A Survey Report on Pavement Damage in the Disaster Areas of Tohoku

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SUMMARY

On March 11,2011,the Tohoku region, Northeast Japan, was hit by a gigantic earthquake which occurred in the Pacific of the Miyagi offing and subsequently a giant tsunami and soil liquefaction occurred over a wide area. This gigantic earthquake was named “the Tohoku Region Pacific Coast Earthquake” by Japanese Government, and it’s magnitude was 9.0, the strongest ever recorded in Japan. These disasters have caused gigantic damage on the eastern coast Japan, areas of damage was wide along Iwate, Miyagi and Fukushima prefectures. As of early May, 2011, over 20 thousand people were reported as dead or missing.
We surveyed the areas damaged earthquake and tsunami from early April, 2011.In this paper we report on the investigation about damage and temporary restoration situation to pavements by this earthquake.

1. INTRODUCTION

The Great East Japan Earthquake which hit Japan at 14:46 on March 11, 2011 recorded a moment magnitude of 9.0 and turned out to be one of the largest earthquakes ever recorded in this country. Its seismic intensity reached 6 on the 0-7 scale of the Japan Meteorological Agency (JMA) in wide areas from Iwate Prefecture in the north and Chiba Prefecture in the south, with the highest level 7 registered in the northern Miyagi Prefecture. Waves of the tsunami which accompanied the mega-earthquake reached unpredicted heights of over 20 meters, causing devastating damage to the Pacific coastal areas. This report presents survey results on damage and restoration of interlocking block pavements, with a special focus placed on Miyagi and Fukushima Prefectures where strong tremors were experienced.

2. DAMAGE OBSERVED IN TOHOKU

Figure 1 shows the distribution of peak ground acceleration measured during the earthquake (official name by the JMA: the 2011 off the Pacific coast of Tohoku Earthquake). The moment magnitude at the epicenter was Mw=9.0, the largest value

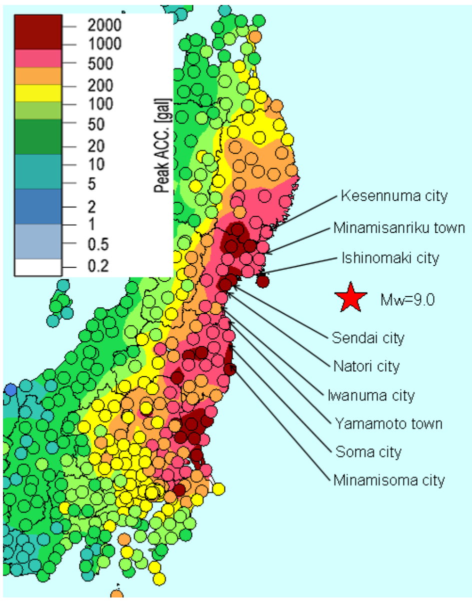


Figure 1: Measured peak ground acceleration, and locations of the survey areas

ever recorded in Japan. The ground acceleration was significantly large in the Pacific coastal areas of Iwate, Miyagi, Fukushima and Ibaraki Prefectures.

The coastal areas of the Tohoku and Kanto regions were also hit by the tsunami induced by the mega-earthquake. The other major consequence was liquefaction of reclaimed land which developed to an unprecedented scale in the coastal areas of Chiba and other prefectures in Kanto.

This damage survey report focuses on the coastal areas of Miyagi and Fukushima in Tohoku as shown in Figure 1 and presents the findings by the type of damage.

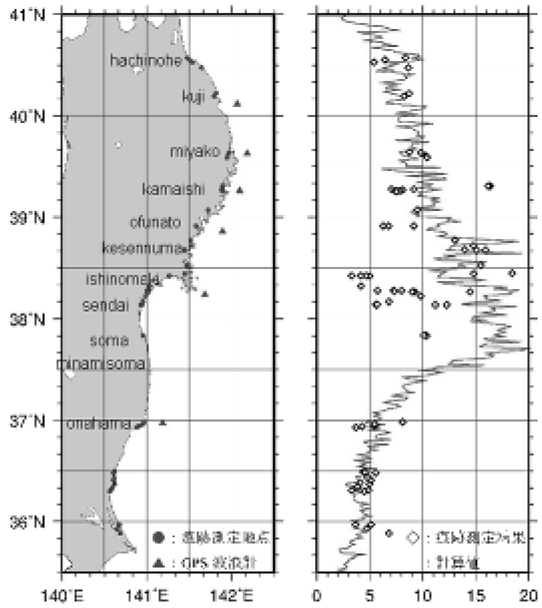


Figure 2 Measured and calculated run-up heights of tsunami

3. IMPACT OF TSUNAMI ON PAVEMENTS

Figure 2 plots the measured and calculated run-up heights of tsunami in the coastal areas of Tohoku and the northern Kanto. Tsunami waves were higher than 10 meters in the survey areas on the Pacific coast from Minamisoma City of Fukushima to Kesennuma City of Miyagi.

Photo 1 was taken at the Port of Kesennuma in Kesennuma City. The city was devastated by the tsunami, and the streets were flooded due to the subsidence.

Photo 2 was shot at a site several hundred meters inland from the Port of Kesennuma. A large fishing boat carried by the tsunami was sitting on the road. This picture shows that the pavement remained unbroken, while houses and buildings were destroyed by the tsunami.

Photo 3 shows an interlocking block used as the base for the support which was applied to prevent the fishing boat from toppling over. The block was withstanding the load without fracturing.

Photo 1 The port facilities flooded due to the subsidence

Photo 2 A large fishing boat carried inland by the tsunami

Photo 3 Wooden support applied to prevent the fishing boat from toppling over

Photo 4 shows a road bridge on National Highway 45 located on a coastal site in Utatsu district, Minamisanriku Town. Only the piers remained standing, with the upper girders destroyed and carried by the tsunami. This picture depicts the extraordinary power of destruction the tsunami had.

Photo 5 shows a car park next to the Ishinomaki Municipal Hospital located on a coastal site in Ishinomaki City. The vastly exposed land shown at the back left in the picture suggests that the tsunami eroded the ground around the pavement and carried the surface course with its backwash.

Photo 4: A road bridge destroyed by the tsunami

Photo 5: Pavement of a car park destroyed by the tsunami

Photo 6 was taken in Yuriage district downstream the Natori River. Although the whole town was devastated by the tsunami, pavement remained undestroyed. This was likely due to the confinement provided by the remaining foundations of the houses and buildings surrounding the pavement.

Photo 7 was taken at the Watari Bridge crossing the Abukuma River in the coastal area. The tsunami overrode the breakwater shown at the right in the picture and prostrated the tide- and wind-protective forest. It is likely that the remaining roots of the forest trees restrained the pavement and prevented the surface course from being carried away.

Photo 6: A town devastated by the tsunami

Photo 7: Damaged tide- and wind-protective forest

Photo 8 was shot near the Soma Fishing Port in Soma City. No major damage was found in the interlocking block-paved walkway or the asphalt-paved driveway, while the buildings shown at the right and back center in the picture were destroyed by the tsunami. The interlocking blocks remained unbroken, although the pavement partly crumbled where the periphery curbs were destroyed by the tsunami.

Photo 9 shows a prefectural road in Minamiebi district, Kashima-ku, Minamisoma City. The road is located immediately at the back of a breakwater. Although the surface course narrowly remained in place, the road is in danger of collapse, with its shoulder extensively eroded by the tsunami which overrode the breakwater.

Photo 10 is a shot taken at Haramachi-ku, Minamisoma City. The pavement was found severely damaged, with its surface course removed at many spots. There were a lot of precast concrete armor units, as well as U-shaped gutter segments from the irrigation channels, lying scattered over the nearby farmland. It is likely that these concrete blocks and debris carried by the tsunami hit and destroyed the pavement surface.

These findings suggest that pavement damage may result from such factors as erosion at the road shoulder by a tsunami, damage to the surface course from collision with obstacles, and loss of periphery restraints, while shear force generated in the pavement surface due to the flow of tsunami does not likely cause pavement damage.

Photo 8: Interlocking block pavement swept by the tsunami

Photo 9: The road shoulder eroded by the tsunami

Photo 10: Precast concrete armor units lying scattered over the farmland

4. IMPACT OF THE LIQUEFACTION ON PAVEMENTS

Figure 3 is an excerpt from the Kanto region liquefaction report by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan and the Japanese Geotechnical Society.

Extensive liquefaction occurred in seashore reclaimed land as well as in lakeside and riverside areas in Kanto, as widely reported by the mass media. However, liquefaction also occurred in Tohoku, though not as extensive as in Kanto, both in coastal and inland areas.

Photo 11 shows the consequences of liquefaction found in a rice paddy field area in Inarido district, Wakabayashi-ku, Sendai City. The utility poles were leaning due to the liquefaction.

The traffic cones were placed for the safety of drivers to

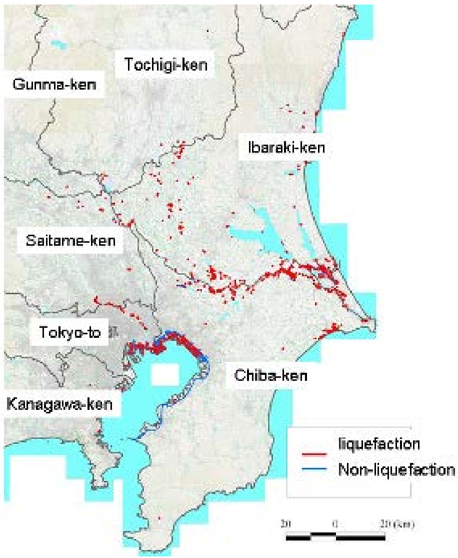


Figure 3: Liquefaction map for the Kanto region

call their attention to bumps and cave-ins made in the roads by the liquefaction.
In Photo 12 the right-hand strip of the road collapsed longitudinally for a considerable distance. There was a water main buried beneath and along the road surface. It is likely that the higher groundwater level than those in the surrounding soil caused liquefaction of backfill sand.

Photo 11: Leaning poles due to liquefaction

Photo 12: Road surface collapsing due to liquefaction

Photo 13 shows a cave-in made in the road surface. A deep and wide cavity was found beneath that by visual check at the site. The heat during the summer increased the road surface temperature and thus decreased the asphalt viscosity, presumably allowing for a collapse of the asphalt mixture due to its weight. This specific spot was likely to have been prone to the collapse by self-weight because of the cavity generated benea
th the surface and base courses (the pavement structure) due to the liquefaction.
Photo 14 shows one of the typical phenomena of liquefaction observed inland on a municipal road in Kashima-ku, Minamisoma City. The lifting of a drainage manhole in a farming village suggests liquefaction of the backfill sand.

Photo 13: A cavity beneath the road surface found after the collapse of the hot mix asphalt (HMA)

Photo 14: A manhole lifting up due to liquefaction

Figure 4 shows an experimental backfill technique proposed for sewer pipelines of drainage systems of farming villages. Crushed stone backfilling or similar technique is used in restoration of sewer pipelines in the damage areas as a prevention of liquefaction. However, such a liquefaction countermeasure is not taken for all underground pipelines. It is extremely highly likely that similar collapse of roads due to liquefaction will occur in future earthquakes.

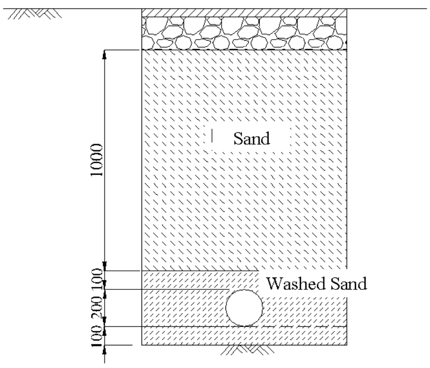


Figure 4 Liquefaction countermeasure for drainpipes in farming villages

5. DAMAGE FROM THE EARTHQUAKE AND TEMPORARY RESTORAION

Photo 15 shows a walkway broken at its periphery. The right-hand (left-hand?) picture shows the walkway immediately after the earthquake, and the left-hand (right-hand) picture shows its temporary restoration. This site is located in Sendai City, Miyagi. Some of the interlocking blocks were found displaced due to loss of confinement where the walkway-driveway boundary blocks had a downward slope toward the driveway. The walkway was restored by reusing the existing interlocking blocks and restraining them at the periphery with new boundary blocks.

Photo 15 A walkway broken at the periphery

Photo 16 shows lift-up of interlocking blocks. The ground beneath the walkway subsided, while the periphery confinement at the right and left ends remained effective, consequently raising the pavement at the center. Since the pavement damage was minor with the blocks remaining unbroken, the blocks were not disposed of but reused in temporary restoration. The repair was made in the following manner:

(1) The existing interlocking blocks and spread sand were removed from the raised areas, the base course was compacted using a roller, and the surface was leveled.

(2) Joint sand was removed from the sides of the blocks for reuse, using wire brushes or similar.

(3) Sand was spread, and the blocks were laid.

Photo 16: Lift-up of interlocking blocks

Photo 17 shows a gap generated between a building and an interlocking block pavement. The walkway pavement surface sunk entirely for about 10 to 20 cm, leaving open gaps and slopes around the building. Mortar was rubbed to cover the gaps and adjust the height at the entrance of the building. The existing interlocking blocks were reused in temporary restoration after confirming the absence of cracking and chipping.

Photo 17: A gap generated between a building and an interlocking block pavement

6. DAMAGE FROM THE LIQUEFACTION AND RESTORATION

Photo 18 shows liquefaction of soil around a manhole and a lamppost. Liquefaction of soil around the manhole and the lamppost caused sand boiling and ground subsidence in the open space, leaving accumulation of soil on the surface. The sinking area was repaired with asphalt mixture.

Photo 18: Liquefaction of soil around a manhole and a lamppost

Photo 19 shows a manhole raised by liquefaction. Sand boiling was also observed, in addition to the lift-up of the manhole. Although the flat block pavement crumbled due to the rise of the

Photo 19: A manhole lifting up due to liquefaction

ground or other causes, most of the flat blocks remained unbroken. The blocks were removed, and the base course was backfilled with crushed stone for temporary restoration.
Photo 20 shows another flat block pavement damaged by liquefaction.
The pavement partly lifted up due to liquefaction. The pavement surface was covered with rubber sheets for temporary restoration to ensure safety of pedestrians.

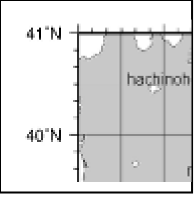
Photo 20: Flat block pavement damaged by liquefaction

7. DAMAGE FROM THE TSUNAMI AND RESTORATION

Photos 21 to 23 show interlocking block pavements damaged by the tsunami. Glasses on the building shown in Photo 21 were broken by the tsunami. Although the pavement crumbled into units due to displacement of periphery curbs, the interlocking blocks remained unbroken.

Photo 21: Interlocking block pavement damaged by the tsunami, 1

Photo 22: Interlocking block pavement damaged by the tsunami, 2



The ground around the interlocking block pavement was eroded by the tsunami where a utility pole was standing (Photo 22). Loosened blocks were carried away. This site was repaired by spreading new gravel over the base course for temporary restoration.
Damage shown in Photo 23 was likely to have been caused by the ground subsidence due to the earthquake which affected the interlock between the blocks in the pavement and allowed the loosened blocks to be carried by the tsunami. The walkway was repaired for temporary restoration, using asphalt mix in place of the interlocking blocks.

Photo 23: Interlocking block pavement damaged by the tsunami, 3

Figure 5 shows the interlocking block reuse ratios at about 60 sites in and around Sendai City, Miyagi during April to May, 2011. It was found that more than 90% blocks were reused at most sites. The majority of the interlocking blocks remained undamaged after the earthquake, without cracking or chipping, and reusing them made restoration work easier with reduced need for transportation for new materials and disposal of old ones. These are considered to be the primary reasons for the very high reuse ratios of the interlocking blocks.

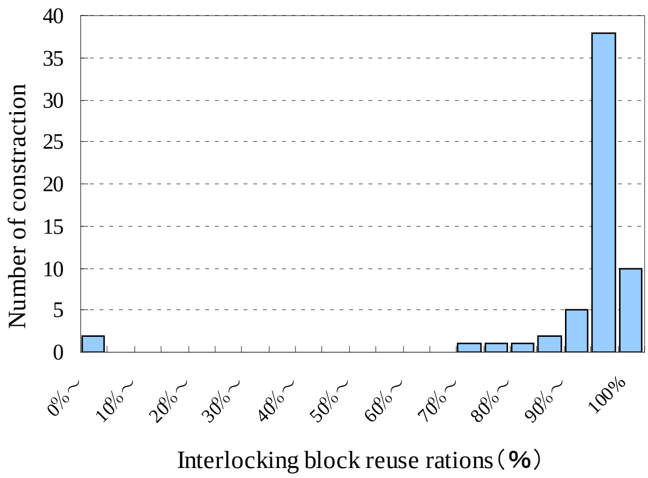


Figure5 Interlocking block reuse ratios
at about 60 sites in around Sendai City

8. CONCLUSION

Pavements were found damaged to a considerable extent by the tsunami and liquefaction which accompanied the Great East Japan Earthquake. Damage from liquefaction was significantly severe and suggested that there must be numerous places in extensive areas where roads have cavities beneath them but exhibit no obvious transformation on the surfaces.

REFERENCES

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