DAMAGE TO ROADS CAUSED BY OCT. 8, 2005 NORTH PAKISTAN EARTHQUAKE

Obaid Hassan QURESHI [1] and Junichi KOSEKI [2]

ABSTRACT: Damage to roads during the 2005 North Pakistan Earthquake is briefly reported. Various local and main roads in northern Pakistan suffered serious damage. The roads in this hilly terrain are mainly constructed in cut. Three modes of damage viz. slope instability, structural damages to bridges, retaining structures etc. and ground rupture were observed. Lack of proper design of cut slopes and inadequate retaining structures increased the hazard. Most landslides appear to be in a meta-stable state and can be readily activated due to aftershocks or rain. Landslide hazard remains high throughout the affected areas.

Key Words: *the 2005 Pakistan Earthquake, roads, slope instability, landslides, bridges, retaining structures, ground rupture*

INTRODUCTION

The North Pakistan Earthquake of October 8, 2005 having a magnitude of Mw 7.6 (USGS) caused serious damage to roads in Pakistan administered Kashmir (Azad Kashmir-AJK) and Hazara Division of North-West Frontier Province (NWFP) of Pakistan. In the recent history, this area had not received an intense earthquake of this magnitude. The area lies in the zone II, corresponding to moderate damage, as per seismic risk map (GSP). The first author visited the affected area on October 25 through 28, 2005. This paper reports the preliminary results from the investigations, focusing on the possible causes of the damage to the roads. It is emphasized that the general observations are based on visual inspection and engineering judgment, with no detailed analysis or formal assessment. They should therefore be taken as preliminary and awaiting further studies and confirmation.

OVERALL DAMAGE TO ROADS

Town of Balakot, located in NWFP and city of Muzaffarabad, located in AJK suffered severe damage during this earthquake. Various main and local roads were affected. 2366 km (45%) length of roads was damaged in AJK, whereas in NWFP, it was 2063 (31%) km (ADB-WB, 2005). Fig. 1 shows the major affected roads during this earthquake. These roads are as under:

1. Mansehra – Muzaffarabad Road
2. Muzaffarabad –Kail Road (Neelum Valley Road)
3. Muzaffarabad – Srinagar Road (Jhelum Valley Road)

[1] Graduate student, Department of Civil Engineering, University of Tokyo
[2] Professor, Institute of Industrial Science, University of Tokyo

4. Muzaffarabad – Islamabad Road (N75)
5. Mansehra –Balakot Road (N15)
6. Balakot –Naran Road (N15)
7. Karakuram Highway (N35)

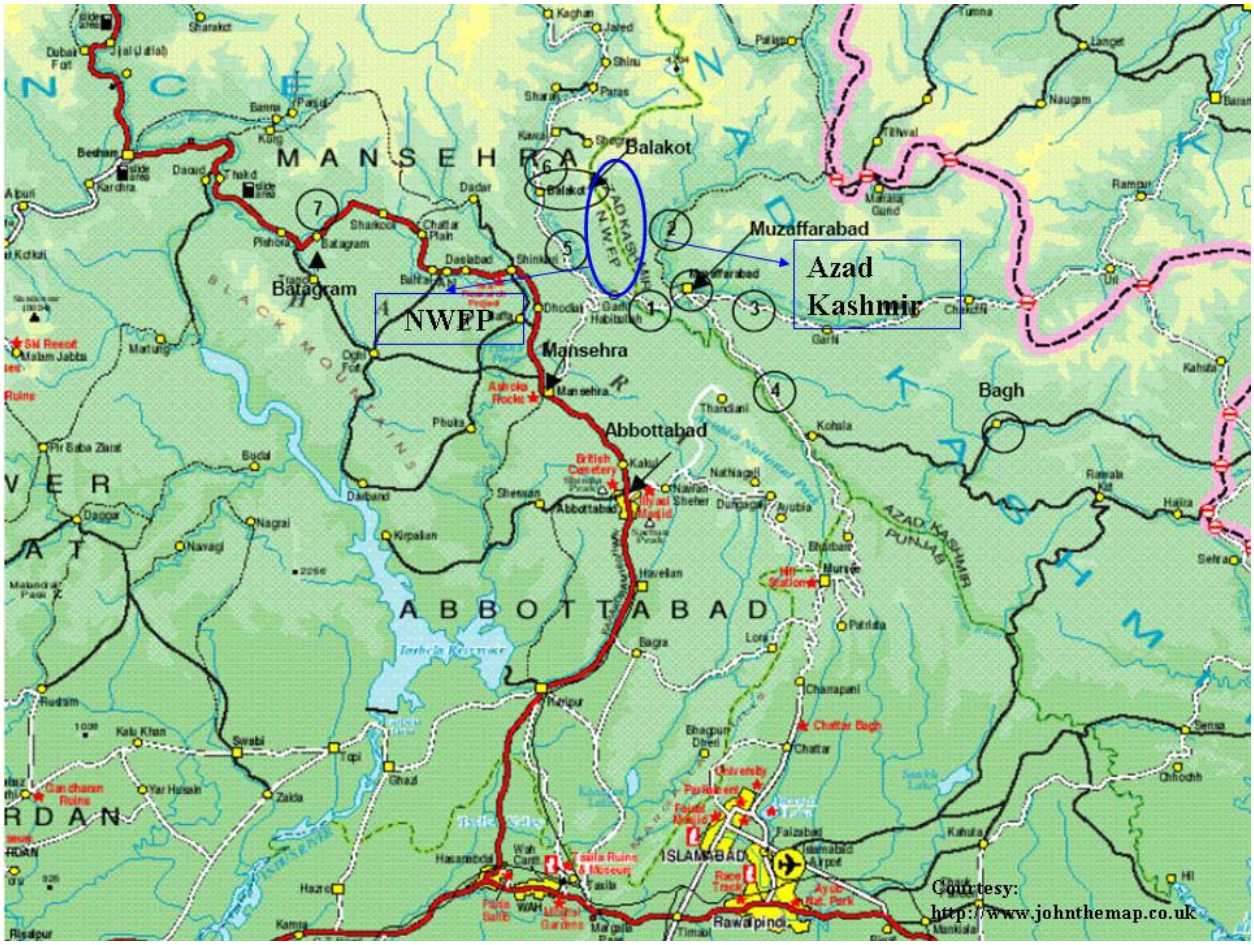

Fig. 1: Location map of major affected roads

The affected area is mountainous and is dominated by steep terrain. The city of Muzaffarabad and the town of Balakot lie in part within the alluvial valleys of three major rivers, the Jhelum and the Neelum (Muzaffarabad) and Kunhar Rivers (Balakot).

The above-mentioned roads pass along various rivers. From a geotechnical perspective the most dominant ground failure mode observed throughout the earthquake zone is landsliding/slope instability. Three types of damage modes are discussed in this paper. These are as under:

A. Slope instability,
B. Structural damage and
C. Ground rupture/surface faulting

SLOPE INSTABILITY

The road network throughout the earthquake zone suffered severe damage primarily due to landsliding. Slope failures were observed at various locations on roads in the affected areas. Some segments of the roads were open to the traffic during the time of visit whereas most of the length of some roads was not open as yet due to heavy landsliding e.g. Road No. 2, Road No. 6 and Road No. 7. Fig. 2 shows the sites on the main roads affected by the landslides. It is to be mentioned that these are only a few representative sites.

Landsliding and critical slope stability was a multi-scale problem that ranged from limited sloughing of surficial nature to a scale that encompassed entire mountain sides.

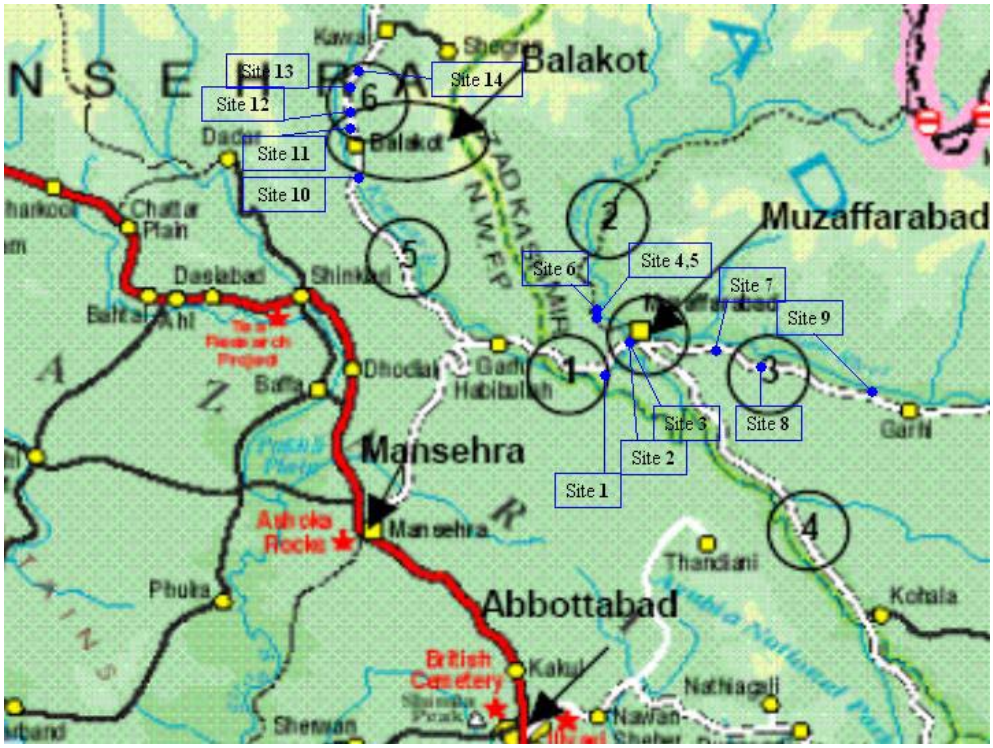

Fig. 2: Map showing the sites affected by slope instability on major roads

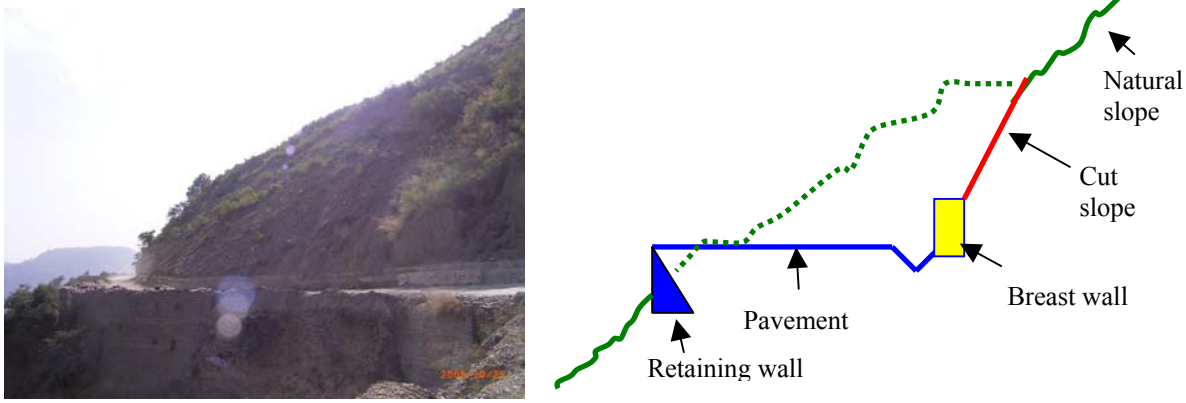

Fig. 3: Typical cross section of the roads in the affected area

Along the roads leading to Balakot and Muzaffarabad there was ample evidence of cleared landslides that blocked these roads. The roads in the affected area are constructed in cut. The typical section of the roads in the affected area is shown is Fig. 3. This geometry greatly helped in clearing most of the landslide sites for light traffic. The occurrence of these surficial landslides along the rather steep slopes is not unexpected. Most landslides appear to be in a meta-stable state and can be readily activated due to aftershocks or rain. Landslide hazard remains high throughout the affected areas.

Fig. 4 shows the slope failure at Site No. 1 (marked in Fig. 2) located at about 10 km from Muzaffarabad. The failure was surficial nature and the road was cleared quickly after the incident.

Fig. 4: Road No.1, Site No. 1

Fig. 5(a): Road No.1, Site No. 2

Figs. 5(a) and 5(b) show the failure of a steep cut slope in the city of Muzaffarabad. This slope has been posing threat for many years. Some shops were constructed right against the slope and were completely damaged by the fall of huge conglomerated alluvial deposit. Similar slope failure is most likely for the slope on local road near Tonga Adda in Muzaffarabad as shown in Fig. 6.

Fig. 5(b): Road No.1, Site No. 2

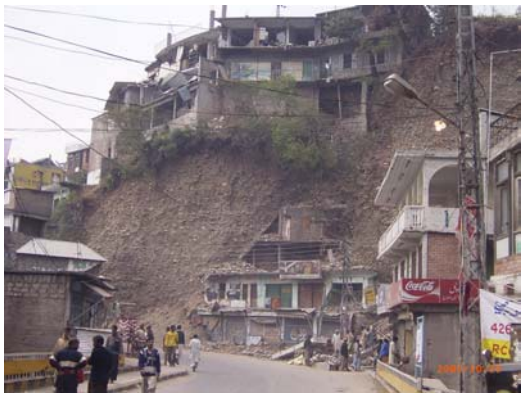

Fig. 6: A local road near Tonga Adda, Muzaffarabad

Fig. 7 shows the disappearance of a local road leading to Dhakki Adda in Muzaffarabad. Some buildings on its valley side have also been collapsed.

Fig. 7: Local road, Site No. 3

Figs. 8 and 9 show that the roadway (Road No. 2) practically disappeared after the earthquake and had to be cleared and realigned. The shown road was paved prior to the earthquake and is now has merely a gravel top layer. Most of the length of this road was closed for traffic at the time of visit.

Fig. 8: Road No.2, Site No. 4

Fig. 9: Road No.2, Site No. 6

A suspension bridge on a local road leading to Dhani Maee, slightly off the Road No. 2, to the north of Muzaffarabad was completely collapsed as landslides toppled the suspension towers as shown in Fig. 10.

Fig. 10: Road No.2, Site No. 5

Fig. 11: Road No.3, Site No. 7

Figs. 11 and 12 show the failure of steep natural and cut slope on Road No. 3, in the west of

Muzaffarabad, whereas Fig. 13 shows the complete collapse of a local road, located opposite to Road No. 3, due to slope instability.

Fig. 12: Road No.3, Site No. 8

Fig. 13: Local road, Site No. 9

Figs. 14 through 18 show the slope failures on Road No. 5 and 6 around Balakot. These roads were upgraded in the recent years and were performing well until the catastrophe. It is to be mentioned that the wet surface of the road visible in Fig. 15 is artificial sprinkling at the roadway done for the convenience of passengers in order to avoid dust.

Fig. 14: Road No.5, Site No. 10

Fig. 15: Road No.6, Site No. 11

Fig. 16: Road No.6, Site No. 12

Fig. 17: Road No.6, Site No. 13

Fig. 18: Road No.6, Site No. 14

STRUCTURAL DAMAGE

Bridges and bridge abutments

Some bridges and other road structures were damaged during the incident.

Fig. 19 shows the Balakot Bridge on the Kunhar River, which was knocked off its bearing supports. Lack of lateral restraints allowed displacement of the bridge that resulted in one outer girder hanging freely and other girders left with minimal bearing over their supports.

Fig. 19: Displacement of deck of Balakot Bridge towards south and east.

Vertical motion may have played a significant role in reducing the vertical force on the bearings, leading to the large observed lateral displacement.

Fig. 20: Abutment failure of Balakot Bridge

Fig. 21: Abutment failure of a bridge on a local road in south of Balakot

Fig. 22: Collapse of a culvert on a local road in south of Balakot

Fig. 23: Abutment failure of a bridge on Road No. 3, east of Muzaffarabad

A suspension bridge on a local road leading to Dhani Maee, slightly off the Road No. 2, to the north of Muzaffarabad was completely collapsed as landslides toppled the suspension towers as shown previously in Fig. 10.

Only a few cases of abutment and culvert failure were observed. Figs. 20 through 23 present those cases.

Retaining structures

Retaining structures used to support the ground experienced significant damage throughout the investigated area. In areas where breast walls (Fig. 3) are used, landslide debris overtopped these walls sometimes resulting in damage due to impact of large boulders. The retaining walls and breast walls in the surveyed area are mostly of gravity type and made up of stone masonry bonded by cement mortar.

Figs. 24 and 25 show the collapse of retaining walls of local roads in the city of Muzaffarabad. The backfill material in these two cases is sub-rounded to rounded cobbles with very small fraction of fine material, rendering an inadequate backfill both in terms of material specifications and compaction.

Fig. 24: Local road in Muzaffarabad

Fig. 25: Local road, Dhakki Adda, Muzaffarabad

Figs. 26 and 27 show the collapse of a retaining wall and backfill material on Road No. 3, east of Muzaffarabad. A truck met an accident during this collapse and can be seen standing vertical in the collapsed debris. Erosion from the river Jhelum water helped in the collapse.

Fig. 26: Road No. 3, east of Muzaffarabad

Fig. 27: Road No. 3, east of Muzaffarabad

Fig. 28 shows the collapse of the gravity retaining wall adjacent to abutment of bridge on Road No. 3, east of Muzaffarabad, near Garhi Dopatta. The retaining wall on the other side of the bridge also collapsed in a similar manner. As were the cases with the retaining walls shown in Figs. 24 and 25, the backfill material as seen in Fig. 28 is rounded to sub-rounded cobbles with very small fraction of fine material.

Fig. 28: Road No. 3, east of Muzaffarabad

Fig. 29: Road No. 6, Balakot

In Balakot, a gravity retaining wall made of stone masonry was severely damaged (Fig. 29) due to massive ground deformations associated with landsliding.

Fig. 30: Road No. 6, north of Balakot

Fig. 31: Road No. 5, south of Balakot

Fig. 30 shows massive tensile cracks in a masonry breast wall on Road No.6, north of Balakot, whereas Fig. 31 shows the collapse of a road segment (Road No.5, south of Balakot) due to combined effect of the earthquake and erosion by the river Kunhar thereby emphasizing the use of properly designed retaining structure.

GROUND RUPTURE/ SURFACE FAULTING

Numerous transverse and longitudinal road ruptures were observed in the affected area. Figs. 32 and 34 indicate that the measured horizontal and vertical movements of road ruptures were about 30 cm.

Fig. 32: Road No. 2, north of Muzaffarabad (Site A in Fig. 36)

Fig. 33: Road No. 6, north of Balakot (Site B in Fig. 36)

Fig. 33 shows huge dislocation of Road No. 6, north of Balakot. The vertical displacement is about 90 cm.

Fig. 34: Road No. 6, north of Balakot (Site C in Fig. 36)

Fig. 35: Road No. 6, north of Balakot (Site D in Fig. 36)

Tobita et al (2005) presented the deformation map of the area during this earthquake (Fig. 36). The sites shown in Figs. 32 through 35 are plotted on the deformation map here, which gives a hint that the ground ruptures at the above-mentioned sites can be the surface effects of underlying fault. But the detailed field investigation is necessary for reaching to a conclusion.

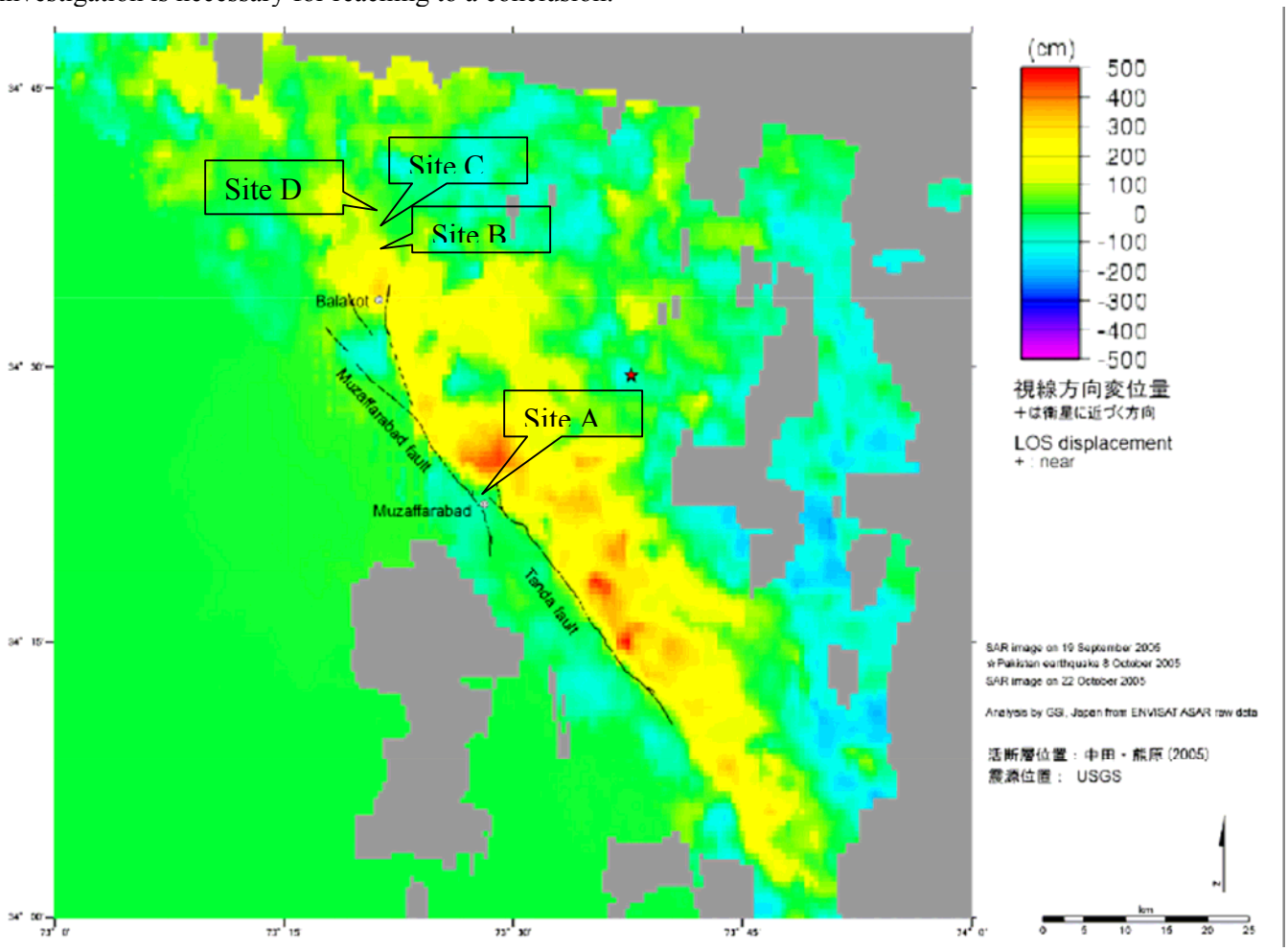

Fig. 36: Deformation map of the earthquake (after Tobita et al, 2005)

CONCLUSIONS

It should be emphasized that the general observations made and conclusions drawn in this study are based on visual inspection and engineering judgment, with no detailed analysis or formal assessment. They should therefore be taken as preliminary and awaiting further studies and confirmation.

The recent earthquake has made it mandatory to update the existing national seismic hazard map, design and construction specifications in order to achieve higher resistance against earthquakes effects.

From a geotechnical perspective the most dominant ground failure mode observed throughout the earthquake zone is landsliding/slope instability.

Lack of proper design of cut slopes and inadequate retaining structures increased the hazard.

Inadequate backfill both in terms of material specifications and compaction was observed in some cases of damaged retaining walls in Muzaffarabad region.

Most landslides appear to be in a meta-stable state and can be readily activated due to aftershocks or rain. Landslide hazard remains high throughout the affected areas.

REFERENCES

Asian Development Bank and World Bank (Nov. 2005) – "Preliminary Damage and Needs Assessment" http://siteresources.worldbank.org/PAKISTANEXTN/Resources/Publications-and-Reports/Damage-Assessment-Main.pdf

Geological Survey of Pakistan, "Seismic Risk Map of Pakistan" http://www.gsp.gov.pk/

Location map of the affected area: http://www.johnthemap.co.uk/pages/kkh/kkhmap.html

M. Tobita, S. Fujiwara, M. Kato, H. Nakai, M. Fujiwara, H. Yarai, F. Hayashi (2005) "Deformation map of Pakistan earthquake generated by SAR image matching", Geographical Survey Institute (in Japanese)

U.S. Geological Survey, National Earthquake Information Center http://earthquake.usgs.gov/