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STUDY ON THE DISASTER INVESTIGATION OF RC BUILDING UTILIZING UAV

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Abstract

Aerial photography by UAV (drone) has been attracting attention since around 2015. Drone technology is constantly improving. Currently, drones are also popular with general individuals. In recent years, the use of drones for building inspection has been studied in the architectural field. The effectiveness of a building investigation utilizing drones for daily use has been reported in the past. On the other hand, drones are considered effective for building damage investigation in a disaster, but there are few examples of actual investigations using drones. The purpose of this paper is to confirm the effectiveness of the building damage investigation using drones. This paper reports the results of confirming the evaluation accuracy of crack width and inclination of equipment on reinforced concrete (RC) government office building damaged by the earthquake.

The investigated building is the RC government office building that was damaged by the 2016 Kumamoto earthquake. It is a three-story RC structure built in 1974. The longitudinal direction is a moment resisting frame structure, and the short direction is a frame with shear walls. In 2010, seismic reinforcement was performed by installing a steel braces with frames. Due to the 2016 Kumamoto earthquake, in the longitudinal direction, it was confirmed that the column was slightly cracked, and the painting of steel braces with frames were partly peeled off. In the short direction, shear failure of the shear wall and shear failure of the short beams were confirmed.

First, in the investigation, the post-earthquake damage evaluation was implemented. The post-earthquake damage evaluation conducted by humans, and those done by drones were the same results in this investigation building. By using drone for building damage assessment, disaster investigation can be streamlined.

Next, the crack width evaluation using a drone was conducted. It was confirmed that possible to evaluate the crack width at a shooting distance of 5m using a 100 million pixel high resolution camera. If the drone can fly up to a shooting distance of approximately 5m, the drone is effective in evaluating the small crack width.

Subsequently, two drones were used to investigate the inclination of the building. While keep flying a drone (Mavic Pro) with a string, the other drone (Inspire 2) shoot the inclined an equipment on the building and the string. The incline angle measurement result was approximately 3° for humans and 4° for drones. There was an error between the inclination read from the picture and the measured value. It is thought that the cause is that the photo of the equipment was not taken from the front. Inclination evaluation using drones is a problem for the future.

The investigation was conducted under favorable conditions such as sunny day and light winds. However, in actual damage investigations, drones cannot be allowed to fly due to bad weather, and crack width evaluation accuracy is reduced due to sunshine conditions on the surface of damaged members. There are subjects for future analysis.

Keywords: UAV; drone; post-earthquake damage evaluation; residual seismic capacity; crack

1. Introduction

In recent years, the utilization of UAVs (drones) for inspection and investigation of buildings during normal times has attracted attention [1]. It has been reported that the drones conducted a verification experiment on the inspection of an actual building, and was able to roughly observe the deterioration of the whole building. The use of drones is considered to be effective for the quick damage investigation of damaged buildings in a disaster such as an earthquake, but there are few examples of actual investigations using drones.

The purpose of this paper is to confirm the effectiveness of the building damage investigation using drones. This paper reports the results of confirming the evaluation accuracy of crack width and inclination of equipment on reinforced concrete (RC) government office building damaged by the earthquake.

2. Objective building of investigation

2.1 Outline of building

Fig. 1 shows the exterior of the objective building of investigation. The objective building was a government building located in Kamimashiki-gun, Kumamoto Prefecture, which was damaged by the 2016 Kumamoto Earthquake in April 2016. It is a RC building constructed in 1974 with three floors above ground, one underground, and one floor of a tower. It has a 9-span moment resisting frame structure in the longitudinal direction, and a 3-span frame structure with shear walls in the short direction. In 2010, seismic reinforcement was performed by installing a steel braces with frames..

2.2 Damage situation

Due to the 2016 Kumamoto earthquake, in the longitudinal direction, it was confirmed that the column was slightly cracked, and the painting of steel braces with frames were partly peeled off. In the short direction, shear failure of the shear wall and shear failure of the short beams were confirmed. Fig. 2 shows the failure situation of the beam in the short direction.

Fig. 1 – Exterior of the objective building

Fig. 2 – Failure situation of the beam in the short direction

3. Outline of the test

3.1 Outline of equipment

Table 1 shows the specifications of the equipment (camera, drone, VR goggles) used in the investigation. There are four types of cameras: 100 million pixel image shooting, 20 million pixel image shooting, infrared thermography shooting, and FPV (First Person View) shooting. Table 1 (a) shows the details of the drone and camera for each shooting function. Table 1 (b) shows the details of the drone used for FPV shooting and VR goggle for viewing the shot video.

3.2 Investigation item and their outline

(1) Post-earthquake damage evaluation

This investigation was conducted in August 2018, more than two years after the earthquake. First, the current damage situation is grasped, and the post-earthquake damage evaluation is performed by a human.

Drones have difficulty entering buildings. Therefore, at the time of the actual damage investigation, the post-earthquake damage evaluation is determined only by the damage level of the outer members. The results of the post-earthquake damage evaluation performed by humans and those performed by using a drone are compared.

(2) Investigation of building utilizing drone

The situation inside and outside the building is shooted by a drone and the damage situation is evaluated. Table 2 shows the specifications of the investigation items. The table shows the shooting contents of each investigation item, the camera, and the shooting distance. The outline of each investigation item is described below.

1) 1-1p

The damage to the building is confirmed by taking a picture of the whole building from a long distance using the “iXU1000” (100 million pixel camera).

2) 2-1p

First, select the cracks on the columns and walls on the outer surface of the first floor that can be investigated by drone. Fig. 3 shows the measurement points of the cracks. At each position, a crack width measurement by a human and a crack width evaluation using a drone are performed. In 2-1p, a 100 million pixel camera is used to photograph cracks and confirm the accuracy of the crack width evaluation. The parameters were the shooting distance (5, 10, 15, 20m).

3) 2-2x

For 2-1p, the camera was changed from a 100 million pixel camera to a “Zenmuse X5S” (20 million pixel camera).

4) 3-1x

In a room, the effect of lighting on the evaluation accuracy of the crack width is confirmed. The camera uses a 20 million pixel camera.

5) 4-1x

Two drones are used to check the accuracy of the measurement of the inclination of the building. One drone (Mavic Pro) is tied with a string attached to a weight, and the other drone (Inspire 2) is used to shoot the string and the inclined water tank with a 20 million pixel camera while flying.

6) 5-1xt

Infrared thermography aerial shooting was performed for the purpose of detecting the outer wall tile peeling. The drone equipped with the “Zenmuse XT” (infrared thermography camera) shoots columns, beams and walls.

Table 1 – Specifications of the equipment used in the investigation

(a) Details of the drones and cameras

		100 million pixel	20 million pixel	Infrared thermography
Drone	Product name	Matrice 600 Pro	Inspire 2	Matrice 210
	Manufacturer	DJI	DJI	DJI
	Size [mm]	1668×1518×759	880×790×250	887×800×378
	Weight [kg]	9.1	3.4	3.8
	Payload [kg]	6	1.2	2.34
	Maximum wind resistance [m/s]	8	10	10
	Appearance			
Camera	Product name	iXU1000	Zenmuse X5S	Zenmuse XT
	Manufacturer	PhaseOne	DJI	DJI / FLIR SYSTEMS
	Pixel number [px]	11608×8708	5280×3956	640×512
	Color depth [bit]	16	14	-
	Appearance			

(b) Details of the drone used for FPV shooting and VR goggle for viewing the shot video

		FPV shooting
Drone and camera	Product name	Mavic Pro
	Manufacturer	DJI
	Size [mm]	430×400×90
	Pixel number [px]	4000×3000
	Maximum wind resistance [m/s]	10
	Appearance	
VR goggle	Product name	DJI Goggles
	Manufacturer	Wi-Fi / HDMI
	Input	640×512
	Resolution	1080p30
	Appearance	

7) 5-2m

FPV shooting is performed using the "Mavic Pro". A video is shot around the building. In addition, an image of the beam damage in the short direction is taken. During these shootings, a technician wears VR goggles and views the shot video to evaluate the damage.

Table 2 – Specifications of the investigation items

	Shooting number	Content of shooting	Camera	Shooting distance
1)	1-1p	Taking a picture of the whole building	iXU1000	20-60m
2)	2-1p	Confirmation of evaluation accuracy of crack width	iXU1000	5, 10, 15, 20m
3)	2-2x	Confirmation of evaluation accuracy of crack width	Zenmuse X5S	5, 10, 15, 20m
4)	3-1x	Shooting inside the building	Zenmuse X5S	4m
5)	4-1x	Confirmation of evaluation accuracy of incline angle	Zenmuse X5S	10m
6)	5-1xt	Infrared thermography aerial shooting	Zenmuse XT	9m
7)	5-2m	FPV shooting of building periphery and beams	Mavic Pro	1-2m

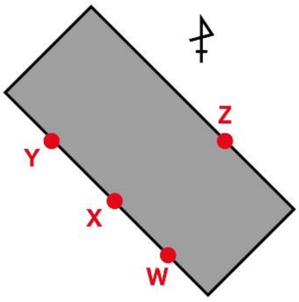


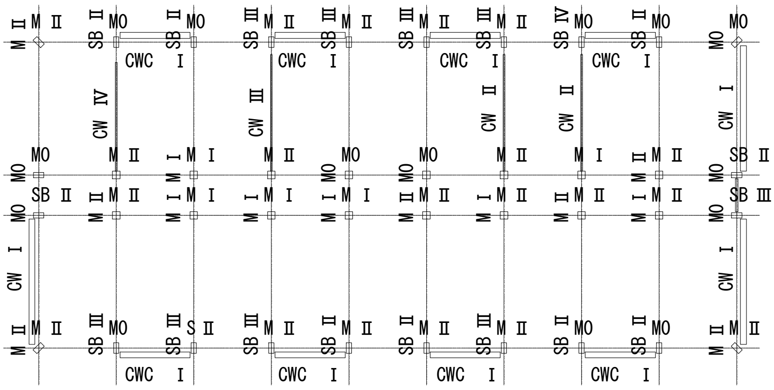
Fig. 3 – Measurement points of the cracks

4. Test result

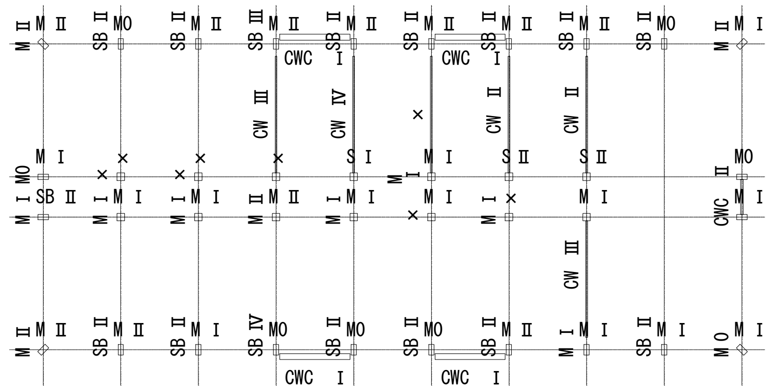
4.1 Result of the post-earthquake damage evaluation

First, the whole building was inspected by humans. As a result, the first and third floors were judged to be severely damaged, and the post-earthquake damage evaluation was performed on the first and third floors. Fig. 4 shows a list of damage levels on the first and third floors. Table 3 shows a list of the residual seismic capacity *R* and the results of the post-earthquake damage evaluation. Both the first and third floors were judged to be "Moderate" based on the determination of the short direction.

Next, the post-earthquake damage evaluation by drone is performed. The post-earthquake damage evaluation is determined only by the damage level of the outer members. Table 3 shows the results. In this building, the results of the post-earthquake damage evaluation in all floors and directions were the same for humans and drones. For the residual seismic capacity *R*, the difference between human and drone was up to 1.25 in the longitudinal direction and up to 4.45 in the short direction. In the short direction of this building, several shear walls inside the building were severely damaged, and the members were not included in the calculation in the post-earthquake damage evaluation using a drone, so a large difference occurred in *R*. From the above, it is necessary to consider the structural type of the building when determining the post-earthquake damage evaluation using a drone.



(a) First floor



(b) Third floor

S: Shear column, SM: Bending-shear column, M: Bending column, SB: Beam dominated shear column, MB: Beam dominated bending column, W: Wall without column, CW: Wall with column on one side, CWC: Wall with column on both sides

Fig. 4 – List of damage levels on the first and third floors

Table 3 – List of the residual seismic capacity *R* and the results of the post-earthquake damage evaluation

		Longitudinal direction		Short direction	
		Ignore seismic reinforcement	Consider seismic reinforcement	Ignore seismic reinforcement	Consider seismic reinforcement
1st floor	Human	82.88 (Light)	85.88 (Light)	66.25 (Moderate)	67.77 (Moderate)
	Drone	81.88 (Light)	86.46 (Light)	64.38 (Moderate)	67.22 (Moderate)
3rd floor	Human	86.62 (Light)	91.00 (Light)	64.66 (Moderate)	
	Drone	86.88 (Light)	92.25 (Light)	69.11 (Moderate)	

4.2 Result of the investigation of building utilizing drone

1) 1-1p

The whole building was photographed from a long distance using a 100 million pixel camera. Fig. 5 shows the whole building taken from the west sky. It is possible to grasp the whole building, and it is considered that if major damage such as collapse or severe damage to the outer peripheral members has occurred after the earthquake, they can be confirmed.

Fig. 5 – Whole building

2) 2-1p

Fig. 6 shows a photograph taken with a drone and the evaluation of the crack width. Table 4 shows a comparison between the measured crack width by humans and the evaluated crack width by drone investigation. The results for 2-2x are also shown. General-purpose software was used to evaluate the crack width from the photographed image. In the image shot with a 100 million pixel camera, the crack width was successfully evaluated at a shooting distance of 5 m. In the case of the shooting distance was larger than 10m, the evaluation accuracy was low.

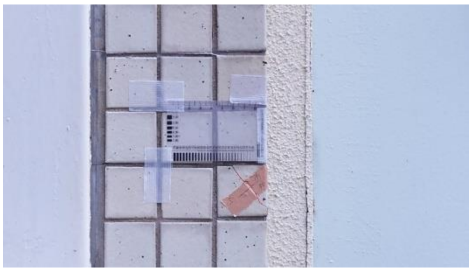


Fig. 6 – Evaluation of the crack width

Table 4 – Comparison between the measured crack width by humans and the evaluated crack width by drone investigation

Measurement points	Crack width measurement by human [mm]	Crack width evaluation value by drone investigation [mm]							
		100 million pixels				20 million pixels			
		Shooting distance							
		5m	10m	15m	20m	5m	10m	15m	20m
W	0.7	0.6	0.6	×	×	×	×	×	×
X	0.4	0.3	×	×	×	×	×	×	×
Y	2.5	1.7	1.4	1	0.5	0.9	×	×	×
Z	0.65	1	0.9	×	×	×	×	×	×

3) 2-2x

In an image shot with a 20 million pixel camera, the evaluation accuracy of the crack width is low at a shooting distance of 5 m. In the case of the small crack widths, automatic detection of cracks by general-purpose software was not possible.

Therefore, if a drone equipped with a 100 million pixel camera can be brought close to a building up to approximately 5m, the drone is effective for the post-earthquake damage evaluation.

4) 3-1x

Four cracks on the shear wall inside the building were measured. Fig. 7 shows the measurement of crack width by humans. Next, the shear wall was photographed with a 20-megapixel camera in the case of turning on and off. Table 5 shows a comparison between the measured values by humans and the evaluation values of the crack width by drone investigation.

In the case of large cracks, it cannot be evaluated accurately. In the case of small cracks, automatic detection by general-purpose software was not possible. From the above, it is considered difficult to evaluate the crack width of members inside the building using a drone.

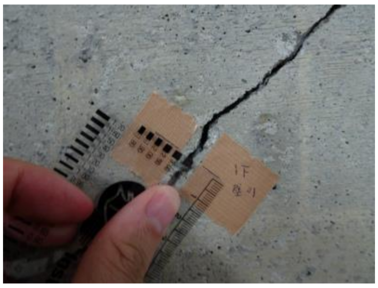


Fig. 7 – Measurement of crack width by humans

Table 5 – Comparison between the measured crack width by humans and the evaluated crack width by drone investigation

Cracks	Crack width measurement by human [mm]	Crack width evaluation value by drone investigation [mm]	
		Lighting	Lights-out
01	3.5	0.7	0.7
02	0.65	0.4	×
03	0.2	×	×
04	1.2	0.6	0.3

5) 4-1x

The water tank installed on the roof and inclined by the earthquake was targeted for the investigation. First, the incline angle was measured by a human using a plumb-bob. As a result, it was approximately 3 °.

Fig. 8 shows the incline angle measurement using a drone. Fig. 9 shows the photographed image. In the measurement of the inclination angle by drone investigation, it is approximately 4 °. The accuracy of the incline angle is somewhat effective. However, in the case of using the above method, two pilots are required. In addition, due to the adjustment of the position where the string appears and the influence of the wind, the required time is longer than that of a human investigation.

On the other hand, as a result of direct measurement of the incline angle from a still picture of the water tank, the value was the same as that of a human measurement of the incline angle (approximately 3 °). By using the gimbal function mounted on the drone, it is thought that the incline angle of the building can be easily measured.

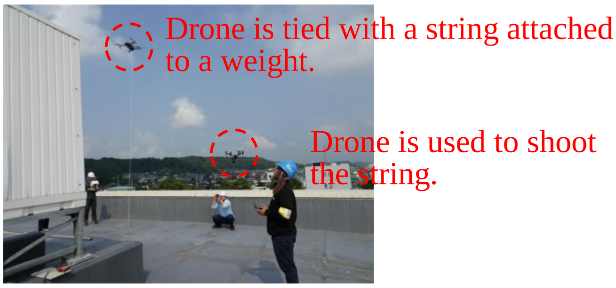


Fig. 8 – Incline angle measurement using a drone

Fig. 9 – Photographed image

6) 5-1xt

Fig. 10 shows the column shooted by the infrared thermography camera. A percussion examination by a human was also performed at the same time. The temperature where the tile peeling was high. In the event of a disaster by earthquake, it is dangerous to approach the tiles for percussion examination. Therefore, using a drone can ensure the safety of the investigator and conduct an investigation.

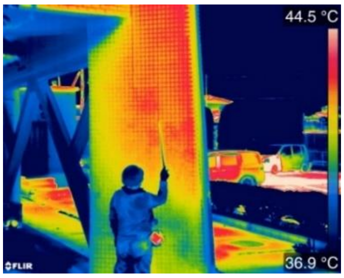


Fig. 10 – Column shooted by the infrared thermography camera

7) 5-2m

First, the pilot took a video by the drone while moving around the building. Technicians can view the video using VR goggles in real time. Fig. 11 shows the video shooting and the technician viewing the video. By using this function, a technician can conduct a disaster investigation without going to the site. Therefore, it is effective for grasping the damage situation in a disaster.

Next, the beam on the first floor was shooted by FPV. Fig. 12 shows the beam damage. If a technician looks at the image, it is possible to estimate the damage level of the structural member.

Fig. 11 – Video shooting and the technician viewing the video

Fig. 12 – Beam damage

5. Conclusions

The disaster investigation using a drone on the RC building that was damaged by the earthquake was conducted. The results obtained are summarized below.

- The post-earthquake damage evaluation conducted by humans, and those done by drones were the same results in this investigation building. By using drone for building damage assessment, disaster investigation can be streamlined. On the other hand, in the case of a structure with many brittle failed members such as shear walls inside the building, a large difference may occur in the residual seismic capacity *R*. It is necessary to consider the structural type of the building when determining the post-earthquake damage evaluation using a drone.
- As a result of crack width evaluation using a drone, it was possible to evaluate the crack width in the case of using a 100 million pixel camera and a shooting distance of 5 m. Therefore, if a drone equipped with a 100 million pixel camera can be brought close to a building up to approximately 5m, the drone is effective for the post-earthquake damage evaluation.

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7. References

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