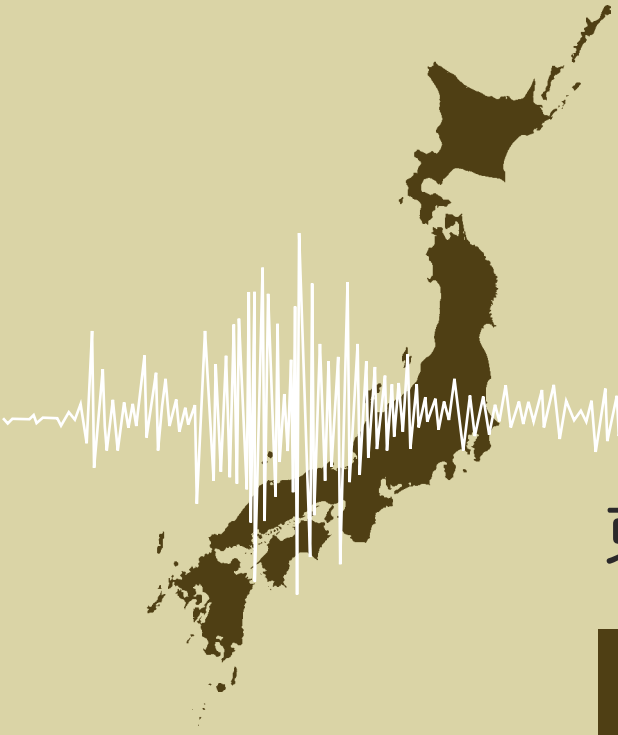

Tohoku, Japan, Earthquake and Tsunami of 2011

東北地方日本 地震・津波 2011

Performance of Structures under Tsunami Loads

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SEI ASCE STRUCTURAL ENGINEERING INSTITUTE

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Acknowledgments

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The Coastal Engineering Committee of JSCE and the 2011 Tohoku Earthquake Tsunami Joint Survey Group, the coordinating body of Japanese tsunami researchers, were particularly helpful in making tsunami information available via an online disaster clearinghouse. This group also provided valuable updates on conditions on the ground that allowed the ASCE SEI Tsunami Reconnaissance Team to understand better the logistics of its itinerary. We would especially like to thank Dr. Ioan Nistor of our team for his assistance in introducing us to Prof. Tomoya Shibayama of Waseda University and JSCE, and thereafter graciously facilitating our pre-reconnaissance communications.

The UNESCO/NOAA International Tsunami Information Center (ITIC), based in Honolulu, Hawaii, also provided useful information on Japan Meteorological Agency offshore tsunami data and details on the tsunami warning chronology. It also furnished ITIC ID badges for the ASCE SEI team to identify us as an international tsunami survey team.

The Chair of the Ocean Engineering Committee of JSCE, Prof. Engineering Tomoya Shibayama, P.E., of Waseda University, greatly assisted the ASCE SEI team with briefings on some of the first observations of tsunami effects in the Sanriku region and in Ibaraki prefecture, and clarified the extent of progress on road clearing and access to the damaged areas. Our itinerary was coordinated with Prof. Shibayama and his colleague, Dr. Hiroshi Takagi of the Japan International Cooperation Agency and the Tokyo Institute of Technology, who then made the in-country travel arrangements. Along with Prof. Shibayama and Dr. Takagi, Dr. Hideyuki Kasano of Waseda University and Dr. Takayuki Suzuki of Yokohama National University, Dr. Hidenori Mogi of Saitama University and Dr. Shusaku Inoue, Researcher with Takenaka Corporation, accompanied the first group of the ASCE SEI Tsunami Reconnaissance Team at various periods, devoting a significant portion of their time to assist us. This assistance made our in-country time much more efficiently spent, and the thoroughness and detail of the arrangements exceeded our expectations.

Dr. Nobuhito Mori and Dr. Tomohiro Yasuda of the Kyoto University Disaster Prevention Research Institute were instrumental in assisting and accompanying the second group of coastal structures investigators associated with the ASCE SEI Tsunami Reconnaissance Team.

Thermo Fisher Scientific donated a number of electronic personal dosimeters for each member of the reconnaissance team, so we were able to monitor radiation exposure while in Japan. This provided reassuring verification of the insignificant radiation levels north and south of Fukushima prefecture.

Thanks to the insight of ASCE President Kathy Caldwell, the ASCE SEI team was accompanied by Tom Sawyer, Senior Editor of *Engineering News-Record*, from April 22–24. He then authored a well-written article explaining the objectives and the value of our reconnaissance to the engineering community ("Rescuing Perishable Evidence," *ENR*, May 9, 2011). Jim Jennings and John Marston of the ASCE Communications Department helped maintain our blog entries from Japan on the ASCE website. Jennifer Goupil and Suzanne Fisher of SEI quickly processed travel reimbursements to participants of both the ASCE and JSCE teams.

Subsequent to the reconnaissance, we were able to exchange information with Japan's National Institute for Land and Infrastructure Management and the Building Research Institute (see Appendix Section 19.A). This provided an additional scope of observations that was useful for validation of our findings and initiated collaboration for further research. Also, Asia Air Survey Co., Ltd. provided aerial photography of several key locations and offered mobile LiDAR data from vehicle-based surveys in Onagawa and Minamisanriku.

Lastly, we would like to express our appreciation to the Japanese people, who were remarkably gracious and hospitable to our team, but also demonstrated great composure and high standards of personal conduct and resilience during the aftermath of one of the greatest natural disasters to befall Japan. This has been an extremely great and widespread tsunami event, but Japan's societal behavior and organization has the capability for commensurate response and recovery. We very much appreciate the value of those exemplary lessons.

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Ian Robertson, S.E.
David Kriebel, P.E.
Mathew Francis, P.E.
Ioan Nistor, P.E.

Chapter 1
Introduction

Japan has a long history of experiencing great earthquakes, and it is also the country with the highest frequency of tsunami attacks in the world (Table 1-1). On March 11, 2011, at 2:46 p.m., the Great East Japan Earthquake of Moment Magnitude (M_w) 9.0 [38.322 N, 142.369 E, depth 32 kilometers (km)] generated a tsunami of unprecedented height and spatial extent along the coast of the main island of Honshu (Figure 1-1). Portions of all coastal cities and numerous ports on the Tohoku (literally meaning northeast) coast were inundated by the tsunami waves. Scenes of widespread destruction stretched up to several kilometers inland. It has been estimated from aerial and satellite photography that about 535 square kilometers (km^2) (207 square miles) of land were inundated (Ministry of Land, Infrastructure, Transport and Tourism 2011).

The primary affected coastline was on the main island of Honshu along the Tohoku region (Figure 1-2). This area can be geographically subdivided further into the Sanriku coast of the three prefectures of Miyagi (north portion), Iwate, and Aomori, which has a 600-km-long sawtooth coastline with numerous estuaries and coastal valleys; and the middle coastline from the city of Sendai in southern Miyagi leading southward towards Fukushima prefecture, where the coastline has broader low-lying plains. Along the Sanriku coast, in most instances the tsunami occurred as a long period high amplitude surge. Along the coastal plain south of Sendai southward to Natori City and Soma City, the offshore bathymetry caused the tsunami to break into a series of bores, which were seen on worldwide television networks as videos taken from Japanese news helicopters.

There is great interest in studying the effects of the Tohoku Tsunami due to the analogous threat posed by the Cascadia subduction zone to the Pacific Northwest of North America, which in 1700 generated a tsunamigenic earthquake estimated to be of Magnitude 9 (Atwater and Hemphill-Haley 1997). Inundation of the Washington, Oregon, and Northern California coastlines would occur within 30 minutes of the earthquake under this scenario (Geist 2005). In addition to severe threat to human life, tsunami inundation poses a significant risk to coastal buildings and infrastructure from fluid and impact loads and scouring.

Table 1-1: Major Historical Damaging Tsunamis Affecting Japan

Date	EQ Mag.	Name	Max Height of Runup in Japan	Fatalities & Missing
Jan. 27, 1700	9	Cascadia	3 m	?
Oct. 28, 1707	8.4	Hoei	10 m	>20,000
June 15, 1896	7.2	Meiji Great Sanriku	25-30+ m	22,000
Sept. 1, 1923	8	Great Kanto	12 m	2,000
March 2, 1933	8.4	Showa Sanriku	28 m	3,000
Dec. 7, 1944	8.1	Tonankai	10 m	1,251
Dec. 21, 1946	8.4	Nankaido	11 m	1,330
May 24, 1960	9.5	Chile	5 m	142
March 26, 1983	7.7	Japan Sea	10 m	107
July 12, 1993	7.8	Hokkaido-Nansei-Oki	10 m in Hokkaido	202
March 11, 2011	9.0	Great East Japan Earthquake &Tohoku Tsunami	38.9 m	20,000

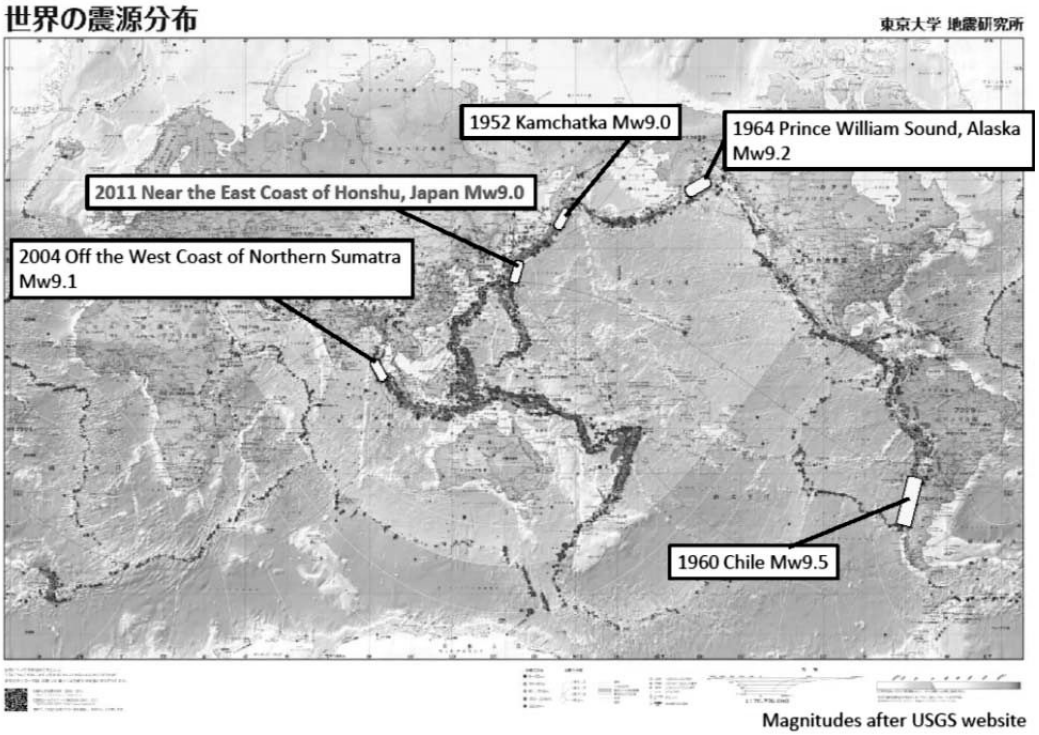

Figure 1-1: Major recent tsunamigenic earthquakes (Earthquake Research Institute, University of Tokyo / Tokyo Cartographic Co. Ltd.)

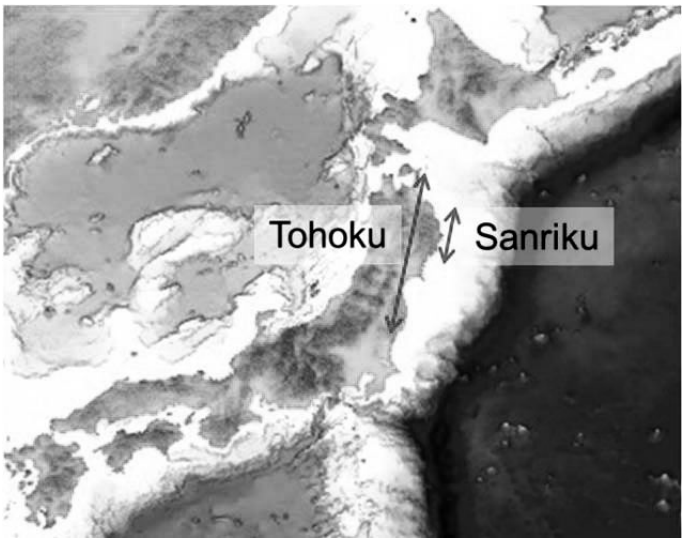

Figure 1-2: Tohoku and Sanriku regions of Honshu Island, Japan

The purpose of this tsunami reconnaissance trip by the ASCE Structural Engineering Institute (SEI) was to investigate and document the performance of buildings and other structures along the Tohoku coastline of Japan, with the specific intent to apply this experience in ongoing work to develop tsunami structural design provisions for the ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures. From this event, there was a large amount of information collected that will greatly enhance tsunami design practice and its application to risk mitigation in the United States. Detailed examination of buildings and other structures damaged by the Great East Japan Earthquake and Tohoku Tsunami of 2011 was therefore an essential task.

Data from this reconnaissance will help resolve some key questions in the tsunami design provisions regarding flow velocities and momentum of tsunami surges over land, hydrodynamic forces on structural elements, debris flow, debris strike effects, and erosion and scouring of foundations. The ASCE SEI Tsunami Reconnaissance Team visited the Tohoku coast in mid-April, roughly one month after the earthquake, and in the course of two weeks was able to examine nearly all towns and cities with significant damage due to the tsunami. This trip focused on studying tsunami effects to buildings, bridges, and coastal protective structures within the inundation zone, as well as acquiring information on overarching questions on risk-based design criteria and the ultimate capabilities of structures to resist a great tsunami. The March 11, 2011 event was a unique opportunity to learn lessons about the effects of a maximum credible tsunami that was greater than the maximum considered tsunami.

On March 15, 2011, the U.S. Department of State declared a recommended 80 km exclusion zone around the Fukushima power plant. Thus, the ASCE SEI tsunami team operated outside of that 80 km perimeter rather than the 30 km exclusion zone designated by the Japanese government.

Nevertheless, the most significant tsunami damage to examine existed to the north along the Sanriku coastline. The team explored the city of Sendai and the coastal ports and towns of Ishinomaki, Onagawa, Minamisanriku, Kesennuma, Rikuzentakata, Ofunato, Kamaishi, Otsuchi, Noda, Miyako, Tarou, Kuji, and other adjacent areas, constituting about 250 km of the coast. Portions of the Ibaraki and Chiba prefecture coastlines south of the nuclear exclusion zone were also examined.

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