## HAITI M<sub>w</sub> 7.0 EARTHQUAKE OF JANUARY 12, 2010 Lifeline Performance

Edited by Curtis L. Edwards



Technical Council on Lifeline Earthquake Engineering Monograph No. 35



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Dowd, Munson, Editor, Annotated Bibliography on Lifeline Earthquake Engineering, 1980.

Smith, D. J, Jr., Editor, Lifeline Earthquake Engineering, The Current State of Knowledge 1981, Proceedings of the Second TCLEE Specialty Conference, August 20-21, 1981, Oakland, CA, (Later designated as the 2nd U.S. Conference on Lifeline Earthquake Engineering), August 1981.

Hall, William J., Advisory Notes on Lifeline Earthquake Engineering, 1983.

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Wang, Leon R. L. and Whitman, Robert, Seismic Evaluation of Lifeline Systems-Case Studies, 1986.

Cassaro, Michael and Cooper, James, Editors, Seismic Design and Construction of Complex Civil Engineering Systems, 1988.

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v

# Contents

Preface		ix
Con	tributors	Х
1.	INTRODUCTION	
1.1	Earthquake Highlights	1
1.2	Lessons Learned	5
1.3	Investigation Team	6
1.4	Web Addresses	7
1.5	Abbreviations	7
2.	SEISMOLOGY AND GEOTECHNICAL ISSUES	
2.1	Seismology	8
2.2	Geotechnical Issues	12
2.3	References	13
3.	WATER, WASTEWATER, AND DRAINAGE SYSTEMS	
3.1	Description of Systems: Water Supply, Wastewater Disposal, and Drainage	15
3.2	Earthquake Performance	18
3.3	Restoration and Future Plans	34
3.4	Major Observations and Recommendations	35
3.5	Acknowledgments	36
4.	ENERGY SECTOR	
4.1	Description of System	37
4.2	Overview of System Performance	37
4.3	Recommendations	48
4.4	Acknowledgments	49
5.	TELECOMMUNICATIONS SECTOR	
5.1	Description of System	50
5.2	PSTN Wireline Telecommunications	51
5.3	Wireless Telecommunications	53
5.4	Major Observations and Recommendations	54
5.5	References	56
6.	ROADS AND BRIDGES	
6.1	Description of System	57
6.2	Overview of System Performance	57
6.3	Site 1—Highway 3 Near Peligre Dam (N72° 2' 23.6"; W18° 54' 05.6")	57

vii

6.4	Site 2—Highway 1 Near Arcahaie	58
6.5	Site 3—Bridge on Highway 2 West of Leogane (N72° 43' 38.23";	
	W18° 25' 21.9")	59
6.6	Site 4—Landslide on Highway 2 (N72° 48' 50.15"; W18° 25' 46.7")	63
6.7	Sites 5 and 6—Highway 2 Damage West of Leogane (N72° 37' 56.9";	
	W 18° 28' 24.2" and N72° 43' 28.5"; W 18° 25' 23.5")	64
6.8	Site 7—Landslide on Highway 2 (N72° 48' 30.6"; W 18° 25' 33.4")	71
6.9	Site 8—Landslide at Road in Boutillier (N72.320043°; W 18.4989°)	74
6.10	Major Observations and Lessons Learned	77
7.	PORTS, MARINE OIL TERMINALS, AND AIRPORTS	
7.1	Description of Systems	78
7.2	Overview of System Performance	80
7.3	Post-Earthquake Repair and Recovery	114
7.4	Major Observations and Recommendations	118
7.5	Acknowledgments	119
8.	HOSPTIALS AND MEDICAL SERVICES	
8.1	Description of System	120
8.2	Overview of System Performance	120
8.3	Electrical Power Systems: Commercial, Emergency, and Solar	139
8.4	Water Systems	146
8.5	Wastewater Systems	150
8.6	Communications Systems: External and Internal	150
8.7	Heating, Ventilating, and Air Conditioning Systems	151
8.8	Natural Gas and Propane Gas Systems	154
8.9	Patient Transportation Systems	154
8.10	Medical Gas Systems	154
8.11	Critical Equipment	155
8.12	Fire Suppression Systems	155
8.13	Hazardous Material	155
8.14	Security Systems	155
8.15	Emergency Preparedness, Response, and Recovery	156
8.16	Conclusions, Observations, and Recommendations	157
	Acknowledgments	158
8.18	References	158
Index		161

viii

#### Preface

The Earthquake Investigations Committee of the Technical Council of Lifeline Earthquake Engineering (TCLEE), American Society of Engineers (ASCE), was established to initiate, organize, train for, coordinate, and evaluate the performance of lifelines following earthquakes. Members of the committee are employees of lifeline industries, consulting engineers, and academics from the United States, Canada, Europe, and Asia. Committee members provide services on a voluntary basis. Travel expenses are covered in part by ASCE. Some members' companies may allow for special paid leave and may also help cover travel costs. In addition to the time and expense of the field investigation, members must spend several weeks of their time preparing the reconnaissance report.

Individuals participating in the investigation need not be members of the committee or ASCE but are expected to follow the committee's earthquake investigation practices as described in the ASCE publication *Guide to Post-Earthquake Investigation of Lifelines* and the July 25, 2009 *ASCE Post-Disaster Assessment Manual*. Members of the investigation team coordinate with other groups and may participate in groups organized by other organizations. They gather performance data, both good and bad, from earthquakes to provide information to help practitioners improve the performance of lifeline systems. The international earthquakes that have been investigated by this committee include 1985 Chile, 1988 Soviet Armenia, 1990 Philippines, 1991 Costa Rica, 1992 Turkey, 1995 Kobe, 1999 Turkey (Izmit), 1999 Chi Chi (Taiwan), 2001 El Salvador, 2001 Peru, 2004 Algeria, 2004 Sumatra, 2007 Kashiwazki Japan, and 2010 Chile. Domestic earthquakes investigated include 1989 Loma Prieta, 1992 Landers, 1994 Northridge, 2000 Napa, 2001 Nisqually, 2002 Denali, and 2003 San Simeon. TCLEE also conducted an investigation of 2006 Hurricane Katrina.

The Earthquake Investigations Committee works closely with the Earthquake Engineering Research Institute (EERI) to provide an abbreviated version of lifeline performance in *Earthquake Spectra*, an EERI publication.

Curtis Edwards, Editor June 2011

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