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Tsunami mitigation in Japan after the 2011 Tōhoku Tsunami

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ABSTRACT

Since the Great East Japan Earthquake and the following Tōhoku Tsunami on March 11th, 2011, Japan has been facing a great challenge of the long-term and costly reconstruction of the impacted Tōhoku Coast, particularly in Iwate, Miyagi and Fukushima Prefectures, where the highest damage ratio was documented. The development of the recovery plans and the new tsunami mitigation strategies, aiming at more efficient protection from such future natural disasters, required in the first step revision of the performance and the efficiency of the tsunami countermeasures employed so far, consideration of the lessons learned from the reconstruction processes after past tsunami disasters as well as adjustment to specific regional conditions (e.g. society aging, diminishing population ratio, land availability, reconstruction visions preferred by local communities). The recovery policies established by the Government of Japan after the 2011 Tōhoku Tsunami promote a combination of three key countermeasures for the reduction of future tsunami risk, namely structural/non-structural coastal protection facilities (under particular consideration of the contribution of green coastal belts), land use regulations and emergency management. The reconstruction policy is presented in this paper with particular attention paid to the planned or already introduced structural/non-structural tsunami countermeasures (such as sea dikes, seawalls, coastal forests, embankments) and land use planning.

1. Introduction

Until March 11th, 2011 Japan was considered worldwide a model country in the field of tsunami preparedness and resilience. The comprehensive tsunami defense system prior this event, encompassing structural and non-structural tsunami barriers, emergency management supported by an early warning system and the concept of tsunami-resistant cities, has been developed over the years, starting after the Meiji Great Sanriku Tsunami in 1896, and was based on the local tsunami and teletsunami events experienced. Several milestones have been reached over the entire period of the establishment of the tsunami countermeasures (Table 1), of which the most significant are: 10-principle guidelines released after the Showa Great Sanriku Tsunami in 1933 by the Council on Earthquake Disaster Prevention, a tsunami forecasting system introduced for the entire Japanese coast in 1952 and revision of the 1933 guidelines in 1997 by the National Land Agency [42].

The 2011 Great East Japan Earthquake and the following Tōhoku Tsunami, resulting in approximately 15,800 fatalities, 6100 injured persons, 2500 missing persons and 220,000 evacuees [6], were of magnitude and devastation extent much greater than the forecast. Several factors contributed to the intensification of this enormous disaster, including: (i) poor evacuation response of the residents due to the false sense of security provided by the coastal protective structures, partial ignorance of the issued tsunami warning and underestimation of tsunami-related hazard [8,13,17,19,45], as well as (ii) failure of the structural countermeasures, designed to withstand an impact of a much weaker tsunami (e.g. [24,44]). The additional effect of community cohesiveness on the evacuation rate was postulated by the results of statistical analysis of social conditions in Tōhoku Region by Aldrich and Sawada [1].

Facing the enormous destruction, development of the approaches for rapid and effective recovery of the regions affected by the 2011 Tsunami, planned to be carried out within 10 years, required collaboration between national government and local authorities on the prefectural and municipal levels [47]. For these purposes, the Government of Japan established two organs: (i) Reconstruction Design Council in June 2011, functioning as an advisory organ that proposed two recovery visions “Seven principles for the reconstruction framework” [38] and “Towards reconstruction – hope beyond the disaster” [39], and (ii) Reconstruction Agency in February 2013 that is in charge of reconstruction planning, coordination and implementation according to two guidelines issued by the government: “Basic act on reconstruction in response to the Great East Japan Earthquake” [14] and “Basic guidelines for reconstruction in response to the Great East Japan Earthquake” [15], as summarized in Table 1.

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Table 1
Selected milestones of tsunami protection strategy in Japan (after [15,18,39,42,47]).

Year, tsunami event	Organization	Countermeasures
After the Ansei-Tokai and Ansei-Nankai Earthquake on 23.12.1854	Private initiative of Goryo Hamaguchi	Goryo Embankment in Hiromura village (Wakayama Prefecture)
3 months after the Showa Great Sanriku Tsunami on 2.03.1933	Council on Earthquake Disaster Prevention	10-principle guidelines: 1. Relocation of dwelling houses to high ground 2. Coastal dikes (may become too large and financially impractical) 3. Tsunami control forests (may dampen the power of tsunami) 4. Seawalls (may be effective for smaller tsunami) 5. Tsunami-resistant areas 6. Buffer zone (e.g. rivers and lowlands that can be sacrificed due to the amplified flooding caused by damming structures) 7. Evacuation routes 8. Tsunami watch 9. Tsunami evacuation 10. Memorial events
1952	Government of Japan	Tsunami forecasting system for the entire coast of Japan introduced through the Meteorological Business Act
1977	National Land Agency	"Guidance on Reinforcement of Tsunami Disaster Prevention Countermeasures in Local Disaster Prevention Planning" (revised guidelines from 1933): 1. Defense structures 2. Tsunami-resistant city development 3. Evacuation-based warning 4. Determination of design tsunami
After Great East Japan Earthquake and Tōhoku Tsunami on 3.11.2011	Reconstruction Design Council	"Seven principles for the reconstruction framework" (10.05.2011): 1. Remember and honor the lives lost in the disaster 2. Make community-focused reconstruction the foundation of efforts towards recovery 3. Tap into Tohoku's latent strengths 4. Construct disaster-resilient and safe communities and a natural energy-powered region 5. Simultaneously pursue reconstruction of the afflicted areas and revitalization of Japan's economy as a whole 6. Seek an early resolution of the nuclear accident 7. Pursue reconstruction with a spirit of solidarity and mutual understanding
	Reconstruction Design Council	"Towards reconstruction – hope beyond the disaster" (25.06.2011)
	Government of Japan	"Basic act on reconstruction in response to the Great East Japan Earthquake" (24.06.2011)
	Government of Japan	"Basic guidelines for reconstruction in response to the Great East Japan Earthquake" (29.07.2011): 1. Recognize the challenges of an aging and declining population by promoting adequate public transportation and support services 2. Promote a strategy of multiple defenses through soft and hard (structural) measures, putting people at the center of disaster reduction 3. Promote a "new public commons" through social inclusion of a wide range of stakeholders in the reconstruction 4. Make municipalities in disaster areas the main actors accountable for reconstruction, aided by financial and technical support from the central government and prefectures 5. Promote rapid reorganization of land use to stimulate investment and prevent speculation 6. Prioritize providing stable residences for the affected through favorable housing loans and low-rented public housing 7. Assist municipalities with reconstruction planning through external experts 8. Promote employment of affected people through recovery and reconstruction investments under the "Japan as One" project 9. Prioritize rehabilitation of key transport and logistics infrastructure and revival of local economic activities 10. Open reconstruction to the world through active international cooperation and lesson sharing 11. Create a special zone for reconstruction to support local projects through flexible procedures and financing

According to the proposed guidelines, the maximum tsunami safety is to be reached through the application of the concept of multi-defense line protection, combining both structural and non-structural countermeasures, as well as evacuation management and land use policy. The type of tsunami strategy and the required means to be applied to ensure these safety levels are governed by two tsunami design levels, established by the government: (i) "level 1 tsunami", corresponding to frequently occurring tsunami of return period of 100 years, and (ii) "level 2 tsunami", representing the largest tsunami in the past with return period of 1000 years such as the 2011 Tōhoku Tsunami. The defense strategy elaborated in the framework of the "level 1" tsunami hazard aims at prevention of tsunami-caused damage and protection of human lives through implementation of structural countermeasures, while damage mitigation against "level 2 tsunami" envisages the employment of land use regulations and evacuation management in addition to coastal barriers [34].

In this publication the development and the implementation of the tsunami defense strategy in the framework of the recovery process after the 2011 Tōhoku Tsunami event is presented, with focus on planned/constructed protective structural and non-structural barriers as well as adopted land use regulations. Special attention is paid to innovative tsunami mitigation concepts and optimization of conventional protec-