第17回性能に基づく橋梁等の耐震設計に関する
シンポジウム講演論文集（2014年7月）

DAMAGE CHARACTERISTIC OF BRIDGES DUE TO 2013 BOHOL EARTHQUAKE

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1. INTRODUCTION

The Bohol earthquake occurred in Bohol Island, Philippines on October 15, 2013. The moment magnitude Mw was estimated 7.2 at a depth of 12 kilometers. The Bohol earthquake was generated by a northeast-southwest trending reverse fault along the western sector of Bohol Island, which caused newfound North Bohol Fault in Anonang, Inabanga.

The earthquake also resulted in significant damage to bridges as well as buildings in Bohol Island. Authors could have an opportunity to involve in the reconnaissance mission team of JICA and investigated 15 bridges administrated by Department of Public Works and Highways (DPWH) of the Philippine Government. Most of these bridges were affected by movement of substructure due to the lateral spreading of ground.

In Philippines, significant earthquakes have repeatedly occurred in the past. Many bridges were collapsed during the 1990 North Luzon Earthquake (Mw=7.7) and the 2012 Negros Oriental Earthquake (Mw=6.7). Bohol Island has also ever been affected by some intensive earthquakes in 1990 and 1996.

In this technical report, the typical damage of bridges due to the 2013 Bohol Earthquake is introduced with summarization of damage characteristic, and some recommendations for seismic design of bridges in Philippines are proposed based on knowledge and experience of seismic design in Japan.

It should be noted that the Super Typhoon Haiyan (Yolanda) struck Leyte and Samar Islands and the storm's eye passed 140km north from Bohol Island on November 8, 2013 (only 24 days after the earthquake). However, the effect of the storm on bridges in Bohol Island was less significant.

2. OUTLINE OF RECONNAISSANCE

Authors investigated 15 bridges located in western Bohol Island from November 19 to 20, 2013, as shown in **Fig. 1**, where the estimated damage level of each bridge was also indicated. Two bridges, namely Moalong Bridge and Abatan Bridge were collapsed. The structural type of both bridges is a multi-span simple-supported bridge. It should be noted that there are some undamaged bridges in the area of reconnaissance in addition to bridges shown on the map. Authors could not investigate for those undamaged bridges due to time limitation, but almost of those bridges might be short single-span simple-supported bridges.

Fig. 2 shows the peak ground acceleration map estimated by USGS [1] and the liquefaction hazard map published by PHIVOLCS [2] in comparison with location of the damaged bridges. It can be found that the damage of bridges was observed at the liquefiable location with relatively high acceleration area due to the 2013 Bohol Earthquake.

3. DAMAGE INDUCED BY MOVEMENT OF SUBSTRUCTURE

(1) Moalong Bridge

Almost of bridges which suffered from severe damage were subjected to movement of substructure in the longitudinal direction, which caused excessive inclination of substructure and finally resulted in unseating of superstructure in multi-span simple-supported bridges. One of the typical examples of the damage is Moalong Bridge as shown in **Photo 1**. Moalong Bridge constructed in 1982 is a 3-spans simple-supported bridge with 42.6m of total length, and it seems to be built on the soft soil condition. As seen in the northeast-side pier wall in **Photo 1(a)**, the bottom of pier wall significantly moved to the side of bridge center, which caused heavy inclination of pier wall. Since larger displacement than the seat width (estimated at around 500mm) developed at the pier top due to the lateral movement and inclination of the pier wall as shown in **photo 1(b)**, the Northeast-side span was unseated. It can also be observed that the southwest-side pier wall moved to the bridge center as shown in **Photo 1(c)**. However the displacement developed at the pier top did not

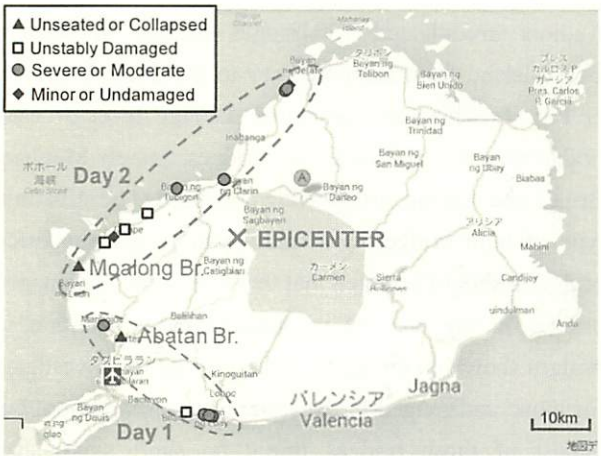


Fig.1 Location of Bridges

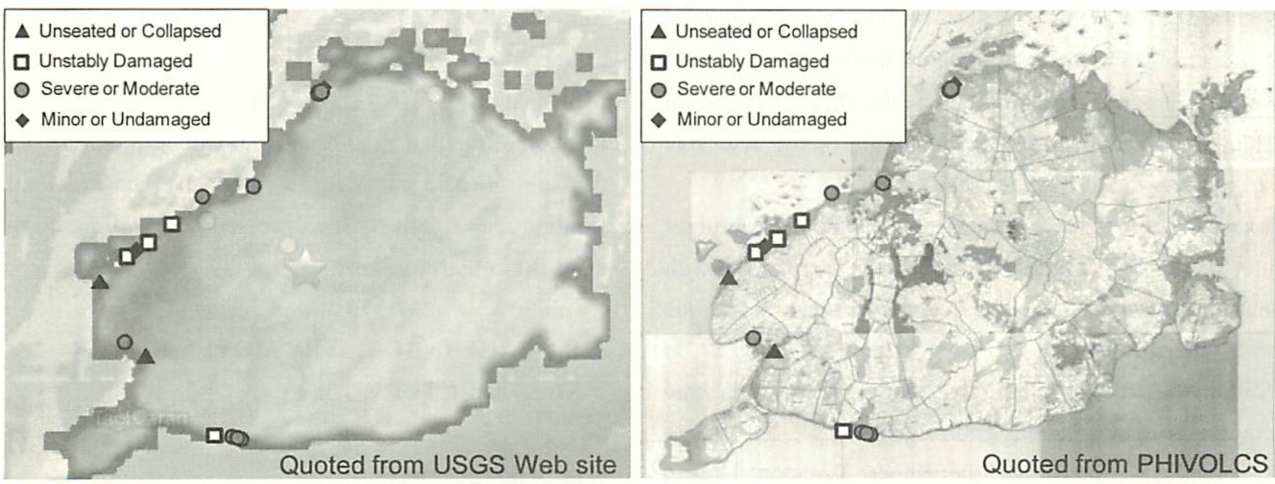
exceed the seat width, which avoided unseating the southwest- side span.

A northeast abutment was also severely damaged. The abutment body was built on the embankment protected with the riprap and the single-aligned 400mm square piles supported the abutment body as shown in **Photo 1(d)**. This structural type of abutment is very typical in Philippines. The embankment significantly settled due to the earthquake as shown in **Photo 2** and moved ahead with cracking the riprap, which induced shear force and moment to the piles. However, since there was very few amount of transverse steel (6mm diameter bar with spacing of 200mm) in the section of the piles, vulnerable shear failure was developed at the pile top as shown in **Photo 1(e)**. Many clear traces of collision between parapet and girder were also observed as seen in **Photo 1 (f)**.

Based on above observations for Moalong Bridge, significant lack of lateral strength of piles of both pier and abutment is one of the most important factors of the damage.

(2) Abatan Bridge

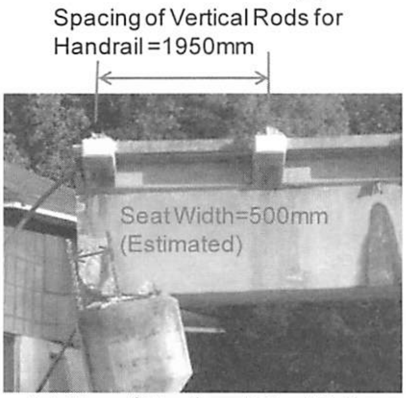
Abatan Bridge crossing Abatan River is a 6-spans simple-supported bridge with 90m of total length, and the ground condition around the bridge seems to be soft. Abatan Bridge was constructed in 1981, and additional two-pile bents were constructed at the front of existing abutments as illustrated in **Fig. 3**. Although design philosophy of additional bents is unclear, these



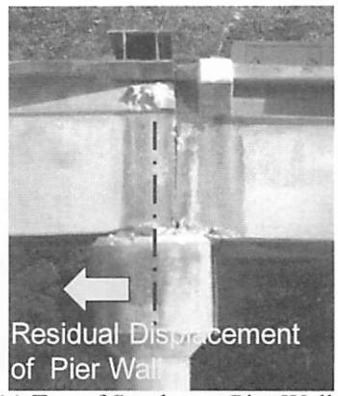
(a) Ground Peak Acceleration Estimated by USGS **(b)** Liquefaction Hazard Published by PHIVOLCS

Fig.2 Effect of Ground Acceleration and Liquefaction on Damage to Bridge

(a) Panoramic View of Moalong Bridge



(b) Top of Northeast Pier Wall



(c) Top of Southwest Pier Wall


(d) Residual Inclination of Northeast Abutment


(e) Shear Failure of Pile Head


(f) Traces of Collision between Parapet and Girders

Photo 1 Damage Observation of Moalong Bridge

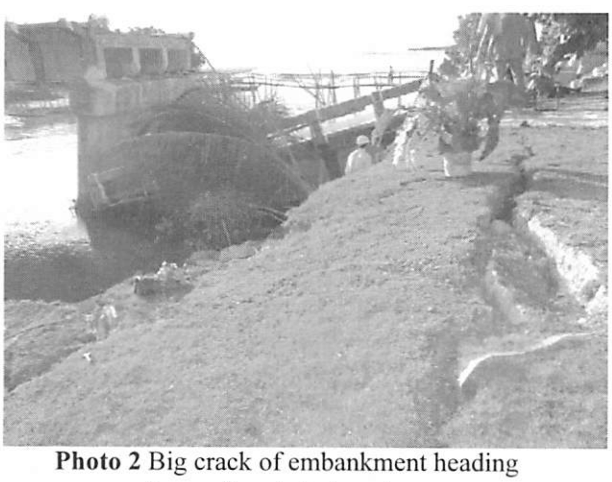


Photo 2 Big crack of embankment heading for northeast abutment

additional bents might be set in the past for rehabilitation of the exiting abutments with settlement and tilting. Some shear keys are equipped on the cap beam of the additional bents as shown in **Photo 3**. The west additional bent moved ahead (to east) with significant tilting due to the earthquake as shown in **Fig. 3**. Furthermore, a west bridge column was collapsed and an adjacent column might be displaced to east. Although precise measurement of column position and investigation for piles of the columns should be performed for the solution of the unseating mechanism, the lateral spreading may cause significant residual displacement of the bent and the columns with failure of

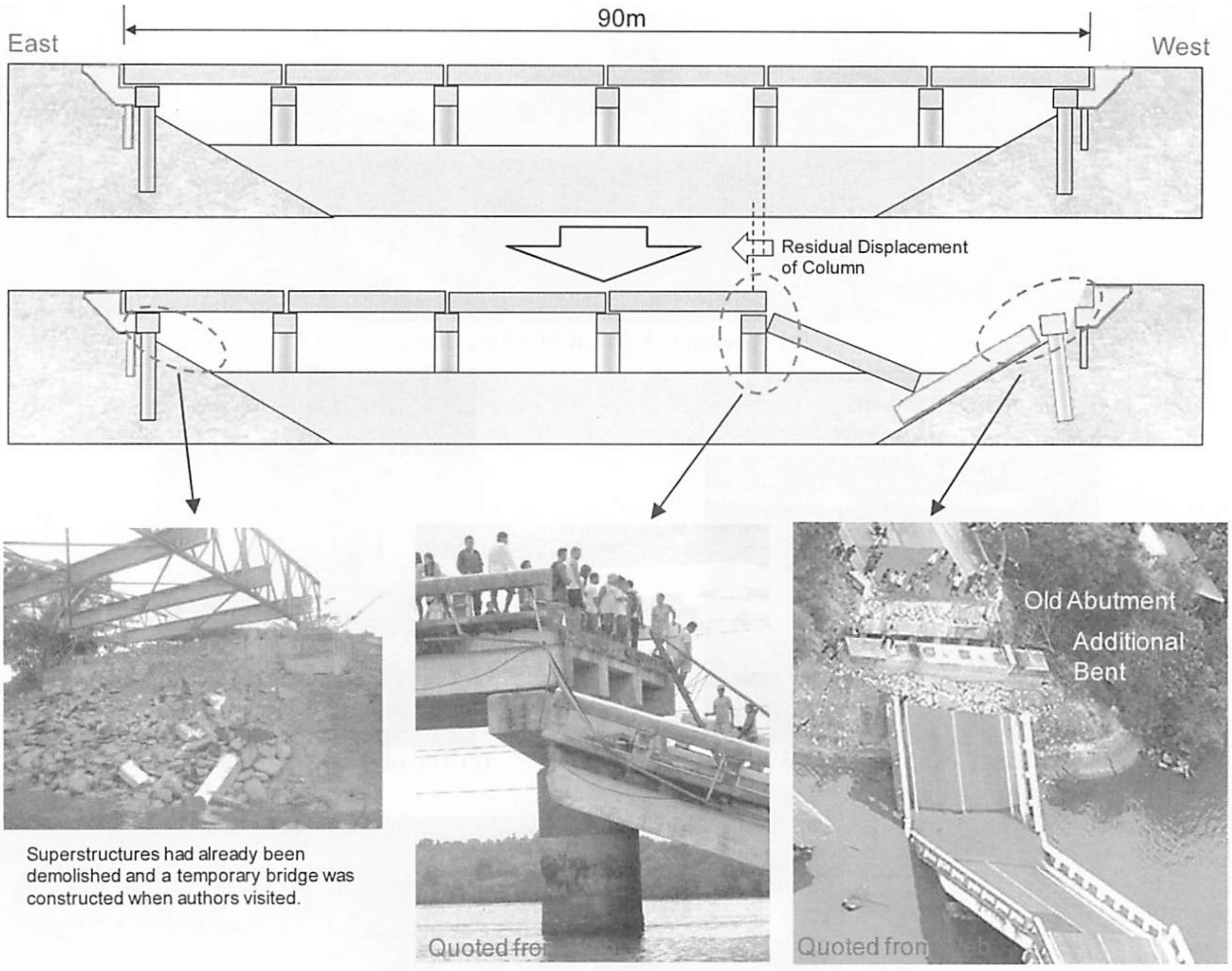


Fig.3 Schematic View of Damage to Abatan Bridge

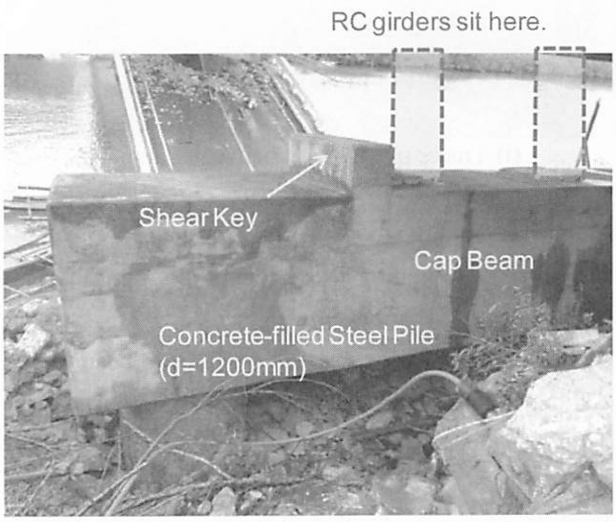


Photo 3 Additional Bent and Shear Key

piles.

(3) Damage to Substructures in Other Bridges

In typical existing bridges in Philippines, the abutment body is built on the embankment protected with the riprap and the single-aligned 400mm square piles supported the abutment body as employed in Moalong Bridge. Damage examples of this type of abutment were also observed in other bridges. **Photo 4** shows the damage observed in Tultugan Bridge which is a single-span simple-supported bridge constructed in 1968. Approach embankment significantly settled with cracking the riprap, however movement of abutment was restrained by collision with girder, which induced shear force and moment to piles. Since there were no transverse steel in piles of Tultugan Bridge, the pile head exhibited severe failure. However, since Tultugan Bridge is a single-span bridge and all of girder ends are supported by the abutments, the bridge has not resulted in the state of unseating of girder.

Photo 5 shows the other example, namely Tagbuane Bridge which exhibited an excessive tilting of a column bent. Tagbuane Bridge is a 3-span cantilever bridge constructed in 1954. The lateral spreading displaced the

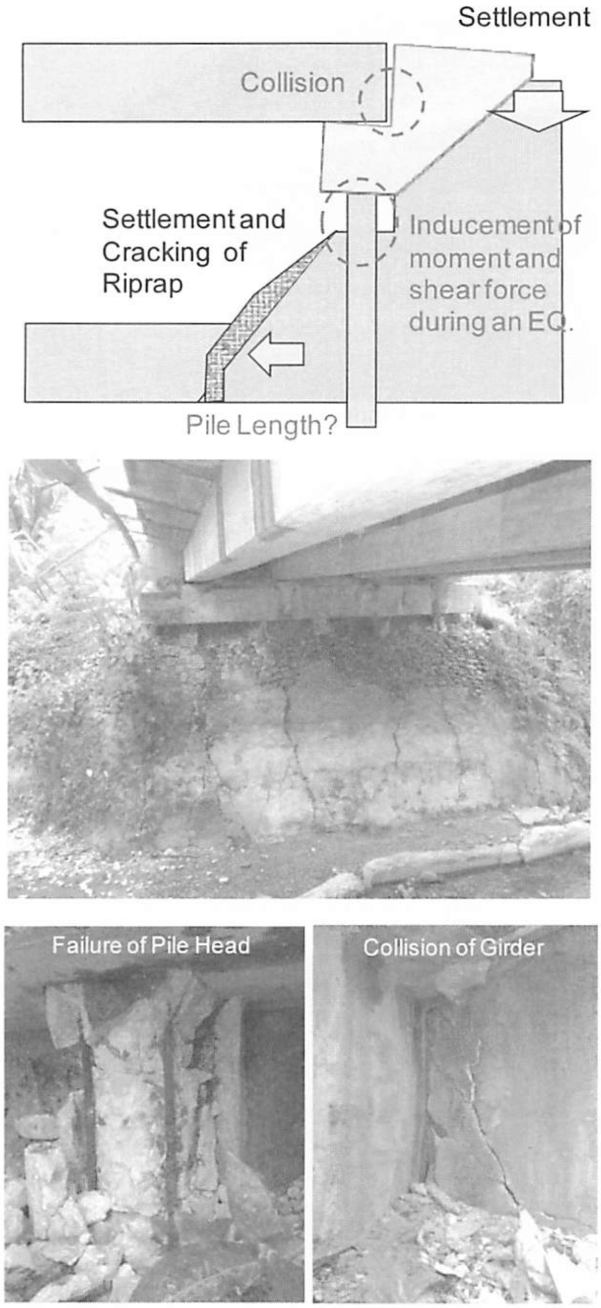


Photo 4 Damage Observation of Tultugan Br.

column base and the damage was developed to the columns. Since the excessive tilting of the column bent makes the bridge unstable for the live load, this damage mode significantly affected the serviceability of the bridge after an earthquake.

Damiao Bridge shown in **Photo 6(a)** is a single-span frame bridge constructed in 2000. Concrete girders are connected with the abutment wall rigidly and the bottom of the wall is put on the footing through rubber pad. Although details of the connection between the wall bottom and the footing are unclear, the connection may be designed to work as a hinge. In this bridge structure,

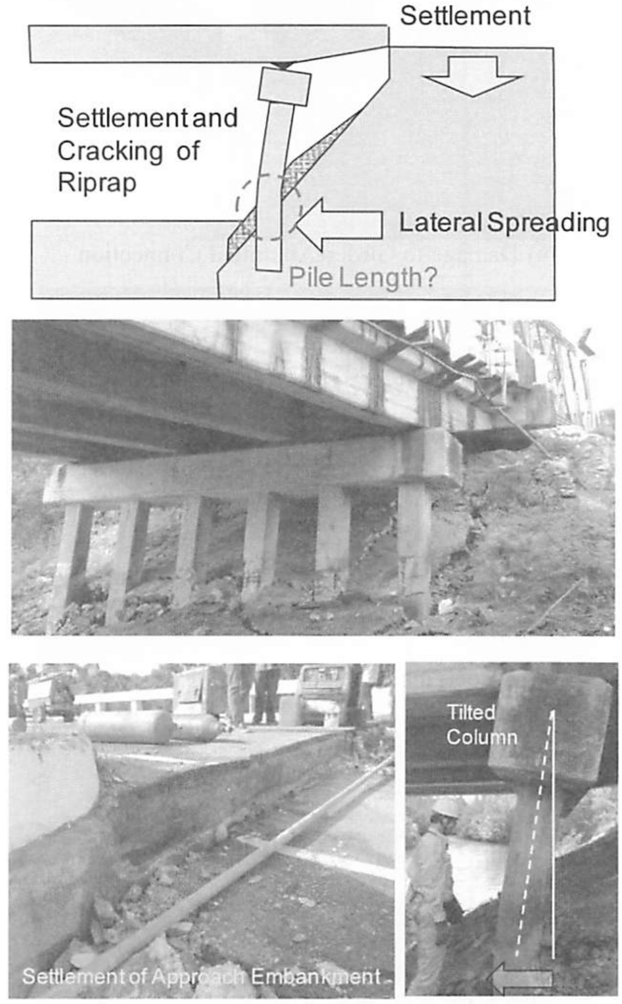


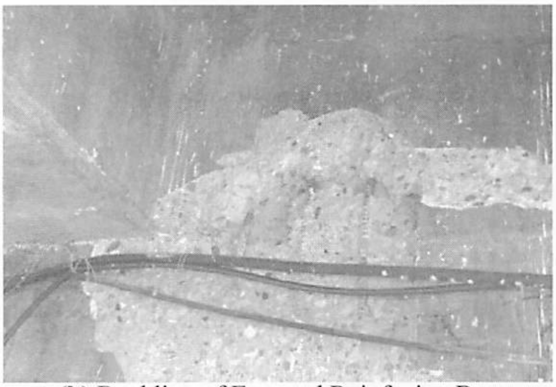
Photo 5 Damage Observation of Tagbuane Br.

the damage was developed at the section of the girder-abutment connection, where cover concrete spalled off as shown in **Photo 6(b)**. Based on residual deformation of exposed reinforcement bars, the abutment wall moved ahead and the front face of the abutment wall at the section of the connection with girders was subjected to compression due to bending moment. Residual gap was found at the front face of the abutment-footing connection as shown in **Photo 6(c)**, which also indicated that the footing moved ahead.

4. SEISMIC PERFORMANCE OF BRIDGES CONSTRUCTED RECENTLY

There were not only damaged bridges but also undamaged bridges in the region under strong excitation. It is also important to study the bridges performed well during an earthquake. For example, Taguimtim Bridge

(a) Damage to Girder-Abutment Connection

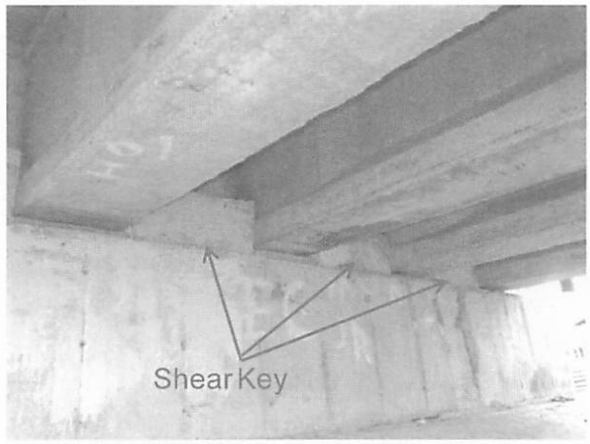


(b) Buckling of Exposed Reinfocing Bras

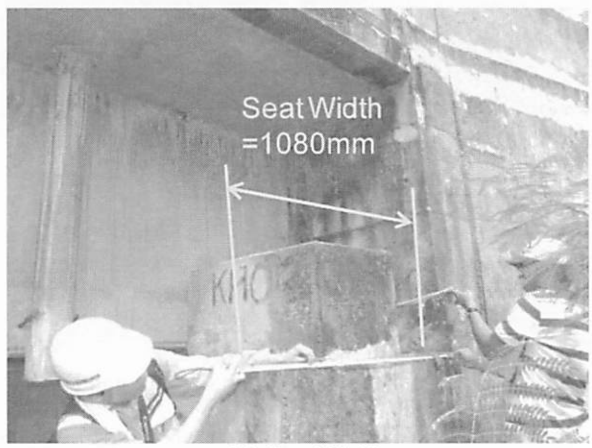
(c) Gap at Abutment-Footing Connection

Photo 6 Damage of Damiao Bridge

(a) Abutment and Footing



(b) Shear Keys on Seat of Abutment



(c) Seat Width

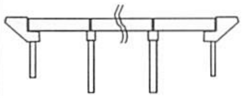
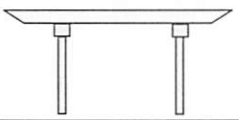
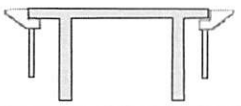
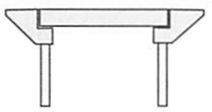
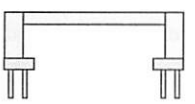
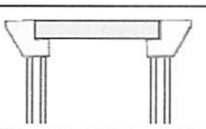
Photo 7 Taguimtim Bridge

shown in **Photo 7(a)** is a single-span simple-supported bridge constructed in 2002. Taguimtim Bridge is located close to Damiao Bridge which suffered from damage as described above. It should be noted that the abutment is equipped with shear keys and the seat width of 1080mm as shown in **Photo 7(b), (c)**. Furthermore, according to hearing from DPWH engineers, the abutment body is supported by footing and two-aligned group piles. Based on these design details, the seismic effect is considered into the design of Taguimtim Bridge. Actually, no structural damage was observed in Taguimtim Bridge due to the earthquake except settlement of riprap. Residual displacement of the abutment and failure of piles observed in Tultugan Bridge as described above were not observed in Taguimtim Bridge, which may indicated that the two- aligned group piles worked well.

5. EFFECT OF STRUCTURAL TYPE OF BRIDGES ON DAMAGE LEVEL

The damage level of 15 bridges located in the region under strong excitation was evaluated with 5 ranks, namely "unseated or collapsed", "unstably damaged", "severely damaged", "moderate damage", and "minor

Table 1 Relation between Structural Type of Bridges and Damage Level

Structural Type of Bridges \ Damage level		Unseated or Collapsed	Unstably Damaged	Severely Damaged	Moderate Damage	Minor Damage
Multi-span Simple-supprted Bridge		Abatan (1981) Moalong (1982)		Hinawanan (1969) Palo (1970) Clarin (1980)		
3-span Cantilever Bridge			Tagbuane (1954) Desamparados (1970)			
3-span Falt Slab Bridge			Mandaug (1992)		Anislag (1993)	
Single-span Girder Bridge with Abutment supported by Single-aligned Piles			Tultugan (1968)	Bateria (1992) Bacani (1967)		
Single-span Girder Bridge with Abutment supported by Double-aligned Piles				Damiao (2000)	Hunan (2000)	
						Taguimtim (2002)

(Year of Construction)

damage", based on the on-site observation. These 15 bridges can also be categorized by the type of structure, so that the effect of the structural type of bridges on the damage level can be examined. A relation between the structural type of bridges and the damage level is summarized in **Table 1**, where the year of construction of each bridge is also noted for reference. It can be mentioned that the fatal damage occurred at multi-span simple-supported bridge. Although unstably damage was developed at 3-span cantilever bridge, 3-span flat slab bridge and single-span bridge with abutment supported by single-aligned piles, these types of structure did not cause the fatal situation such as unseating or collapse. It is also noted for the bridges built on the soft soil condition and subjected to the effect of the lateral spreading that the performance of the bridge with the two-aligned grouped piles is better than that with the single-aligned piles.

6. SUMMARIES OF RECONNAISSANCE AND RECOMMENDATIONS FOR SEISMIC DESIN FOR PHILIPPINE BRIDGES

Based on the reconnaissance, damage observations of bridges built on the liquefiable soil condition can be summarized as follows.

- Single-aligned piles of abutment designed without seismic effect were severely damaged due to lateral spreading. Similar damage has already been observed in past earthquakes of Philippines [3].
- Some of recent-designed abutments with double-aligned piles in the longitudinal direction suffered very minor damage and performed well as compared with those with single-aligned piles.
- In two multi-span simple-supported girder bridges, superstructures were unseated due to large movement of substructures with severe damage of single-aligned piles. On the other hand, there were no single-span simple-supported girder bridges with unseating of superstructure, while single-aligned

piles of abutment in those bridges were damaged severely and lost lateral capacity.

- Based on behavior observed in unseated bridges which are affected by lateral spreading, sufficient lateral strength of piles and seat width will prevent unseating and thus improves structural resilience.

Furthermore, some recommendations for the seismic design for bridges in Philippines are proposed based on damage experiences of bridges in Philippines and the seismic design specifications in Japan improved with damage experiences of bridges in Japan.

- Investigation of geological condition at the position of each substructure is very important, and bedrock should be examined through the geological investigation.
- Effect of geological condition should be considered into design of foundation. Soft soil or liquefiable soil significantly affects the seismic behavior of foundation.
- In unstable geological condition, inverted T-shape abutment is generally employed in Japan, instead of pile-bent abutment with riprap, to prevent from scouring and ensure longitudinal strength of abutment during an earthquake.
- Plastic hinge would recommended to develop in not piles but columns in terms of inspection and repair after an earthquake, if the easy-to-repair bridge is required for the seismic performance.
- Multi-aligned group piles are recommended instead of single-aligned piles, to enhance strength of foundation in the longitudinal direction.
- Sufficient seat width is recommended to design of cap beam for unexpected behavior of bridge during an earthquake.
- Reinforcement details in column and pile should be specified to prevent shear failure and thus enhance ductility.

ACKNOWLEDGEMENTS

Since damage investigation was performed with JICA mission, arrangements of itinerary and a meeting with DPWH were made by JICA. Reconnaissance was accompanied by Mr. Toru Tsuchihashi, JICA, Mr. Seitarou Tsukuda, DPWH, and other staffs of JICA Philippines Office and DPWH Headquarters. Sincere appreciation is extended to many DPWH engineers, particularly Mr. Erwin R. Aranaz, Mr. Basilio Elmba, Mr. Fransis L. Flores, Mr. Rebocato R. Uayan for assisting reconnaissance and providing information.

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2) PHIVOLCS Homepage: http://www.phivolcs.dost.gov.ph/index.php?option=com_content&view=article&id=465&Itemid=500028
3) Japan Society of Civil Engineers: Reconnaissance Report on the July 16, 1990 Luzon Earthquake, the Philippines, June, 1993