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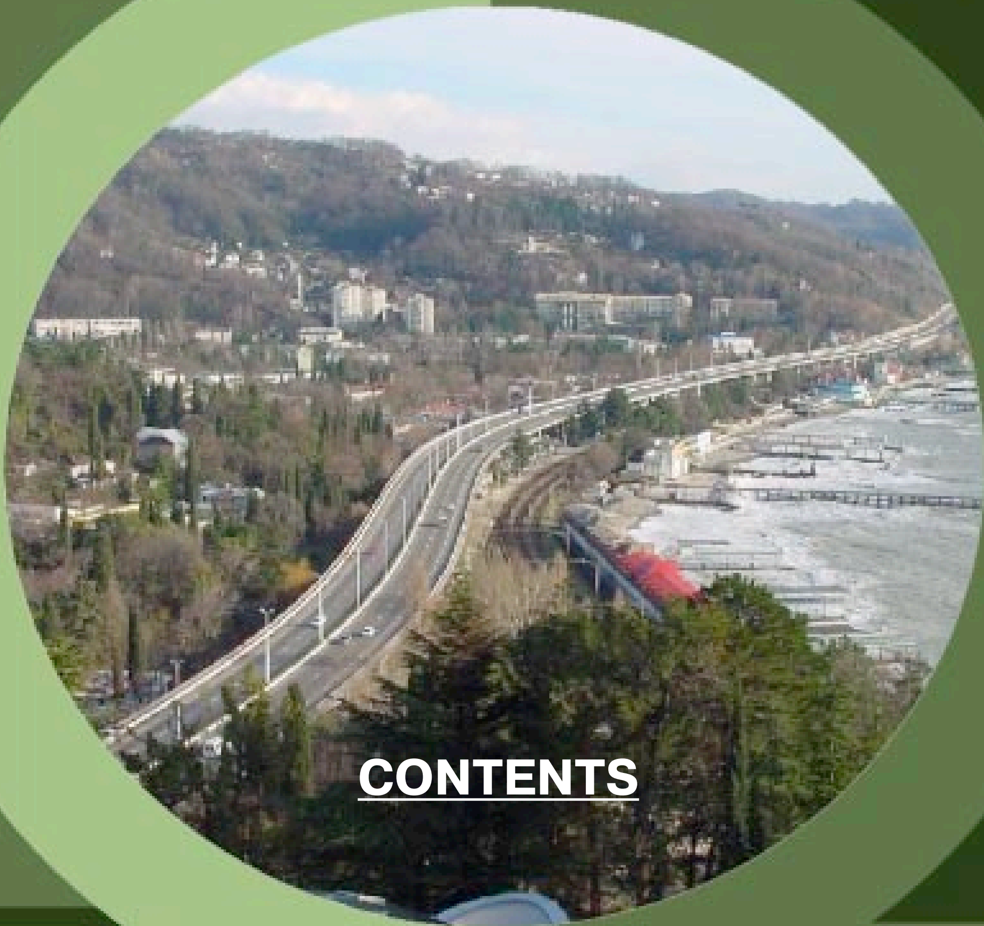

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THE MW=9.0 TOHOKU JAPAN EARTHQUAKE (MARCH 11, 2011) TSUNAMI IMPACT ON STRUCTURES AND INFRASTRUCTURE

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Abstract: *The March 9th 2011 earthquake of Mw=9, that occurred offshore NE Japan, triggered major tsunami waves that affected almost all of the NE coast of Japan and caused massive casualties. Great damages were observed as whole residential, industrial and rural areas were swept away. Preliminary field observations on the behaviour of different types of structures and critical infrastructure are presented, the causes are analyzed and comparisons are made with the damage caused by the tsunami of Indian Ocean of December 26th, 2004.*

1. Introduction

On March 11th, 2011, 14:46:23' (JST) a mega-thrust earthquake of moment magnitude 9.0 occurred offshore NE Japan. The mega-earthquake occurred on the margins of two tectonic plates, that of Eurasia, moving to the east and thrusting and that of Pacific which moves to the west and subducting. The vertical uplift on the sea-floor at the epicentral area is estimated to be more than 4.5 m., while to the west, both offshore and onshore, a subsidence of 1 – 1.5 m. was observed [1].

The generated tsunami waves traveled across the entire Pacific Ocean, but their effects were devastating to the coastal areas of NE Japan, striking the areas between Aomori Prefecture (to the north) and Chiba Prefecture (to the south), a distance of about 850 km.

The tsunami affected the coastline of NE Japan, with varying run-up heights, depending on the orientation of the sea-gulfs in relation to the epicentral area, the local bathymetry, the development of the local drainage systems etc. In Ishinomaki area (Fig. 1), the tsunami wave inundation reached up to 10 km. inland, while in Onagawa and Ogatsu areas the destructive run-up height exceeded 30m [5]. In large areas, the sea water permanently inundated great inland parts, due either to the erosion of soils, or the general subsidence [5].

Below, there is first description of damage on buildings and critical infrastructure of the tsunami affected areas, based on field investigation, and an estimation of the constructions behaviour during the event.

2. Effects on structures

The low-lying coastal areas were largely affected by the tsunami waves. Residences, hotels, public buildings, industrial facilities and critical infrastructure were subjected to varying run-up heights. The forces on structures caused by the tsunami, were in the form of hydrodynamic pressure, erosion (scouring), buoyancy, and impact by objects and debris carried by the water.

Specifically, the following effects were recorded, according to the type of constructions and/or critical infrastructure

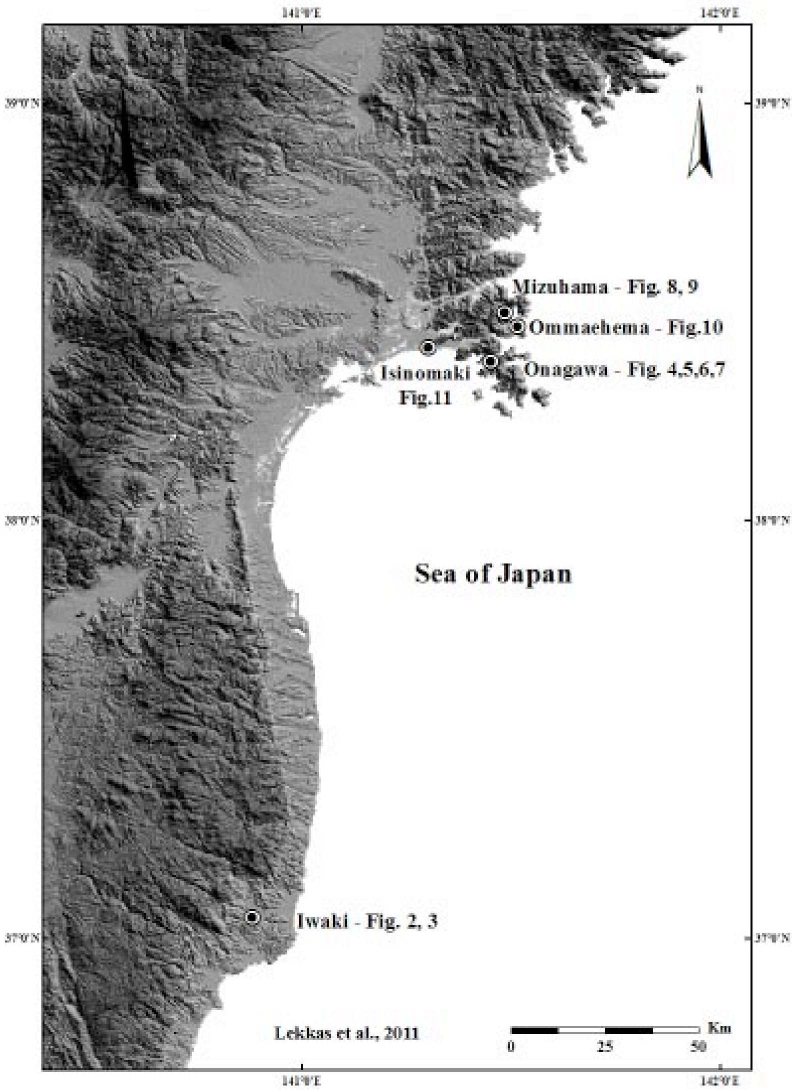

Fig.1. Map of affected area, between Iwaki and Mizuhama, where the field investigation was focused

Residential wood houses

This type of construction is typical in the affected area, as it provides a low-cost housing solution. These are one or two-story houses, constructed of wood frame made up of columns and beams that support wood joists. The roof is usually covered with thin corrugated steel sheets or clay tiles. These constructions successfully coped with earthquake loading, absorbing the seismic energy mainly through ductile deformation.

On the contrary, the tsunami impact was devastating. More specifically, they were totally swept by the wave forces and by the impact of objects carried by the water. They were broken to small pieces of debris, which were deposited in the inundated areas, or were carried to the cost-line or the open sea, when the water receded. A great number of this particular type of constructions were swept by their footings and were carried, practically unchanged, to great distances (Fig. 2, 3, 4).

Fig.2. Collapse of a wood frame house in Iwaki area. Tsunami height of about 5 m

Fig.3. Of a wood frame residential construction and collapse of others, in Iwaki area

Fig.4. Transport and collapse of wood frame constructions inn Onagawa city

Some of these wooden houses were destroyed by fires broken out during the earthquake, or as a result of specific conditions that prevailed when the tsunami arrived.

Engineered reinforced concrete constructions

The fact is that the ground acceleration of the earthquake was close to that considered as the design recommendations in Japan. The frame structures behaved exceptionally well, despite the extreme ground acceleration and the duration of the earthquake, attesting to the top designing standards used for their construction. Damage to these building was minor, throughout the meisoseismal area. Very few total collapse cases were recorded.

Damage to the engineered constructions was limited to broken doors and windows and masonry failures. Masonry walls suffered out of plane failures and were jettisoned in great distance, mainly in buildings constructed near the shoreline. No damage on the supporting structure caused by the tsunami was observed (Fig.5). Only in certain areas and isolated cases, minor damage to columns was observed, resulting from the impact of debris or objects carried by the water, such as cars and boats.

Upon coming to shore, as well as during recession, the tsunami waves were highly turbulent. This led to scouring of granular foundation material in some buildings (particularly those that were closest to the shoreline), resulting in loss of support and partial overturning or collapse.

Fig. 5. Total collapse of constructions in Onagawa area. Near the coast, engineered reinforced concrete constructions can be seen damaged but standing

Steel frame buildings

The behaviour of steel frame buildings during the earthquake was conformant to the provisions of building codes. The damage to this type of construction was limited to non-supporting elements, such as windows, doors or infill walls.

In contrast, the tsunami had important effects on these constructions, both in supporting and non-supporting elements. In most cases masonry walls out of plane punching shear failures were observed, due to tsunami lateral forces and the impact of debris carried by the water, up to the wave maximum run-up height in a given area. In many cases the steel frame buildings were left empty of all infill walls as well as flooring.

Many of these buildings, mainly those built near the shoreline, suffered great lateral loading on structural elements, resulting in a more or less general deformation of the structure. In some cases all of the steel elements were lifted from their reinforced concrete bases and were carried (totally deformed) in different areas. It should be noted that the masonry of the metal frame buildings proved to be much more vulnerable than that of the engineered reinforced concrete buildings (Fig.6, 7).

Fig.6. Masonry failures in steel frame building in Onagawa city

Fig.7. Total deformation of steel frame building elements in Onagawa city

Port Facilities and Related constructions

Small and medium sized port facilities suffered major damage, especially in the areas from Ishinomaki up to Aomori, where the tsunami waves reached maximum runup height, along the East coast. Medium ports at Hachinohe city in Aomori and Kamaishi in Iwate were severely damaged by the tsunami waves, as they surmounted the ports' breakwater. In Kamaishi port, the world's largest tsunami protection breakwater, built in 2009, measuring 1950m long, 20m thick and 63m foundation depth failed to protect the city as more than 800m of the brakwater were completely destroyed. Smaller breakwaters were also destroyed, as 50-m long, 40-m deep breakwater in Ofunato Port, a smaller scale port in Iwate [4].

Specifically, failing and deformation of quay walls was observed, caused either by the hydrodynamic forces of the waves, or the impact of objects such as boats and containers.

In many cases the quay walls and the accompanying supporting constructions collapsed or were overturned, due to the intense scour of the foundation materials. Moreover, the seaport constructions proved to be especially vulnerable to receding waters, which caused intense deformation and overturning.

Finally, the piers constructed in order to protect against tsunami waves, could not cope with the observed tsunami, either because of inadequate or underestimated structural design, or because of collapse, resulting in devastating effects on inland areas. In addition, severe failures because of intense erosion were observed in levees and coastal river regulation constructions (Fig. 8, 9).

Fig.8. Destroyed port facilities and general alteration of the shoreline in Mizuhama town

Fig.9. Destroyed port facilities and general alteration of the shoreline in Mizuhama town

Bridges

Very few of the bridges built in the tsunami affected areas suffered partial or total collapse. Mainly the suspended elements suffered severe damage or collapsed of the bridges located in areas of Ookawa, near Ishinomaki city, in Miyagi refecture and at Nakajima, near Kesennuma, city, both at Miyagi Prefecture. In Namegata, Ibaraki Prefecture, the bridge was destroyed even though tsunami runup height was a lot lower than in Miyagi. Damage in the bridges was caused by the lateral forces of the tsunami or by the impact of carried away objects (cars, boats). Less damage was observed on the piers, also caused by impact of massive objects or debris.

Critical Infrastructures

A large part of the coastal road network of the tsunami affected areas was totally destroyed, either by the waves themselves, or by debris impact. Damage was observed on the pavement, mainly caused by the erosion of the substrate material. There are also many cases in which the road deck was transferred in great distance, having suffered intense deformation (Fig.10).

The railway network also suffered great damage along a length of many kilometers, resulting in the interruption of railway connection. Damage was observed either on the permanent way of the rails, or even the rail themselves which, in some cases, were intensely distorted. In the area south of Sedai city, the rails were carried by the tsunami wave for more than 100 m.

The power generation systems, telecommunication networks and mobile telephony towers were completely destroyed, resulting in the interruption of communications (Fig.11).

Finally, the water supply was interrupted because many of the water distribution pipes along rivers or canals broke, while the sanitation system suffered extensive damage, since the concrete slabs were lifted, displaced and broken.

Fig. 10. Intense erosion and destruction of road network in Ommaehema town

Fig. 11. Power distribution network damage in Isinomaki town

3. Conclusions

The Mw=9.0, March 11th 2011 earthquake offshore NE Japan resulted in relatively limited damage on constructions, caused by the tremor, but extensive damage was caused by the generated tsunami waves that followed. Based on the above-mentioned preliminary field observations, the following conclusions can be reached:

The engineered reinforced concrete buildings behaved very well in the tsunami, suffering only, in some cases, minor failures in constructed elements (columns) resulting from tsunami involved impact by objects. Limited damaged was observed in first floor masonry, because of the hydrodynamic forces that developed. This type of buildings showed a better behaviour than the non-engineered buildings affected by the Indian Ocean tsunami, generated by the December 26th 2004 earthquake [6, 2, 10, 9].

On the contrary, the steel frame constructions suffered important damage, both in non-structural masonry and constructing elements. The anchorage system on the reinforced concrete base, in many cases, proved to be inadequate.

The wood frame constructions suffered enormous damage due to their minimal resistance in static and hydrodynamic loads.

The port facilities were severely damaged by the tsunami. The most common failure is quay walls collapse or overturn. In addition, major damage was observed in road networks, water regulation works and communication networks. Some damage was also observed in a number of bridges.

These constructions have been also proven vulnerable in other similar circumstances, such was the 2004 Indian Ocean tsunami that followed the December 26th earthquake [6, 2, 7, 8, 9, 10].

Concluding, a new design of critical infrastructure needs to be adopted, one that takes into account lateral hydrodynamic forces, protection of impact forces by the debris, the scour of the foundation materials and the adequate anchorage system of wood and metal frame constructions on their bases. Finally, the port facilities should be designed using largely increased safety factors.

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STRUCTURAL-AND-GEODYNAMIC RESEARCHES IN ENGINEERING GEOLOGY SURVEYS AND ENVIRONMENT STUDY

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Abstract: *This report is devoted to structural and geodynamical problems and questions which must be taken into consideration by engineering geology surveys. First of all it concerns the special zonation of territories under survay, estimation of their general recent structural position and potential stress field, the distribution of geodynamical active and potentially dangerous (week) zones, techniques of their revealing. Normatives for their using must be advanced (developed) as well.*

All these topics seem to be rather clear in general, at some well studied areas and by routine surveys. Nevertheless they need to be discussed further as in principal sense as well in direct applications for constructions and using of many responsible objects (NPS, power stations river dams, oil and gas pipelines, toxic waste tombs, and other industrial and civil ones).

The main directions and tasks of such investigations concern wide range of questions. Among them there are:

– revealing, mapping and estimation of structural forms of different sizes and ages (at first of neotectonic, youngest one, active recently);

– estimation of degree and style of inheritance of old structures by younger and youngest ones;

– revealing, mapping and classification of recent geodynamical active zones which are different in ranges, nature, forms of the manifestation and indicators;

– study of regularities of space distribution and development of recent geodynamical active zones;

– revealing and study of geodynamic conditions by which nature and induced geological, structural-and-geomorphologic, hydrogeological, geophysical, gas- and hydro- geochemical and other anomalies of geological media were or could be formed;

– lineaments, their nature, forms of manifestation and necessity of account of them;

– estimation of connections of exogenous geological processes (erosia, karst, suffosia, landslides et al.) with geodynamical active zones and other nature and induced anomalies;

– interrelation of radon concentration with geological substratum, relief and gedynamical activity.

Structural-and-geodynamic setting. It is basic state by survey. It can be realized first of all with special mapping of the area which is enough to answer the key questions to make clear the main attributes – properties of the grounds and possible changes of them. ***What*** and ***where?*** They become clear after analysis of geological maps and some additional surveying. In general 3D-pictures of distribution of geological facieses usually satisfy us. But sometimes it is necessary to know more – ***when?*** and ***why?*** Beds of rocks (grounds) formed at different geological times under some primary geodynamical conditions. The last ones did not stay constant. Nowadays grounds reflect not only primary properties, but also subsequent changes. Among