Visual Damage Interpretation of Buildings Using QuickBird Images Following the 2007 Peru Earthquake

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Summary

A strong earthquake struck the city of Pisco in the coastal region of central Peru on 15 August 2007. The earthquake brought massive destruction to the regions of Ica and Lima. QuickBird, a satellite with a high-resolution sensor on board, captured clear images of Pisco both before and after the earthquake. In this paper, the authors performed visual damage detection of buildings using the high-resolution satellite images. The visual damage interpretation based on the European Macroseismic Scale (EMS-98) was carried out building by building, comparing the pre-event and post-event images. Then the damage grades of about 10,800 buildings were classified. The result of the damage inspection was compared with field survey data, and the accuracy and usefulness of the high-resolution satellite images in damage detection was discussed.

Keywords: QuickBird; visual damage detection; the 2007 Pisco earthquake; building damage

1. Introduction

After natural disasters, such as earthquakes, tsunamis, volcanic eruptions, landslides and floods, it is extremely important to capture the regional damage distribution in all phases from emergency response to recovery works [1]-[2]. Recently remote sensing technology has been used for grasping the damages. One of the advantages of remote sensing is the ability to observe the same area repeatedly, which allows analyzing the time series variation.

Although the high-resolution satellite image is inferior to the aerial photography in resolution, it has an advantage to cover larger areas at once. Several studies show the damage detections of buildings in urban areas using satellite images after earthquakes. In particular, since QuickBird (QB) commercial satellite [3] was launched in 2001, damage interpretations with satellite images have been widely performed because of its high spatial resolution (0.61m). One of the methods to detect damages from optical satellite images is visual damage interpretation while the other is automatic damage extraction based on digital image processing.

As an example of visual damage interpretation, approximately 1,400 buildings were inspected for the 2003 Boumerdes, Algeria earthquake [4]. Similarly, in the case of the 2003 Bam, Iran earthquake, about 12,000 buildings were inspected and the results were compared with field survey data [5]. These studies have reported the dispersion of results among examiners, in addition to the difficulty in identifying middle and minor level damages, and determining for densely built-up areas.

Other than QuickBird images, damage detection was also tried for the 2001 Bhuj, India earthquake

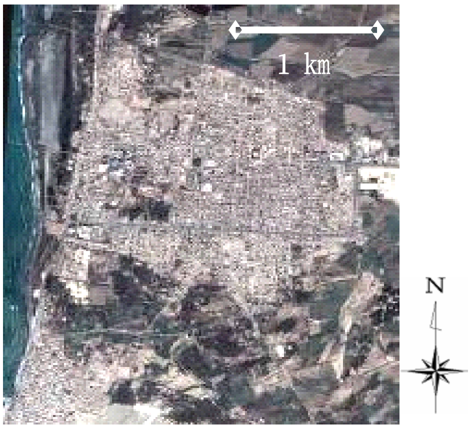


Fig. 1: QB satellite image of Pisco acquired 12 days after the earthquake.

Fig. 2: Enlargement of a part of the images: the pre-event (left) and post-event (right) ones.

using an IKONOS satellite image [6], and also for the 2008 Sichuan, China earthquake using FORMOSAT satellite images [7]. However the accuracy of the interpretation is still under review because it has not been long since these individual buildings damage detection begun and the validation data from field survey has not been sufficient.

This paper presents the results of visual damage interpretation of buildings using QuickBird images following the 2007 Pisco, Peru earthquake. The damage interpretation based on the European Macroseismic Scale (EMS-1998) was carried out building by building, comparing pre-event and post-event images, and then the damage grades of about 10,800 buildings were classified. The result of the damage inspection was compared with field survey data [8] obtained by Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID), National University of Engineering (UNI). The authors also detected damages comparing the pre-event QuickBird image and a post-event aerial photograph of the some places, then demonstrated the accuracy and usefulness of the high-resolution satellite images in damage detection.

Since the field survey Geographic Information System (GIS) data of more than 10,000 buildings were available as ground truth data, it was possible to examine so many samples in this study. The result of this visual interpretation is useful for developing an automatic extraction method as basic data for examination.

2. The 2007 Pisco, Peru Earthquake and QuickBird Imagery

An earthquake of moment magnitude 8.0 hit the coastal area of central Peru in the evening of 15 August 2007 [9]. Approximately, five hundreds lives were lost and more than 90,000 buildings were collapsed. The earthquake caused most extensive damages to the cities in the region of Ica such as Pisco, Chincha and Ica. A maximum Modified Mercalli Intensity (MMI) was estimated as IX in Pisco [10]-[12].

The city of Pisco is about 200 km south from the capital city Lima, facing the Pacific Ocean with desert climate. According to Peru National Institute of Statistics and Information, the urban population in 2007 was estimated to be 55,000 [13].

According to the survey performed by CISMID, most of the structures were categorized as low-rise buildings, 72% of those were one-story, and 23% were two-story before the earthquake. The roofs were flat and roof-tiles were not used in the area because of desert climate of the region. Most of the buildings in Pisco were masonry, and 18% of all buildings were made of adobe (sun-dried mud brick), and 79% were confined burned brick masonry with RC frames. In Peru the confined brick masonry structure has relatively high horizontal stiffness, as generally it has concrete slab and reinforced concrete column and beam. On the other hand, the adobe structure with roof of mud and bamboo is vulnerable to earthquakes due to its fragile behavior. In the Pisco earthquake, many adobe houses were collapsed.

QuickBird satellite captured a clear image of Pisco city on 27 August 2007, 12 days after the quake, as shown in Figure 1. QuickBird also observed Pisco city on 3 June 2007, 3 months before the earthquake. Figure 2 shows partial enlargements of the pre- and post- event QB images. In the post-event image, the building damages could be identified by debris from the variation of texture and the disappearance or decrease of shadow of collapse buildings. As a characteristic of this region in remote sensing imagery, the shadows of buildings are relatively small due to the low-latitude with little vegetation. The building materials in the city are of similar color with that of bare ground.

3. Visual Damage Interpretation of Buildings

3.1 Damage interpretation using QuickBird images

Visual damage interpretation of buildings was performed using the pre- and post-earthquake images based on the EMS-1998 classification for masonry buildings [14] as shown in Table 1. Superimposing polygon data of lots on the satellite image for confirming each shape of the sites, the damage level due to the earthquake was identified lot by lot. Only one person (the first author) completed the detection work of 10,826 lots.

The result of the detection was compared with ground truth damage data from the field survey. More than 40 persons took 3 months to carry out the field damage survey.[8]. The survey recorded the building use, the number of stories, structure types, and damage levels. The damage levels were classified into 4 grades, namely, *no*, *slight*, *severe*, and *serious* damages. The classification guideline was originally produced by CISMID to reflect the local structural characteristics. It has been well known in Peru, and the consensus had been built among decision makers, researchers, professors, and people involved in building construction. The damages were classified lot by lot. The comparison of the two classifications, CISMID's scale and EMS-98, is shown in Table.2.

Figure 3 shows the result of interpretation displayed on GIS. In the image interpretation, it was too difficult to distinguish Grades 1 and 2 because these are defined by a slight damage to lateral faces of a building. Therefore, these two damage levels were unified as Grade 1/2 in this study. Severe

Table 1: Damage Classification for masonry buildings (EMS 1998).

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse.

Table 2: Damage classification of field survey and corresponding grades of EMS 1998.

Damage Classification by CISMID		EMS 1998 Grade
—	**No damage** (SIN DAÑO) or very slight damage	G1, G2
 	**Slight** **(LEVE)** Cracks on wall but not structural damage, completely repairable	
 	**Severe** **(SEVERO)** Structural damage, needs to be evaluated by expert for retrofitting	G3
 	**Collapse** **(GRAVE)** Serious, No usable or collapsed	G4, G5

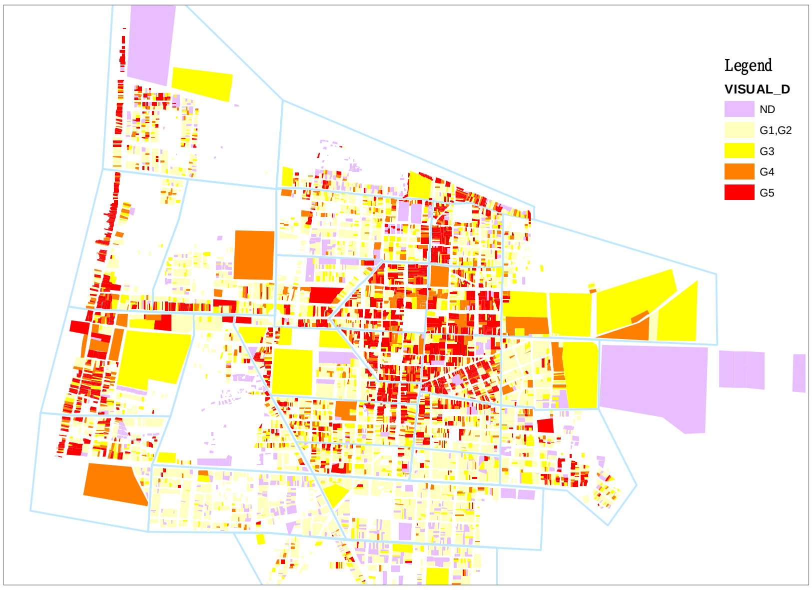


Fig. 3: Result of visual damage interpretation plotted on GIS using QB satellite images.

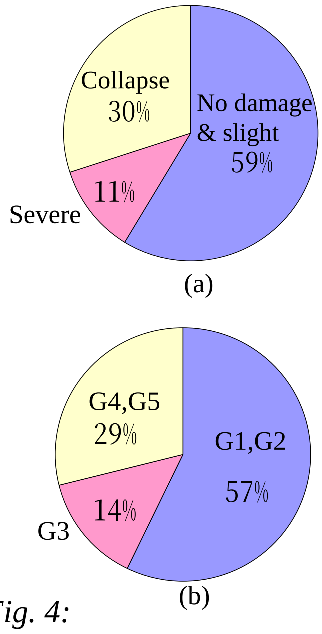


Fig. 4: Ratio of each damage rank by (a) QB visual detection and (b) field survey.

Table 3: Results of QB image interpretation compared with the field survey data and their accuracy.

		Field Survey				
		Slight or No damage	Severe	Collapse	Sum	User's Accuracy
Quick Bird	G1, G2	4900	735	725	6360	77.0%
	G3	714	266	240	1220	21.8%
	G4, G5	570	501	2175	3246	67.0%
	Sum	6184	1502	3140	10826	
Producer's Accuracy		79.2%	17.7%	69.3%		

Overall accuracy＝67.7%

damaged buildings of Grade 5, which represent completely collapsed buildings, were observed in the area along the coast and in the old urban area located in the eastern part of the city. A building with certain damages in roof was classified as Grade 4. Large lots in the outskirt of the city are the properties of schools, hospitals and factories. Approximately, 1,100 lots were categorized as no data, and those are denoted as ND in Figure 3.

The ratios of damage grade by images interpretation and field survey are illustrated in Figure 4. Each corresponding damage rank is almost the same ratio. Most of the damaged buildings were classified as Grade 4 and Grade 5, and only a few of them were categorized into Grade 3 (moderate damage). The trend of damage observed in this earthquake may depend on the characteristic of masonry structures, specifically lack of rigidity, and thus they collapsed quickly.

Table 3 shows the comparison between the result of visual interpretation using the QB images and the field survey result with the accuracy of visual damage detection through the satellite images. The tabulated data present the number of the judged buildings. The accuracy calculated to the column of the matrix is called the producer's accuracy, indicating the degree of omission error. In contrast, the accuracy calculated to the row is called the user's accuracy, showing the degree of commission error that is the accuracy rate of the work result. The overall accuracy was obtained from the diagonal elements.

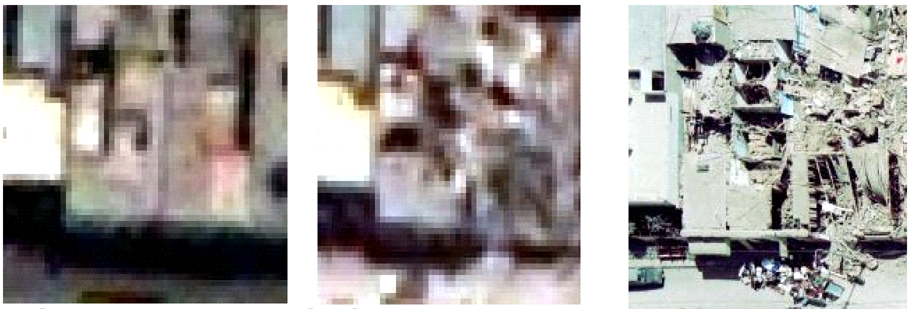
The accuracy of 10,826 lots except 1,149 data of No Data was evaluated. In terms of serious damage levels (G4 and G5), both user's accuracy and producer's accuracy were 70% or less. The accuracy of the medium damage (G3) was remarkably low, about 20%. In the case of serious damage, it was easy to judge the rank but medium damage was difficult to interpret. However, it is noted that the damage rank was quite different for some buildings between the satellite image detection and the field survey. This is attributed to the limitation of remote sensing since it mainly captures the damage to roofs; the damage to upright members, such as walls and columns, are often not recognized.

3.2 Damage interpretation using aerial photographs

To confirm the accuracy of the whole area detection using the satellite image, the authors performed damage detection using aerial photographs taken in the next day of the earthquake. The target areas are 425 lots surrounding the Plaza de Armas in the central part in the city where the damage was serious. The post-event aerial photographs were compared with the pre-event QB image.

A part of each image is shown in Figure 5. The resolution of the aerial photograph is considered to be about 0.2 m, remarkably high, and thus even the detail of building damage is recognized. It can be clearly confirmed that the roof had been broken down and only the walls remained at the building located in the center of the photo.

Table 4 and Table 5 present the result and accuracy of visual damage interpretation using the



(a) the pre-event QB (b) the post-event QB (c) the post-event aerial photo

Fig. 5: Comparison of the satellite images and an aerial photograph

Table 4: Results of QB satellite image interpretation in central Pisco compared with the field survey data and their accuracy.

		Field Survey				
		Slight or No damage	Severe	Collapse	Sum	User's Accuracy
Quick Bird	G1, G2	59	15	36	110	53.6%
	G3	14	5	18	37	13.5%
	G4, G5	22	20	236	278	84.9%
	Sum	95	40	290	425	
Producer's Accuracy		62.1%	12.5%	81.4%		

Overall accuracy＝70.6%

Table 5: Results of Aerial photograph interpretation in central Pisco compared with field survey data and their accuracy.

		Field Survey				
		Slight or No damage	Severe	Collapse	Sum	User's Accuracy
Quick Bird	G1, G2	61	3	10	74	82.4%
	G3	15	8	10	33	24.2%
	G4, G5	18	29	266	313	85.0%
	Sum	94	40	286	420	
Producer's Accuracy		64.9%	20.0%	93.0%		

Overall accuracy＝79.8%

: Agreement part of image detection and ground survey

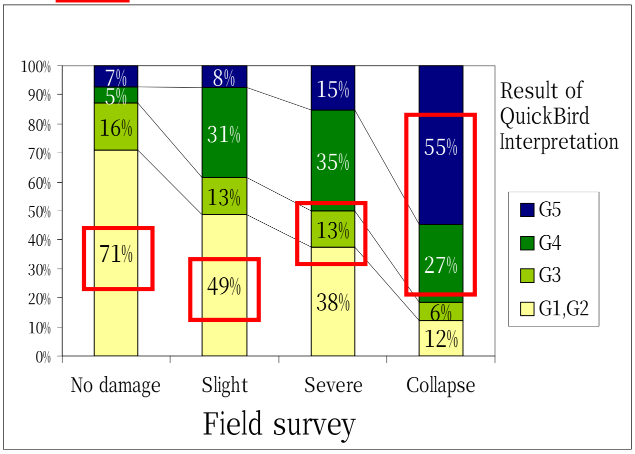


Fig. 6: Producer's accuracy of QB image interpretation in central Pisco.

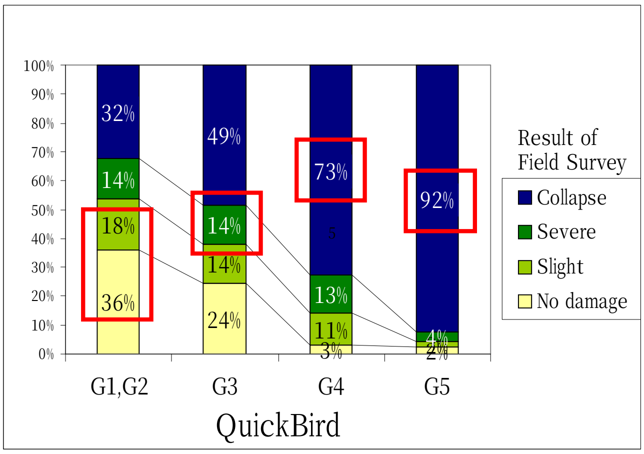


Fig. 7: User's accuracy of QB image interpretation in central Pisco.

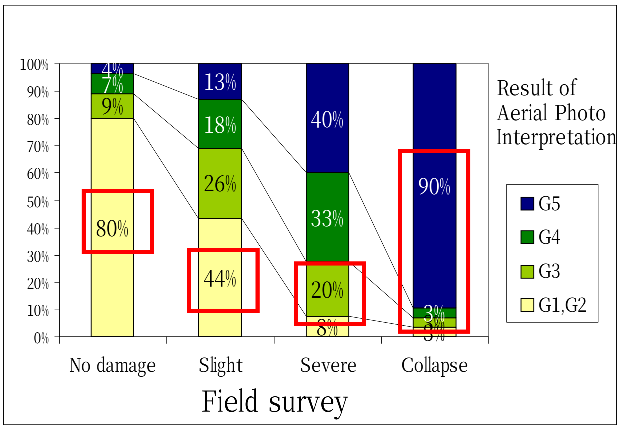


Fig.8: Producer's accuracy of aerial photo interpretation in central Pisco.

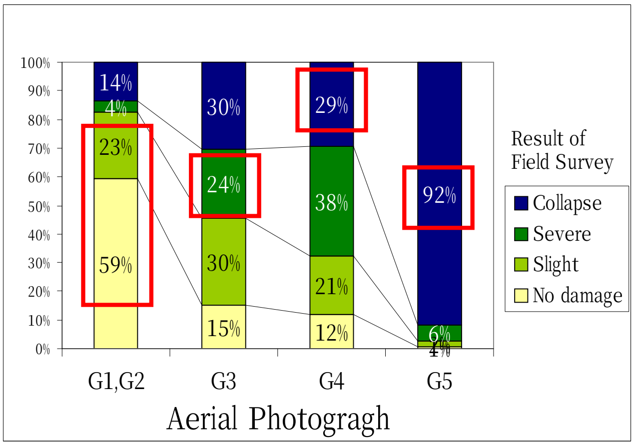


Fig.9: User's accuracy of aerial photo interpretation in central Pisco.

QuickBird images and the aerial photographs, respectively. The five lots images were not obtained from two mosaic images of the aerial photographs, and thus 420 lots could be detected. In the case of using the aerial photographs, the producer's accuracy is 12% higher than that from the QB images at the collapse levels (G4, G5), and the overall accuracy is improved by 9%. Therefore, in the low-rise built-up area like Pisco city, it can be concluded that the resolution of image is remarkably relevant to the improvement of the damage detection accuracy.

Figures 6 to 9 summarize the accuracy of building damage classification by visual interpretation against field survey. The accuracy of G5 has significantly improved using the high resolution aerial image. When the levels G4 and G5 are added together, the accuracy of 80% or more is achieved in any case, thereby demonstrating the usefulness of QB high-resolution satellite images in damage detection.

4. Discussions of the Interpretation Result

The present study shows the following problems those are similar to the results by Yamazaki et al. [4]. Firstly, it takes time for the detection work and classifications, especially in the level rank of G3-G4, which mainly consists of damaged walls and columns and partly collapsed structures. It is also difficult to classify the damage levels in densely built-up areas since the boundaries of structures are obscure. Therefore, it tends to underestimate the damage class generally due to omission error. It is also noted that a pre-event image should be employed as a reference in a detection work because damages can be perceived by a comparison with the pre-event condition.

There are several factors to affect the accuracy of image interpretation for this region. The major ones are the building structure type, the influence of shadow of buildings, the method of damage level classification, the time of data acquisition, and the reliability of field survey data.

The masonry building has a tendency to completely collapse at once. Therefore, only a few medium level damages were observed, which makes the classification easier in this region. However, the accuracy of the present study was the same level compared with the previous researches. Meanwhile, the shadows of buildings are smaller in this region due to the low latitude with a lot of low-rise buildings. Therefore the work is easier due to the absence of dark and large shadow. Small shadow is helpful to identify a building and pick up the difference before and after the earthquake. In addition, the various damage classifications should be employed for remote sensing and field survey to fill the detection gap each other.

5. Conclusions

In this paper, the authors performed visual damage interpretation of buildings using QuickBird satellite images following the 2007 Pisco, Peru Earthquake. The results of the damage inspections were compared with the field survey data, and also with aerial photographs, consequently the accuracy of damage inspection was investigated. The following conclusions were drawn.

The results show that about 70% of collapsed buildings of the whole city were detected. Some amount of omission error was observed due to the limitation of the satellite images. Moreover, omission errors decreased by rising image resolution in the Pisco city using aerial photographs. As a result, more than 80% of collapsed and seriously damaged buildings were determined. However, the accuracy of damage grade also depends on the influence of shadow of buildings, the difference in the times of data acquisitions and the local building/environment conditions, etc.

A further study is required to systematize efficient damage detection methods, considering also the past studies. For example, important topics are the relationship between the structural types of buildings and detection accuracy, and the methodology to adjust the detection work depending on the local situation. The results of the present study may contribute some amount as a comparison with a well-documented database when automated extraction methods using digital image processing are studied.

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