by the LPMitP.

For the slope maintenance responsibility that belongs to private owners, GEO promotes public awareness and response in slope safety through public education, publicity, information services and public warnings. It also safety-screens private man-made slopes and recommends statutory action to require owners to investigate and carry out necessary upgrading works to substandard slopes.

2.1.3 Reducing risk by minimizing possible consequences of landslides

Non-engineering approach plays a key role in enhancing slope safety. Public support and community involvement is also essential to the successful implementation of the Hong Kong Slope Safety System. GEO has developed a series of proactive public education and communication strategies over the years to engage the public in reducing landslide risk, such as:

(a) Fostering general public's understanding of landslide hazards through broadcasting of Announcement in the Public Interest (API) on television (Figure 5) and radio, publishing the book "When Hillsides Collapse – A Century of Landslides in Hong Kong", organizing carnivals and exhibitions, and disseminating slope safety information on the Hong Kong Slope Safety website, YouTube and Facebook;

Figure 5 The 2014 TV API to enhance community resilience to severe landslides caused by extreme weather event

(b) Implementing public education initiatives targeting teachers and students through organizing workshops, field trips and competition activities (Figure 6), giving school talks on slope safety, and collaborating with Hong Kong Scout Association;

Figure 6 A Day Camp was organized to inspire students' interests in geotechnical engineering and awareness of slope safety

(c) Encouraging responsible ownership of private slope maintenance, provision of community advisory services, and distribution of guidance booklets and leaflets related to slope maintenance and slope safety;
(d) Promoting public awareness of Landslip Warning and proper response to landslide risk; and
(e) Enlisting public support and cooperation through issuing of information note and organizing media events. (Figure 7)

Figure 7 Pre-wet season media briefing on slope safety in 2014

Besides, GEO also adopts other non-engineering means to reduce the risk by minimizing possible consequences of landslides, including operation of the Landslip Warning System, maintaining a 24-hour year-round landslide emergency service for providing geotechnical advice to Government departments in dealing with immediate or potential landslide dangers, and recommending clearance of the squatter huts on slope safety ground.

3. ACHIEVEMENTS

3.1 Reduced overall landslide risk

Since 1977, the HK Government had spent a total of about HK$18.5 billion for the studies and upgrading works on substandard slopes as well as mitigation works on natural terrain catchments under the LPMP and LPMitP carried out by GEO.

By the end of 2014, the LPMP and LPMitP had completed upgrading about 5,250 government slopes, safety-screened about 5,600 private slopes, and implemented hazard mitigation measures for about 110 natural hillside catchments (Figure 8). The safety-screening studies resulted in the issue of Dangerous Hillside Orders (DHO) for about 1,750 private slopes under the Building Ordinance requiring the responsible private slope owners to undertake studies and necessary follow-up improvement works.

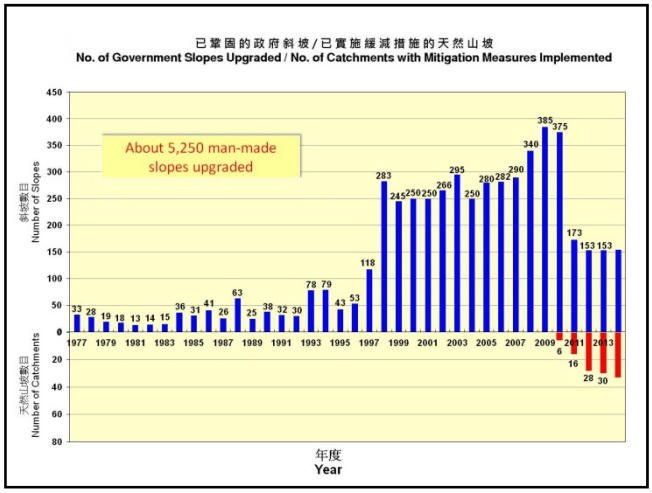

Figure 8 Number of slopes upgraded under LPMP and LPMitP from 1977 – 2014

Furthermore, about 4,200 Government slopes had been dealt with under the Enhanced Maintenance Programme (completed in 2010) and additionally about 1,400 improved or upgraded under the Preventive Maintenance Programme (from 2010 onwards), carried out by 7 slope maintenance departments in Hong Kong.

With the Government and public's concerted efforts under the comprehensive slope safety system, the landslide risk in Hong Kong has been drastically reduced to less than 25% of the 1977 level by 2010, and it has been 20 years since the last multiple fatality landslide incident occurred in Hong Kong in 1994 (Figure 9).

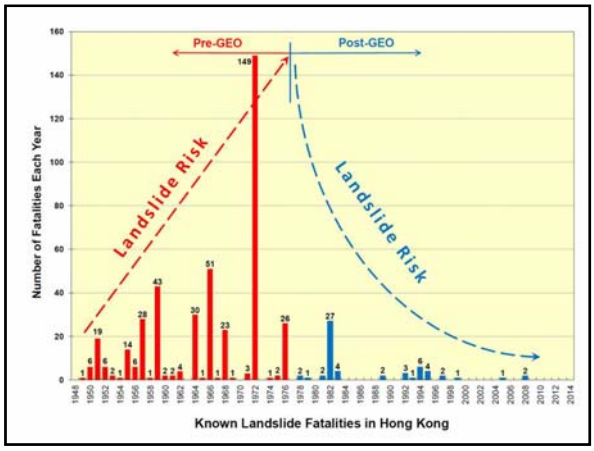

Figure 9 Landslide fatalities decreased since 1977

3.2 Improved living environment

It is the Government's policy to upgrade the man-made slopes under the LPMP and LPMitP to look as natural as possible through the use of soft and/or hard landscape treatment. For natural hillside catchments, the existing vegetation including trees and shrubs is preserved as far as practicable during the construction of mitigation measures, with soft and/or hard landscape treatments similar to those for man-made slopes to minimize their visual impact and blend them with their surrounding environment.

With the slope greening experience gained, GEO has issued a technical guideline, i.e. GEO Publication No. 1/2011, Technical Guidelines on Landscape Treatment for Slopes, on good practice in landscape treatment and bio-engineering for slope works. All newly constructed and upgraded government slopes are landscaped. Besides the government slopes, GEO has also published a Layman's Guide to Landscape Treatment of Slopes to help and encourage private slope and retaining wall owners to provide landscape treatment to their slopes and walls when planning maintenance or upgrading works (Figure 10).

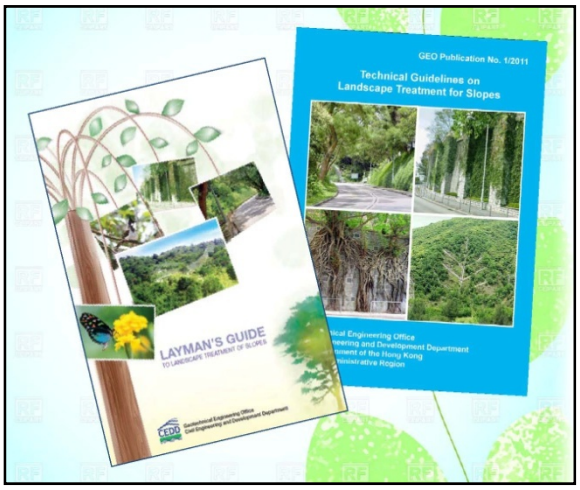

Figure 10 GEO's recent publications on landscape treatment for slopes

To meet the increasing public expectations on slope appearance, GEO has spent a great deal of effort in enhancing the appearance of upgraded Government slopes, where technically feasible and under safe site conditions. Under the LPMitP, over 300,000 trees/shrubs have been planted in 2014. GEO's commitment and effort in slope greening has made Hong Kong's living environment greener and more harmonious. The effort is well received by the public, with 76% of the respondents of the 2014 public opinion survey satisfied or very satisfied with the appearance of man-made slopes in Hong Kong, as indicated in Table 2.

Table 2 Results of the last 3 public opinion survey
Survey question: How satisfied are you with the appearance of man-made slopes and/or retaining walls in HK?

	Percentage in various surveys		
Response	**2012 Survey**	**2013 Survey**	**Current Survey**
Very satisfied	4.3	4.8	5.0
Satisfied	65.9	67.7	71.2
Dissatisfied	11.0	9.8	7.8
Very dissatisfied	0.6	0.8	1.1
Don't know / Hard to say / Declined to answer	18.2	17.0	15.0
Total (%)	**100.0**	**100.0**	**100.0**
Base (Number)	**1,035**	**1,014**	**1,028**

3.3 Contribution to advancement of slope safety standards in other countries

GEO has been putting great effort in technical development work, with a view to improving the slope safety standards, technology, and administrative and regulatory frameworks. Geotechnical research projects have been undertaken, which resulted in the promulgation of slope safety standards and professional guidance documents. It also enhanced the geotechnical control strategy on building and infrastructure developments. Furthermore, investigations into the causes of significant and serious landslides have been undertaken for forensic purposes and with a view to continuously improving the slope safety system in Hong Kong.

The Hong Kong Slope Safety System and standards have won high regard from the geotechnical engineering community, both locally and internationally. GEO and the geotechnical professionals in Hong Kong have made leading contributions to the understanding of failure mechanisms in man-made slopes and natural terrain, to the quality and cost-effectiveness of geotechnical construction, and ultimately to the reduction of landslide risk. From the extensive use of soil nailing as slope stabilization measures in man-made slopes to the increasing usage of debris resisting barriers as natural terrain mitigation measures, there are much innovations and significant technical advancements in slope engineering practice.

Hong Kong's experience and technical developments in landslide prevention and mitigation works have drawn many visitors from countries and cities in Asia, Europe, North America, South America and Middle East to visit Hong Kong to share and exchange experience in landslide risk management. On average there were about 18 visits received by the GEO annually over the past 10 years, from places including Australia, Brazil, Canada, Germany, Italy, Japan, Korea, Kuwait, Malaysia, Norway, Singapore, Switzerland, Taiwan, US, UK and the Mainland China (Figure 11).

Figure 11 A Kuwaiti delegation visited GEO in 2012

Experience sharing and technical exchanges in the visits are proven beneficial to both the visitors and GEO, as many countries and cities have since developed their own slope safety system making reference to the Hong Kong Slope Safety System. (Figure 12)

Figure 12 Signing of a Memorandum of Understanding on Mitigation of Landslide Hazards between Hong Kong and Seoul (delegates on left) in 2013,

4. CHALLENGES

4.1 Remaining landslide risk

Despite the Government's effort in the past 3 decades that has substantially improved the slope safety and significantly reduced the number of landslide fatalities in Hong Kong, landslide risk to the community remains.

By adopting quantitative risk assessment (QRA) methodology to assess the global natural terrain and man-made slopes landslide risks, landslide risk profile in 2010 was established, as shown in Table 3. The risk profile forms the basis for the slope safety policy for 2010 onwards.

Table 3 Risk Profile in 2010 based on Global QRA

Slope Categories		Approximate Risk Proportion
Natural hillsides	Historical Landslide Catchment	25%
	Other natural terrain	25%
Remaining old man-made slopes	'Moderate' risk	15%
	'Low' risk	Insignificant
Man-made slopes affecting registered squatter structures		15%
Man-made slopes treated by 'old technology'		20%
Man-made slopes treated by robust technology		Insignificant

The majority of the remaining landslide risk comes from about 15,000 moderate-risk man-made slopes, the man-made slopes treated by 'old technology' and the about 2,700 Historical Landslide Catchments (HLC) with known landslide hazards that are close to existing buildings or important transport corridors. From the QRA, it is estimated that the overall risk of landslides from natural terrain is comparable to that from man-made slopes in 2010.

Unlike stabilizing man-made slopes, it is impractical, costly and environmentally undesirable to carry out extensive stabilization works on natural hillsides. Natural terrain landslide risk is typically dealt with by provision of mitigation measures, such as debris-resisting barriers. Landslides in natural terrain would still occur even after completion of mitigation works, and residual risk will always exist.

4.2 Adequacy of the natural terrain risk assessment and mitigation

Natural hillside catchments extend over large areas and involve highly variable ground and hydrogeological conditions. Their behaviour is often affected by geomorphological processes and human activities and influenced by climatic changes, which are not fully comprehended with the current state of knowledge. Conventional geotechnical approaches of detailed ground investigation and slope engineering are generally not applicable in the study for natural terrain risk assessment and mitigation, as there are many uncertainties involved that need to be recognized and properly addressed. Such uncertainties include the reliability of the priority ranking methodology for hillside catchment selection, the estimates of source failure location and volume, debris mobility, debris volume, and the runout path prediction.

Failure in addressing the uncertainties in the assessment and mitigation may under-estimate debris volume, which may result in over-flow of debris from fully filled barriers that may in turn result in damage or collapse of debris-resisting barriers, and impact on areas that have been assessed as being beyond the reach of the debris. Under-prediction of the reach of landslide debris could result in debris hitting unprotected zones that have not been recognized as being within the debris runout path.

GEO endeavours in areas of technical developments in relations to the natural terrain hazard study and mitigation. GEO Report No. 138 – Guidelines for Natural Terrain Hazard Studies was published in 2003 to provide technical guidance to geotechnical and engineering geological practitioners. Upon gaining experience over the years, Technical Guidance Note Nos. 36, 37 & 38 were issued in 2013 to depict the latest enhanced approach for natural terrain hazard studies and design of mitigation measures. The development of technical know-how in handling natural terrain landslide risk takes time to consolidate.

In short, the adequacy of the risk mitigation provisions, credibility of the professional practice, and professional competence is crucial for the successful implementation of LPMitP.

4.3 Increasing chance of extreme rainfall events

The number, scale and severity of landslides in man-made slopes and natural terrain are sensitive to rainfall conditions. Given the observed trend of climate change, it is possible that extreme rainfall conditions will occur more frequently in future. This could introduce more uncertainties to risk assessment and mitigation.

In recent years, extreme weather events have caused significant casualties and economic losses worldwide. Table 4 gives a list of recent serious weather events in places near Hong Kong.

Table 4 Extreme Weather Events near Hong Kong

Year	City / Country	Fatality (number)	Economic Loss (HK$)
August 2009	Typhoon Morakot struck Taiwan	439	About 3,500 million
July 2011	Torrential rain struck Seoul, South Korea	> 30	About 1,600 million
September 2013	Typhoon Usagi struck Guangdong, China	> 30	About 22,300 million
October 2013	Typhoon Wipha struck eastern Japan	> 31	About 800 million
November 2013	Typhoon Haiyan struck the Phillippines	> 6000	About 6,900 million
August 2014	Torrential rain struck Hiroshima, Japan	> 70	(not available)

** Reference: GEO Information Note no. 5/2014*

The Hong Kong Observatory (HKO) has predicted that climate change is likely to increase both the frequency and intensity of extreme rainfall events. It is noted that the maximum hourly rainfall recorded in 2008 was 145.5mm. This compares with the 88.4mm recorded in 1886 (Figure 13), with intermediate records of 100.7mm, 108.2mm, 109.9mm and 115.1mm held for about 40, 26, 14 and 2 years, respectively. The trend indicates that the holding time for

rainfall records is getting shorter. Hence there is an increasing possibility of extreme weather that could cause landslides with multiple fatalities and serious economic losses in Hong Kong. It is imperative that Hong Kong maintains highly vigilant about serious landslides and be prepared to deal with extreme weather events. The 7 June 2008 rainstorm with its record high rainfall resulted in 2 fatalities and havoc in the western Lantau Island is a case in point. Should this rainstorm hit the Hong Kong Island, the impact would be much more serious.

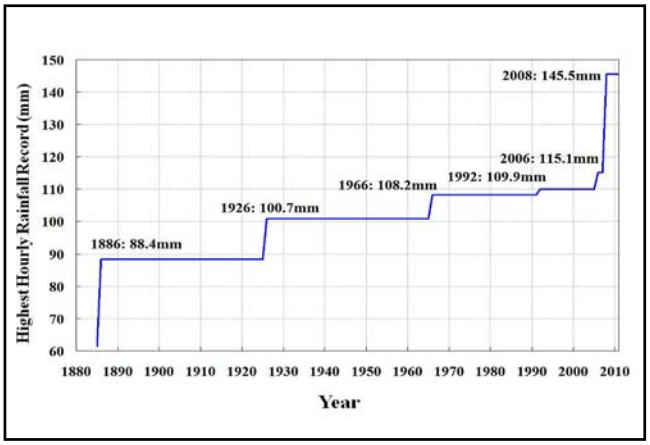

Figure 13 HKO's hourly rainfall record

5. CONCLUSION

The Hong Kong Slope Safety System is world-acclaimed and has successfully brought about a substantial reduction in landslide risk in Hong Kong. However, given Hong Kong's climate, hilly terrain, dense population and continuing development, there is still significant landslide risk posed by man-made slopes and natural hillsides.

The mitigation of natural terrain landslide risk is particularly challenging and there is no room for complacency notwithstanding the advances made in the subject of natural terrain landslides in Hong Kong over the years. More has yet to be learnt by the geotechnical profession in Hong Kong in improving the understanding of natural terrain landslides and capability in combating their risk.

The concerted efforts of the Government and the general public could enhance public resilience against landslide disasters and reduce the loss of life and damage to property to the lowest possible level. It is crucial that GEO should continue to assess the potential landslide impacts that may arise from extreme weather events and to further improve emergency preparedness of the community.

6. ACKNOWLEDGEMENTS

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