Invited Paper

NATIONWIDE FIELD SURVEY OF THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE TSUNAMI

The 2011 Tohoku Earthquake Tsunami Joint Survey Group

Key Words: *inundation height, run-up height, Sanriku, ria coast, tsunami disaster countermeasure, watermark, debris*

An earthquake of magnitude 9.0 occurred off the Pacific coast of Tohoku, Japan, on March 11, 2011. It generated a tsunami 130 km off the northern coast of Japan. The tsunami first reached the Japan mainland 20 min after the earthquake and attacked over 1,300 km along the Pacific coast, inundating over 400 km^2 of land. As of 14 July, estimated fatalities were 16,011 with additional 5,242 missing. This tsunami was the first case that the modern and well-developed tsunami countermeasures faced such an extreme event.

A nationwide tsunami survey has been conducted by joint research groups of 299 researchers among 64 different universities/institutes. Inundation heights and run-up heights measured at 5,247 points in total. On the Sendai plain, the maximum inundation height was 19.5 m, and the tsunami propagated as a bore more than 5 km inland. Along the ria coast, about 50-200 km to the north of Sendai, the narrow bays caused focusing tsunami and generated the largest inundation heights and run-ups. The maximum run-up height measured 40.4 m, resulting in the catastrophic destruction of towns and cities.

1. INTRODUCTION

An earthquake of magnitude 9.0 occurred off the Pacific coast of Tohoku, Japan, on March 11, 2011, at 5:46 (UTC). The rupture area, assumed to be approximately 450 km × 200 km, generated a tsunami 130 km off the northern coast of Japan. Three minutes after the earthquake generation, severe tsunami warnings were issued by the Japan Meteorological Agency. Then, the tsunami first reached the Japan mainland 20 min after the earthquake and attacked over 1,300 km along the Pacific coast (**Fig. 1**), inundating over 400 km^2 of land. As of 14 July, estimated fatalities were 16,011 with additional 5,242 missing. The major cause of death was the tsunami and was more than 99% of total causalities in the Tohoku district.

2. TSUNAMI SURVEY AND DISCUSSION

A nationwide tsunami survey has been conducted by joint research groups of 299 researchers among 64 different universities/institutes (see a list of members at the end of this report). The survey began two days after the earthquake in less affected areas and intensified at the end of March after major rescue and relief activities were conducted in the severely affected Tohoku district. Inundation heights (local tsunami height above sea level), and run-up heights (elevation at maximum inundation) measured at 5,247 points in total and are freely available via our web site (`www.coastal.jp/tsunami2011`). Inundation heights were collected from watermarks on buildings, trees and walls, and corrected for tidal elevation at the time of tsunami inundation. Run-up heights were determined from the maximum landward extent of debris and seawater marks.

The remarkable feature of this tsunami was not only the magnitude of the event, but also range of inundation areas from urban cities with modern coastal defenses to agricultural lands. On the Sendai plain, the maximum inundation height was 19.5 m, and the tsunami propagated as a bore more than 5 km inland. Along the ria coast, about 50-200 km to the north of Sendai, the narrow bays caused focusing tsunami and generated the largest inundation heights and run-ups. The maximum run-up height measured 40.4 m, resulting in the catastrophic destruction of towns and cities. This tsunami is the third mega tsunami in this decade since Sumatra[1)] and Chili[2)].

Prior to this event, the Tohoku district was assumed to be at high risk to an offshore earthquake and tsunami. The Japanese government reported that a M7.4 earthquake along a 200 km fault offshore of Sendai was expected with 99% occurrence probability within 30 years. The 1896 Meiji-Sanriku earthquake tsunami (M8.2-8.5) occurred causing 21,915 deaths, and smaller tsunamis have occurred every few

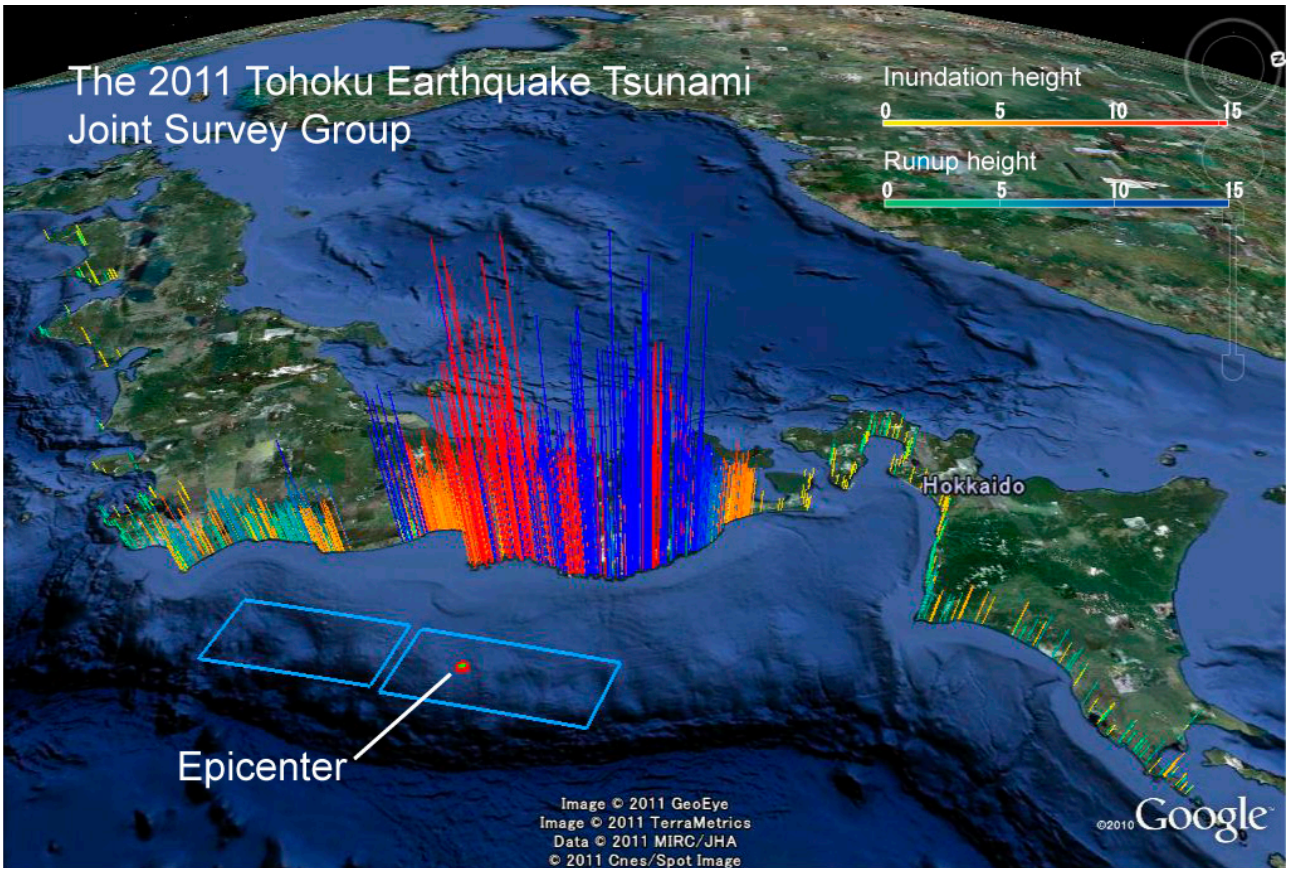

Fig.1 Measured inundation and run-up heights along the Pacific coast of Japan.

decades. Thus, earthquake and tsunami disaster countermeasures, such as offshore and onshore tsunami barriers, natural planted tree barriers, vertical evacuation buildings and periodic evacuation training had been introduced to these areas. Hence, we emphasize that the Tohoku district was one of the best prepared areas against the tsunami in the world.

Nevertheless, we must note that the tsunami disaster countermeasures were insufficient against the 2011 event. Tsunami barriers were severely damaged, some concrete buildings were totally destroyed, and maps underestimated the inundation. Some hard protections (e.g. tsunami barriers) may have lessened overall inundation heights, and their effects should be evaluated by detailed surveys and analyses. Both horizontal and vertical evacuations from a tsunami are common in Japan. The vertical evacuation strategies were effective in many areas very close to the epicenter. Although many people survived the tsunami inundation by the planned evacuations, tragically, there were casualties in some areas designated for vertical evacuation due to the extreme inundation levels.

3. CONCLUSIONS

The 2011 tsunami was the first case that the modern and well-developed tsunami countermeasures faced such an extreme event. Detailed analysis of the efficiency of different protection schemes and evacuation strategies will be required for the different coastal geometries. One of the most important issues among global communities in natural science, engineering and social science is to learn and to improve tsunami disaster countermeasures from this catastrophic event. Detail data from further surveys and future accurate numerical modeling of the tsunami inundation will help with restorations of the Tohoku district and world-wide planning for tsunami risks.

ACKNOWLEDGMENTS: The authors thank Dr. Nobuhito Mori for his contribution to draw the figure in this report.

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MEMBER OF JOINT SURVEY GROUP

Shun-etsu Hamaura, Kazuya Miyakawa, Katsuhiko Tanabe, Keisuke Tanaka, Mitsuyuki Tanaka, Tsukasa Watanabe (Aomori Local Meteorological Observatory), Hideo Matsutomi, Kazunori Naoe, Takuya Noumi, Eriko Yamaguchi (Akita University), Shoichi Ando, Yushiro Fujii, Toshihide Kashima, Yasuo Okuda, Bun'ichiro Shibazaki (Building Research Institute), Tsutomu Sakakiyama, Takumi Yoshii (Central Research Institute of Electric Power Industry), Kazuhisa Goto (Chiba Institute of Technology), Takashi Aida, Yuuji Kurata, Mabumi Miyazaki, Katuya Shutou, Jun Suzuki, Hikari Takeuchi (Choshi Local Meteorological Observatory), Takayuki Nakamura (Ehime University), Osamu Fujiwara, Kyoko Kagohara, Haruo Kimura, Junko Komatsubara, Yukari Miyashita, Yuichi Namegaya, Yuki Sawai, Masanobu Shishikura, Koichiro Tanigawa (Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Hermann Fritz (Georgia Institute of Technology), Ken-ichi Uzaki (Gunma University), Mikio Sasaki (Hachinohe Institute of Technology), Masato Minami (Hachinohe National College of Technology), Hitoshi Endou, Masaki Hashimoto, Yutaka Kobashigawa, Masamitsu Kumagai, Masahiro Ietsune, Kazuhiko Nakamura (Hakodate Marine Observatory), Aditya Gusman, Kazuomi Hirakawa, Kei Ioki, Yugo Nakamura, Takafumi Nakayama, Yuichi Nishimura, Purna Putra, Ayumi Saruwatari, Yasunori Watanabe, Tomohito Yamada (Hokkaido University), Yasunori Nabetani, Hisamichi Nobuoka (Ibaraki University), Takashi Tamada (Idea Co. Ltd.), Yuriko Matsubayashi, Toshinori Ogasawara, Shigeki Sakai (Iwate University), Masao Abe, Yutaka Hayashi, Hideki Iino, Kazuhiro Iwakiri, Kazuhiro Kimura, Kenji Maeda, Masami Okada, Hiroaki Tsushima (Japan Meteorological Agency), Taro Kakinuma, Kei Yamashita (Kagoshima University), Shinya Umeda (Kanazawa University), Takahiro Nakamura, Shuji Seto, Tomoyuki Takahashi, Kurokawa Takahiro, Tetsuya Torayashiki (Kansai University), Gozo Tsujimoto, Kohji Uno (Kobe City College of Technology), Shoichi Yoshioka (Kobe University), Norio Dewa, Tetsuya Hayashi, Mitsuyoshi Kitamura, Shusaku Kuroda, Akihiko Nakahira, Takeshi Nozawa, Kazuya Taniwaki (Kochi Local Meteorological Observatory), Kunio Ohtoshi (Kochi University), Takashi Aoyama, Tatsuo Chiba, Hiroshi Enomoto, Kazunori Hirahara, Shigeki Murai, Hiroshi Narayama, Satoshi Yamanaka, Hitoshi Yamazaki, Satoshi Yoshiiri (Kushiro Local Meteorological Observatory), Ryoukei Azuma, Yasuyuki Baba, Daniel Cox, Kyung-Duck Suh, Eiji Harada, Tetsuya Hiraishi, Hiroyuki Ikari, Hajime Mase, Nobuhito Mori, Kazuya Oki, Shingo Suzuki, Tomohiro Yasuda, Nozomu Yoneyama (Kyoto University), Yukio Oshima, Harutomi Sugaya, Mikio Tanaka (Mito Local Meteorological Observatory), Masashi Fujiwara, Hideaki Suzuki, Tatsuya Suzuki (Morioka Local Meteorological Observatory), Masaki Chinda, Shinsuke Ichikawa, Yasuo Kanamaru, Ryouji Niiyama, Akira Saitou, Hidenori Saitou, Michinori Sasaki, Eikichi Shioya, Toshiharu Shibata, Hiroshi Sugita (Muroran Local Meteorological Observatory), Naoyuki Inukai, Tokuzo Hosoyamada (Nagaoka University of Technology), Tomoya Abe, Kwang-Ho Lee, Koji Kawasaki, Tomoaki Nakamura (Nagoya University), Hirohide Kiri, Kenichi Matsushima, Tetsuo Nakaya, Hajime Tanji (National Agriculture Food Research Organization), Koji Fujima, Yasuko Shigihara, Yoshinori Shigihara, Ryota Tsudaka (National Defense Academy), Takuya Izumiyama, Fuminori Kato, Kentaro Kumagai, Takashi Negi, Kenji Noguchi, Jinkatsu Sugeno, Yoshio Suwa, Shuichi Tsuchiya, Kunihiro Watanabe, Yuji Watanabe (National Institute for Land and Infrastructure Management), Noritaka Asakawa, Sugimatsu Koichi, Akiyoshi Nakayama, Kimiyasu Saeki, Sano Tomoaki, Hiroshi Yagi (National Research Institute of Fisheries Engineering), Yuka Nishikawa (National Taiwan University), Daisuke Itou (Obihiro Weather Station), Toru Endo, Tsuyoshi Haraguchi, Takaaki Shigematsu (Osaka City University), Natuski Mizutani (Osaka Sangyo University), Susumu Araki, Mamoru Arita, Hiroshi Kogi, Daisuke Sakai (Osaka University), Kenzo Kumagai, Kiyohiro Okada, Yousuke Ookubo, Tsuyoshi Nagasawa, Tatsuya Niwa, Shunji Takanishi (Pacific Consultants Co., LTD.), Taro Arikawa, Masayuki Banno, Hiroaki Kashima, Yoshiaki Kuriyama, Yasuyuki Nakagawa, Jun-ichiro Sakunaka, Masaharu Sato, Katsumi Seki, Ken-ichiro Shimosako, Kojiro Suzuki, Shigeo Takahashi, Daisuke Tatsumi, Takashi Tomita, Makoto Washizaki (Port and Airport Research Institute), Takahiko Hasegawa, Teruo Matsuyama, Mitsuharu Nishimura, Hideki Sato, Hirofumi Takano, Kouji Tobe, Hiroshi Yonekawa (Sapporo District Meteorological Observatory), Takeo Fukuda, Minoru Funakoshi, Satoshi Hagiya, Kazumasa Kayano, Tooru Kobayashi, Takashi Masaki, Takashi Sasaki, Yuka Yoshida (Sendai District Meteorological Observatory), Masanobu Hasebe (Shimizu Corporation), Kenji Harada (Shizuoka University), Atsusi Furuta, Kazunori Ito, Yukinobu Oda, Yuriko Takayama, Kanako Yokota (Taisei Corporation), Jiang Jing-Cai, Hitoshi Murakami, Yasunori Mutoh, Susumu Nakano, Kenichi Nishiyama, Ryoichi Yamanaka (The University of Tokushima), Yoshihiro Asaoka, Hideomi Gokon, Kentaro Imai, Fumihiko Imamura, Sou Kazama, Shunichi Koshimura, Akira Mano, Erick Mas, Abdul Muhari, Shosuke Sato, Daisuke Sug-

awara, Anawat Suppasri, Hitoshi Tanaka (Tohoku University), Tadashi Aki, Tokihisa Fuji, Masanobu Houdai, Kazuhiro Kageyama, Kazuaki Kawata, Shigeaki Kumano, Kouichi Satou, Shinji Takeda, Haruo Taninaka, Yasuaki Yabuuchi (Tokushima Local Meteorological Observatory), Takuya Nakamura (Tokyo District Meteorological Observatory), Hiroshi Takagi (Tokyo Institute of Technology), Yasuei Masame, Akio Okayasu, Yanzi Piao, Takenori Shimozono, Takumi Suzuki (Tokyo University of Marine Science and Technology), Shin-ichi Aoki (Toyohashi University of Technology), Wataru Funayama, Hitoshi Imai, Takafumi Ishiwaki, Mototaka Itou, Eiji Kajiya, Kunihiro Mashimo, Kaneyoshi Mochiduki, Kazuki Okamoto, Munehiro Okuda, Naoki Ueda, Mitsunobu Sawada (Tsu Local Meteorological Observatory), Mamoru Nakamura (University of the Ryukyus), Vassilis Skanavis, Costas Synolakis (University of Southern California), Tomoya Harada, Takeo Ishibe, Masahiko Isobe, Mohammad Heidarzadeh, Haengyoong Kim, Yukio Koibuchi, Satoshi Kusumoto, Haijiang Liu, Satoko Murotani, Akihito Nishiyama, Satoko Oki, Kenji Satake, Shinji Sato, Megumi Sugimoto, Yoshimitsu Tajima, Tomohiro Takagawa, Jiro Tomari, Yoshinobu Tsuji, Toshihiro Ueno (University of Tokyo), Shigehiro Fujino, Gaku Shoji, Satoshi Takewaka (University of Tsukuba), Kazuaki Hamaoka, Tamotsu Kawata, Yoshio Miki, Harutaka Miyamae, Yuichi Satou, Yoshiaki Tokuda, Masahiro Ueda (Wakayama Local Meteorological Observatory), Nobuaki Koike (Wakayama National College of Technology), Miguel Esteban, Ryo Matsumaru, Takahito Mikami, Koichiro Ohira, Akira Ohtani, Tomoya Shibayama, Hiroshi Takagi (Waseda University), Retno Utami Agung Wiyono, Kimitoshi Hayano, Kazuhiko Hayashi, Jun Sasaki, Takayuki Suzuki (Yokohama National University)

(Received July 26, 2011)