RELATIONSHIP BETWEEN SAR INTENSITY AND ASPECT ANGLE OF BUILDING CONSIDERING SCATTERING BEHAVIOR

Yuzuru Kushiyama [1], Masashi Matsuoka[2], Hiroyuki Miura[3] and Fumitaka Ogushi [1]
[1]Dept. of Built Environment, Tokyo Institute of Technology,
4259-G3-2 Nagatsuta, Midori-ku, Yokohama 226-8502 Japan,
Email: kushiyama.y.aa@m.titech.ac.jp, ogushi.f.aa@m.titech.ac.jp
[2]Dept. of Architecture and Building Engineering, Tokyo Institute of Technology,
4259-G3-2 Nagatsuta, Midori-ku, Yokohama 226-8502 Japan,
Email: matsuoka.m.ab@m.titech.ac.jp
[3]Hiroshima University, 1-4-1 Kagamiyama, Higashihiroshima-city, Hiroshima 739-8527 Japan,
Email: hmiura@hiroshima-u.ac.jp

KEY WORDS: Building Inventory, Double Bounce, SAR, Urban

ABSTRACT: Urban area is expanding in developing countries, and the demands to create and update building inventory data, which can be used for land use planning, infrastructural construction, risk assessment etc. Attributes of building inventory data can be derived from various sources such as census data, field survey, aerial surveys, remote sensing and so on. Currently field survey is one of the major methods to obtain details of building inventory data, but it needs lots of human resources and a long period of time. Remote sensing can be an effective method if it is possible to obtain the appropriate inventory information from the wide coverage. A typical method using remote sensing is to edit building footprints on high resolution optical satellite image. And it is considered that height of building can be derived from digital surface model (DSM). However, we have a problem to obtain timely optical image and DSM in cloudy weather area. Therefore, it is important to develop alternative approach to estimate the building attributes by using synthetic aperture radar (SAR).
Firstly, we investigated the scattering behavior of SAR by a simplified building model and surrounding ground. A strong backscattered echo returns by the front wall. Because a double bounce effect is caused by a sort of corner reflection between the front wall of the building and ground surface. There is an expectation that the strength of the backscattering echo is related to height and aspect angle of buildings. In this paper, we theoretically calculate the relation between the backscattering strength and the height of the building model. Then, we examined the value of backscattering coefficient in a PALSAR image observed in Bogota, Columbia and compared with the result of theoretical calculation.

1. INTRODUCTION

Building inventory is capable of land use planning, design for infrastructure, energy demands etc. As it is particularly valuable for loss estimation on occurrence of disaster. It is also reported that several applications and software providing the function for loss estimation from hazards by importing inventory data (World Bank, 2014). A global database of building inventories is developed for loss estimation in near-real-time post-earthquake and pre-earthquake risk analysis, for the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) program (Jaiswal et al., 2010). The database is created from statistics sources of World Housing Encyclopedia (WHE), UN database, census data, literatures, and so on. The paper also gives a map showing quality rating of the PAGER urban residential building inventory data in each country as shown in Figure 1.

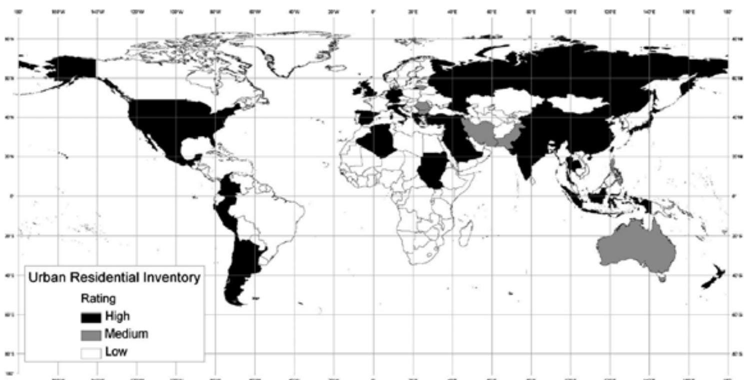

Figure 1 Quality rating of the PAGER urban residential building inventory data

for different countries (Jaiswal, K., 2010)

The figure implies that the database is inadequate in many developing countries. In addition, urban area which is still expanding demands to create and update the building inventory data.
Some attributes of building inventory, for example construction type and the number of stories, are required for damage estimation from earthquake. The vulnerability and seismic capacity of buildings are assessed by those attributes. The attributes can be derived from various sources such as census data, field survey, aerial surveys, remote sensing and so on. Currently field survey is one of the major methods to obtain details of building inventory data, but it needs lots of human resources and a long period of time. Remote sensing can be an effective method if it is possible to obtain the appropriate inventory information from the wide coverage. A typical method using remote sensing is to edit building footprints on high resolution optical satellite image. The building inventory data is developed for estimating earthquake damage reliably in Lima, Peru (Matsuoka et al., 2014). IKONOS satellite images are used to automatically detect mid and high-rise buildings from image shadows and to update existing building inventory (Miura et al., 2006). It is also studied that height and 3D model of building are derived from a stereo pair of high resolution optical image (Fraser et al., 2001).
We tried to extract height data from digital surface model (DSM) for the purpose of risk assessment and updating building inventory in Bogota, Columbia. However, we have a problem to obtain timely optical image and DSM in cloudy weather area. We need to develop alternative approach to estimate the building attributes by using ALOS PALSAR data which has the capability of observation in cloudy condition and is archived in multi-temporal. A strong backscattered echo returns by the front wall. There is an expectation that the strength of the backscattered echo is related to height and aspect angle of buildings. A double bounce effect is caused by a sort of corner reflection between the front wall of the building and ground surface. We consider a method to estimate the height of building based on the theory of double bounce effect.
In this paper, we examined the relevance of the strength of the backscattered echo to height and aspect angle of buildings by the steps shown in Figure 2.

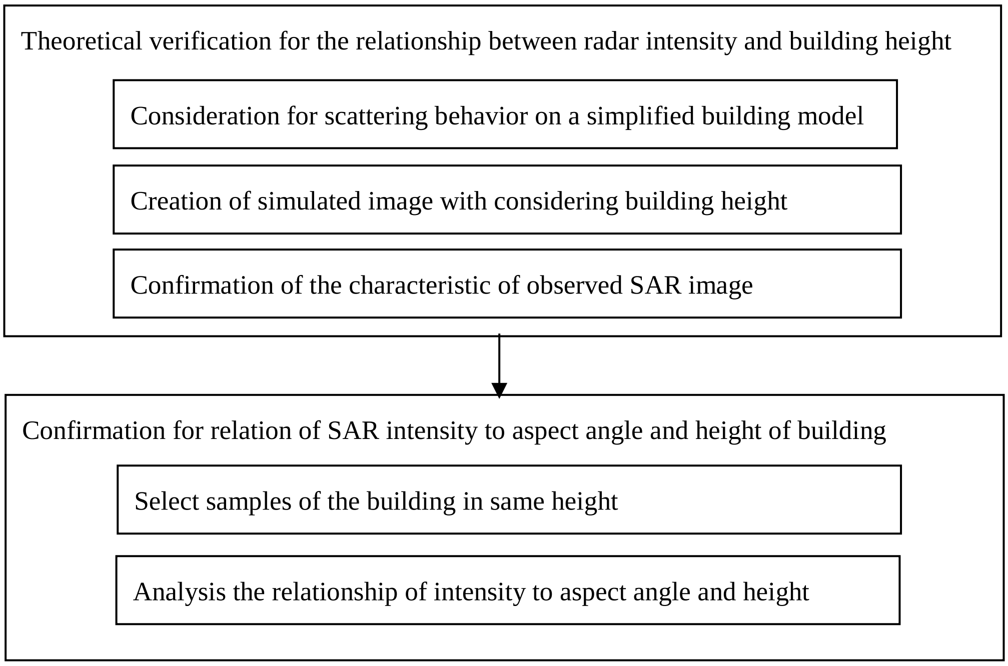

Figure 2 Study flow

We theoretically examined the scattering behavior of SAR by a simplified building model and surrounding ground. And we created simulated image based on the theory of backscattering behavior in some levels of height. Then the occurrence of double bounce effect was confirmed in accordance with the theory and simulation the observed ALOS PALSAR image. Subsequently, we confirmed the relation of SAR intensity depending on the aspect angle and height of the buildings. The buildings which have same number of story were sampled to analyze the relation. The aspect angle on the front wall of the sampled buildings were measured in GIS software. The SAR intensity values near facade of the building were extracted and analyzed for the trend of the backscattering strength and the aspect angle with referencing the previous study.

2. SCATTERING BEHAVIOR ON SIMPLIFIED BUILDING MODEL

2.1 Characteristics of Backscatter and Reflection on Simplified Building Model

We assume a 2D-rectangular building model and analyze the scattering behavior of SAR on the building model in order to examine double bounce effect and the geometry of backscattering echo. As the surface gets rougher, the reflection becomes more diffuse. We assume that ground surface and building surface are slightly rough and reflected component and backscattered component are reflected as shown in Figure 3.

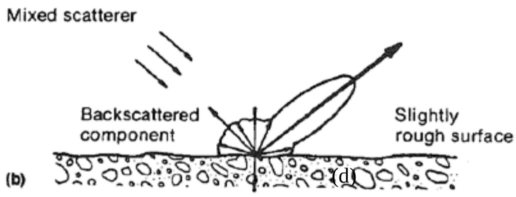

Figure 3 Specular reflection and diffuse scattering from slightly rough surface (Henderson et al., 1998)

The scattering behavior is described in Figure 4 (a)-(g). Microwave of radar is transmitted from left side to the building. Figure 4 (a) shows backscattered component returns from flat ground in front of the building. Reflected component is directed to forward and does not return to radar. Figure 4 (b) shows backscattered component of B-C is returned to radar and as same as Figure 4 (a). And the reflected component is reflected towards to the building wall and some part of them are bounced to radar as shown in Figure 4 (c). If incidence angle of radar is θ and the height of the building is h, the position B is $-h\tan\theta$ from position C. Hence, a double bounce effect is caused by a sort of corner reflection between facade of the building and ground surface. And the double bounce from B to C is illuminated at the bottom of the exterior wall which is the position C in Figure 3. Figure 4 (d) shows a reflected component backscatter from the facade is bounced to ground and returned to radar. It is also double bounce effect and the illumination position is C. Figure 4 (e) describes the backscattered component from the building's face returned to radar and layover occurs in front of the building. The position D' which is the illumination of D is $-h\cot\theta$ from position C (Ouchi, 2004). Backscattered echo is reflected from top roof as shown in Figure 4 (f). As foreshortening is caused, the illuminated position is $-h\cot\theta$ from the nadir position. Radar shadow is caused in backside of the building and backscattered component returns from a ground surface which is far from position G as shown in Figure 4 (g). The geometry of radar shadow is from the position $F-h\cot\theta$ *to* the position $F+h\tan\theta$. According to the double bounce effect which is described in Figure 4 (c), the number of the microwave paths is increased as the building is higher and double bounce area is larger. Based on this consideration, the intensity of backscatter echo is enhanced by the building height. Figure 4 shows segments with symbols, P1 to P8. The segments indicate the projected area and the intensity of the backscattered and reflected component. In particular, the segment P3 describes the reflection component concentrating on one point and the strong reflection. P1, P2, P4, P5 and P7 show the week backscatter, but the position of the segments for P4 and P5 are shifted due to foreshortening. The segment P6 shows area of radar shadow.

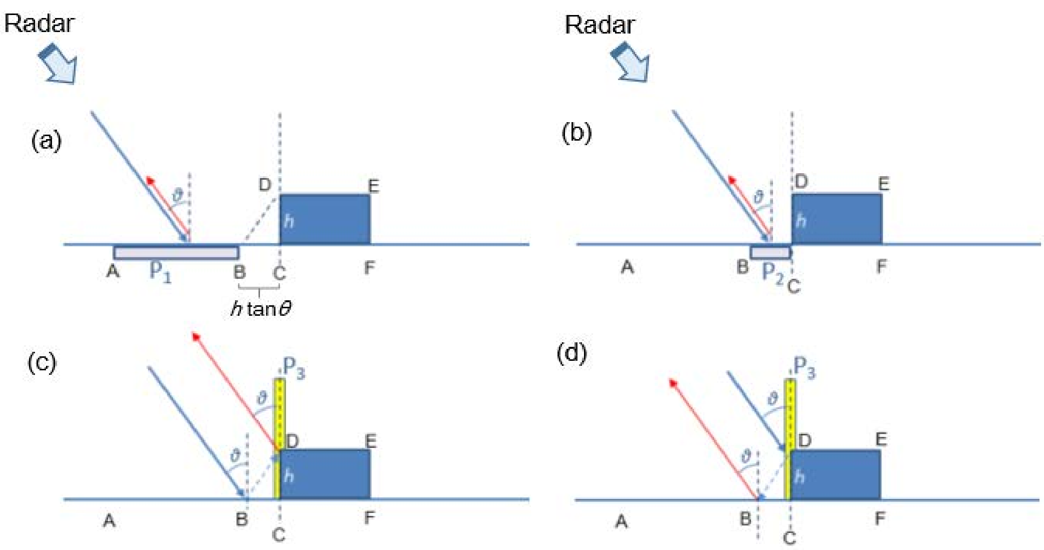

Figure 4 Scattering behavior on simplified building model (2D side view)

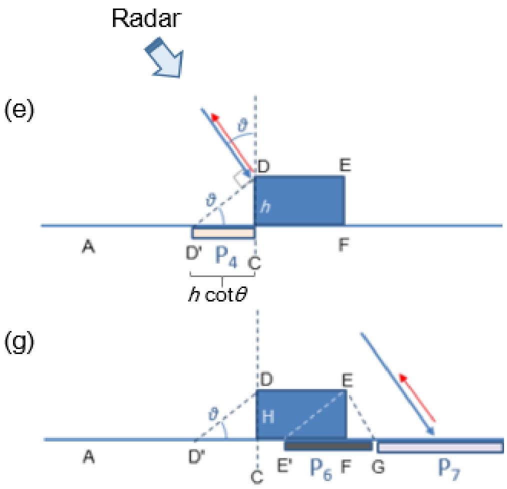

Figure 4 Scattering behavior on simplified building model (2D side view)

2.2 Simulation for Power Image Considering Building Height

We simulated power image which consists of the backscatter, the double bounce, the foreshortening and radar shadow to confirm the intensity of double bounce is enhanced by the building height. The power image was calculated based on a summation of each component as it is summarized in Figure 5.

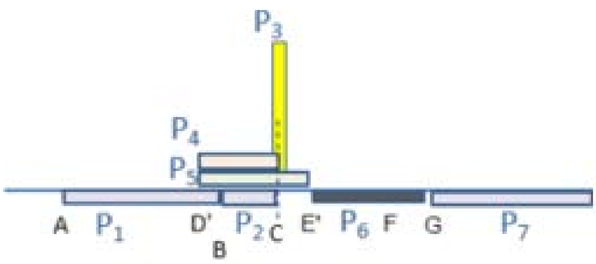

Figure 5 Backscattered echo near building

We created the power image if the building height are in case of 15m, 9m and 6m. The power image is shown in Figure 6 and the height of each image is shown in Table 1. In the simulation, it is assumed that SAR incidence angle is 34.3 degree and ground surface and building surface are moderately rough, backscatter coefficient from moderately rough surface is around -20dB (NASA, 1989). Backscatter coefficient of reflected component is -2dB. We confirm that the intensity at front wall of the building model is enhanced related to the height of the building by the simulated power image.

Table 1 Simulated value of double bounced area

	Height	Power (dB)
(a)	15m	9.44
(b)	9m	7.49
(c)	6m	6.05

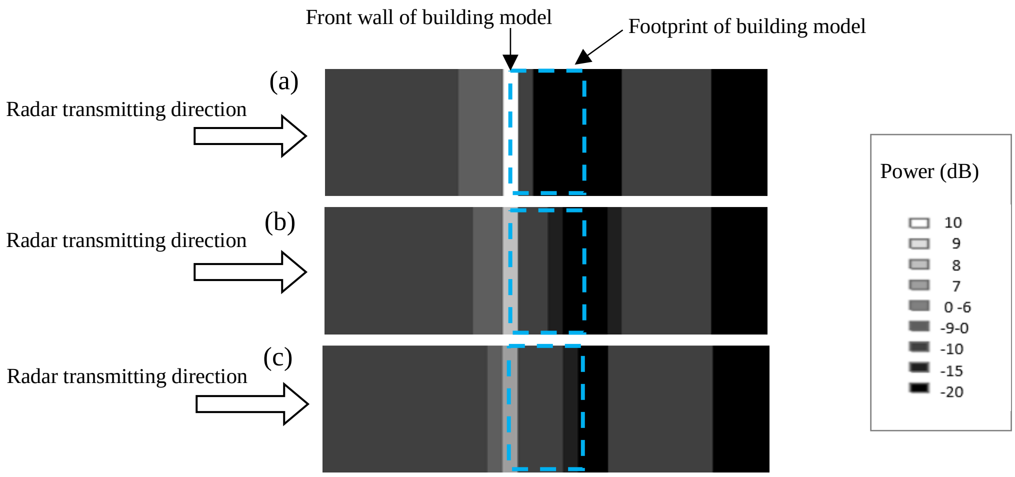

Figure 6 Simulated power image

2.3 Confirmation of Characteristics of Observed SAR Image

We confirmed that high backscatter appeared in a PALSAR image observed in Bogota, Columbia. The observation mode of PLASAR is FBS and the direction of orbit is ascending. High value pixel is found near the facade of some buildings. We measured profiles of backscatter coefficient across three same types of buildings which have 5 stories (approx. 17m height). The profiling lines and the values are shown in Figure 7. The peak of profile (b) is close to the theoretical value, but the value of profile (a) is very low. Direction of the profile line (b) is nearly along with the microwave transmitting direction. It is found that the occurrence of double bounce effect and the intensity depend on the angle between the direction of microwave and aspect of the building wall.

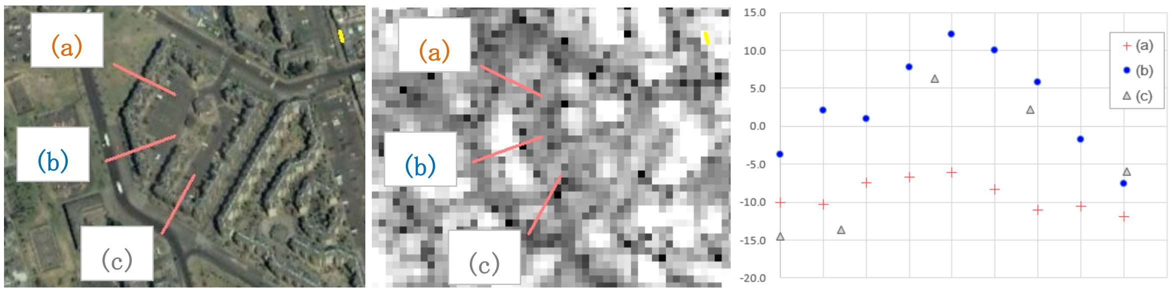

Figure 7 Profiles of radar image across building

3. RELATION OF SAR INENSITY TO ASPECT ANGLE AND HEIGHT OF BUILDING

3.1 The method of analysis for SAR Intensity Depending Aspect Angle

In order to focus on the dependence of double bounce effect for the aspect angle of the building, we analyzed the characteristics of SAR intensity at the building exterior wall in various aspect angles. We used building inventory data of Bogota for the validation. The building inventory includes shape of cadastral area, land use, story of building etc. We selected several buildings that have same story based on the attribute in the inventory data. The numbers of story are categorized in 2 to 5. We drew the line along with the facade of building on optical image and measured an aspect angle of the face towards to satellite. We calculated the transmitting microwave direction of PALSAR, i.e. range direction from observed data and differential angle between the aspect angle of the building's face and the range direction. The intensity of double bounce area was obtained by mean value for backscatter coefficient of several pixels near the facade of the building.

3.2 The result of analysis comparing with the previous study

In the previous study, the double bounce effect was verified by a laboratory experiment (Brunner et al., 2008). The intensity of double bounce reflection from a simple rectangular solid model with changing aspect angle was measured in the European Microwave Signature Laboratory (EMSL). Schematic view of the EMSL is showed in Figure 8 and the dimension of building is 120 cm× 90 cm × 60 cm. A frequency of the microwave of the experiment is 10 GHz to verify the backscattering behavior of X-band radar on building.

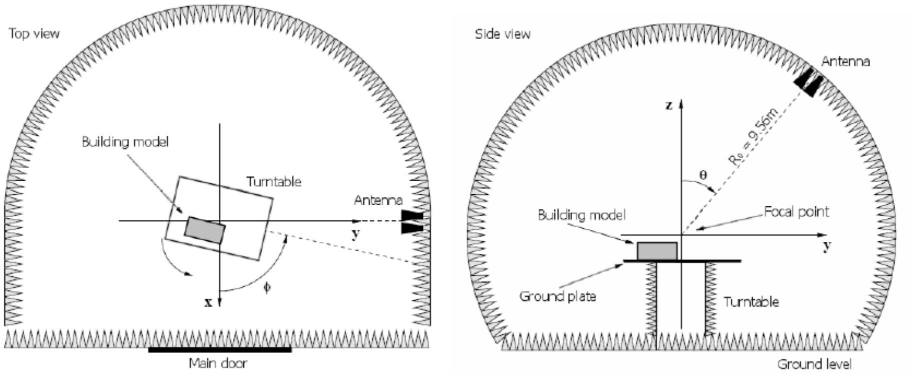

Figure 8 Schematic view of the EMSL and measurement setup of the experiment (Brunner et al., 2008)

According the result, the intensity tends to decrease with a major peak around 0 degree of the aspect angle. Although the range of power is between -5 dB to 35 dB and not same as that of PALSAR image, we compared our analyzed data with the result of EMSL in order to verify a trend and a relationship between the intensity and the differential angle. Figure 9 shows the backscattering characteristics from the buildings having the same number of story. Y axis is for intensity and X axis is for a differential angle for each number of story. The amount of samples for 4- and 5-story buildings is not sufficient to examine the dependence. Because there are few building groups with a same story higher than 4 in Bogota. The graphs for 2- and 3-story buildings show the correlation between the intensity and the aspect angle. And these decreasing trends are same as the result of EMSL. The values of back scatter coefficient within 10 degrees are mostly higher than 0 dB and the narrow peak appears in 0 to 5 degree of differential angle. The values are substantially near or less 0 dB when the differential angle is larger than 10 degrees. From this result, we consider that double bounce effect occurs in narrow aspect angle to range direction. The relationship between intensity and height was verified by average of intensity within 10 degrees in each height of building. The average intensities for 2- to 5-srory buildings are shown in Table 2. The number of samples for 4- and 5-story buildings was not enough to evaluate the trend; however the average intensities except for 4-story likely increase.

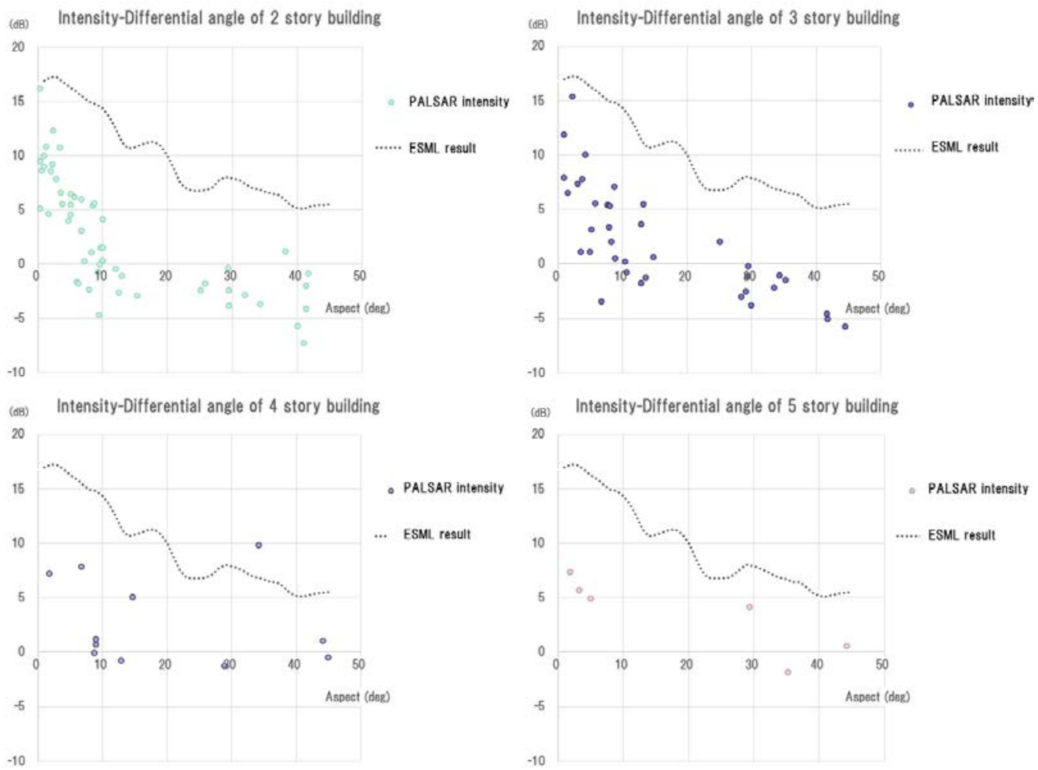

Figure 9 Relationship between intensity and differential angle for the same number of stories of the buildings

Table 2 Average of intensity within 10 degrees of the differential angle

Number of Stories	Average Intensity
5	5.95
4	3.33
3	5.42
2	5.20

5. CONCLUSIONS

We verified the possibility to estimate the building height derived from the simulated image data based on the backscattering behavior on the simple building model. It is found that the double bounce effect depends on the condition of the aspect angle and the backscatter coefficient is considerably high when the differential angle between aspect angle and range direction is within 10 degree. The values of back scatter coefficient within 10 degree are mostly higher than 0 dB and the narrow and rather higher peak appears in 0 to 5 degree of the differential angle in the image analysis. The values is substantially near or less 0 dB if the differential angle is larger than 10 degree. From this empirical result, we found that the double bounce effect occurs in a narrow range of the aspect angle directed to radar position. For the relationship the intensity of backscatter and the height of building we analyzed the average of the intensity within 10 degrees of the differential angle and it seems to increase. But it was not sufficient to obtain a particular trend for the relationship between the intensity of backscatter and the height of building. The conditions of the sampled buildings, for instance construction type, material, shape of its roof are not homogenous. Thus, we consider that those complicated condition cause backscatter effect which doesn’t match with theoretical behavior. In the future study, we will find the study site where the building has similar condition except for the story and aspect angle.

6. ACKNOWLEDGEMENT

We would like to thank Makoto Ono, Hirokazu Tanaka and Kazuo Isono of RESTEC for lots of technical discussions about SAR scattering mechanism. We also thank to Hiroyuki Miyazaki of CSIS, University of Tokyo, for technical discussions and sharing reference data of urban mapping. The authors acknowledge that Yuko Takeyama fully support to provide PALSAR data from National Institute of Advanced Industrial Science and Technology (AIST). A part of this study was supported by the JST-JICA SATREPS Colombia (PI: Prof. H. Kumagai of Nagoya University). The building inventory data is provided from IDIGER, Colombia.

REFERENCES

Brunner, D., Bruzzone, L., Ferro, A., Fortuny, J., Lemoine, G., 2008. Analysis of the double bounce scattering mechanism of buildings in VHR SAR data. In: SPIE, Image Signal Processing for Remote Sensing, XIV, Cardiff, U.K., Vol. 7109, pp. 710 90Q-710 - 90Q-12.

Fraser, C., Baltsavias, E., Gruen, A., 2001a. 3D building reconstruction from high-resolution IKONOS stereo imagery. In: Automated Extraction of Man-Made Objects from Aerial and Space Images (III), E. Baltsavias, A. Gruen, L. Van Gool (Eds.), Balkema Publishers, Lisse, pp. 325-338(in press)

Henderson, F, Lewis, A., 1998. Radar Fundamentals: The Geoscience Perspective. In: Principles and Applications of Radar Imaging, edited by Ryerson, R., Henderson, F. and Lewis, A., John Wiley & Sons, New York, pp. 159.

Jaiswal, K., Wald, D., Porter, K., 2010. A global building inventory for earthquake loss estimation and risk management. Earthquake spectra, 26 (3), pp. 731–748

Matsuoka, M., Shun Mito, S., Midorikawa, S., Miura, H., Quiroz, L., Maruyama, Y., Estrada, M., 2014. Development of building inventory data and earthquake damage estimation in Lima, Peru for Future Earthquakes. Journal of Disaster Research 9 (6), pp. 1032–1041

Miura, H., Midorikawa, S., 2006. Updating GIS building inventory data using high-resolution satellite images for earthquake damage assessment: application to Metro Manila, Philippines. Earthquake Spectra, 22 (1), pp.151-168

NASA, 1989. Instrument Panel Report. SAR: Synthetic Aperture Radar. In: Earth Observing System Instrument Panel Report Volume II f, Earth Science and Application Division, NASA Headquarters, Washington, DC, pp. 233

Ouchi, K., 2004. Principles of Synthetic Aperture Radar for Remote Sensing, Tokyo Denki University Press, Tokyo, pp. 128-131.

World Bank, 2014. Understanding risk in an evolving world - Emerging best practices in natural disaster risk

assessment.