

RESEARCH OF DAMAGED CONDITION BY THE 2016 KUMAMOTO EARTHQUAKE AND GROUND INVESTIGATION ON STONE WALLS AND EARTH STRUCTURES IN KUMAMOTO CASTLE

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ABSTRACT: There are a lot of valuable historical structures with stone wall in Japan. Those structures are still active not only as roads and waterways, but also are designated as cultural properties, and in some places, they also play an important role as a tourism resource for the region. However, the current situation is that countermeasures against disasters are delayed like the damage of Kumamoto Castle due to the 2016 Kumamoto Earthquake. In particular, it is considered that it is important to elucidate the earthquake disaster mechanism by the interaction between the ground and the stone wall.

In this research, the tendency of the damage of stone walls and earth structures will be clarified based on the survey team of the Geotechnical Engineering Society and the Kumamoto Castle Research Center, and it is discussed on the mechanism of collapse occurrence by estimating the geological structure under the several sites in Kumamoto Castle by surface wave profiling method and so on.

Keywords: Kumamoto Castle, Earthquake disaster, stone wall, earth structure, investigation

1. INTRODUCTION

A lot of historical and valuable stone structures continue using for hundreds of years in Japan. These structures have valuable roles as regional tourism resources with registration for cultural heritage and practical usage. Almost structures degraded with age, it is necessary to do maintenance and repair work. However, it is difficult to do them because mechanical evaluation method is never established from an engineering perspective, and information and references are not sufficient about these structures.

Some researchers investigated on the stone walls and embankment in Kumamoto Castle and so on. Kuwahara carried out to survey stone walls of Kumamoto Castle about 30years ago [1]. He collected the data of surface shape on stone walls by surveying tool. These data will be basic and important on comparison of current cross-sectional shape. Yamanaka et.al. carried out to survey embankment of several traditional castles by microtremor in Japan [2][3]. They tried to clarify the distribution of unstable area under the ground surface. It is expected that this method will be able to estimate the intricate geological structure with broken stone, embankment and original ground.

The 2016 Kumamoto earthquake gave huge damage for several structures in Japan. Kumamoto Castle was also damaged on architectural structures, stone wall, embankment and so on. The number of damaged stone walls and embankment

is over hundreds especially. Therefore, the evaluation method of stone wall and embankment stabilization is required from the view of geotechnical engineering quickly. This paper reports the investigation of structures' damaged condition and ground survey around damaged stone walls in Kumamoto Castle after that earthquake with cooperation of Kumamoto Castle Research Center and the survey mission of Japan Geotechnical Society.

2. CHARACTERISTICS OF KUMAMOTO CASTLE AND OVERVIEW OF GEOLOGICAL STRUCTURE

Kumamoto Castle was constructed by Kiyomasa KATO as a domain head in 1607. Fig.1 shows the landscape around the castle before construction in second hand of sixteenth century [4]. There is Mt. Chausu-yama in center of this picture map, and this mountain was shaped a southern part of Ueki tableland at an altitude about 50 meters. There is a scattering of erosional valleys surrounding here shown in Fig. 2 because an ignimbrite layer exists under the ground surface with humid climate [5].

Fig. 3 and 4 show the geological cross-section based on the past boring survey in the Kumamoto Castle [6]. There are only 12 boring data collections around northern part of the castle tower surveyed in 1958 or 2015. Developed land material and volcanic cohesive soil that N Value is around

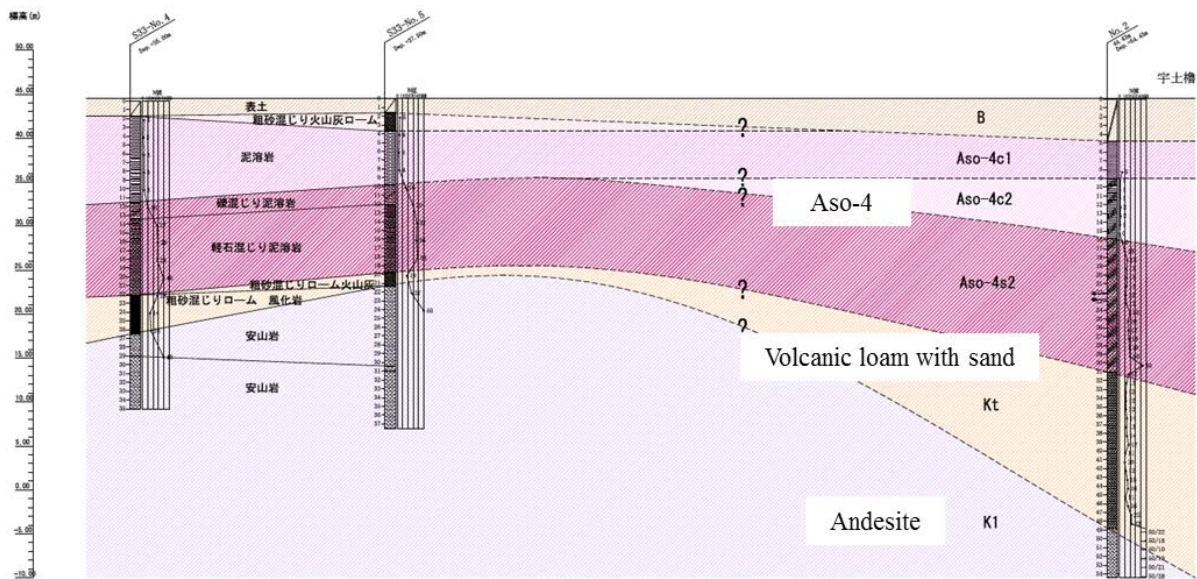


Fig. 4 Geological structure under the tower of Kumamoto Castle. [6]

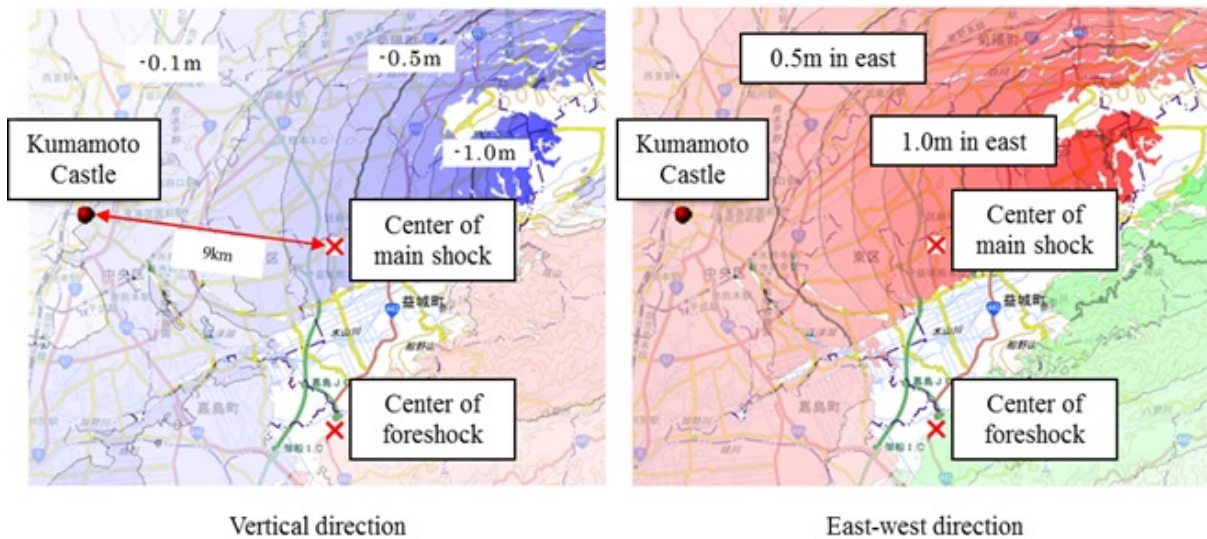


Fig. 5 Ground surface deformation by the 2016 Kumamoto earthquake. [7]

the damage conditions. The JGS disaster investigating team confirmed the following damages in the whole site of the castle; collapse and destabilization of stone walls, slope failure and surface settlement of embankment and crash of architectural structures.

Fig.8 shows the distribution of damaged stone wall locations, collapse areas, maximum stone movements and directions. It is not clarified that damage scale has causal relation between with height, gradient, width and direction of each stone wall.

Fig. 9 shows the relationship between the maximum stone movements and directions of damaged stone walls in the Honmaru area with the photos by UAV and CAD's plan views. There are a lot of cases that data of stone wall movement in north-south direction are more than the cases in

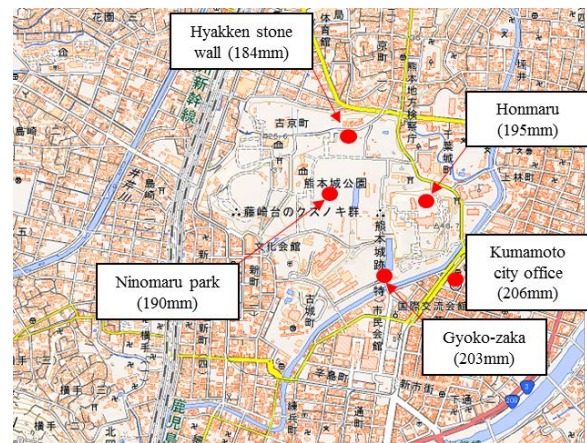


Fig. 6 Ground settlement in center of Kumamoto City and Kumamoto Castle.

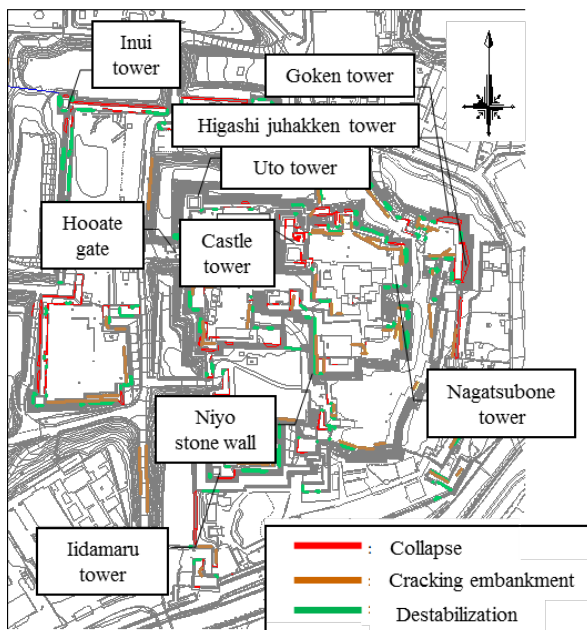


Fig. 7 Distribution of damaged stone wall and embankment.

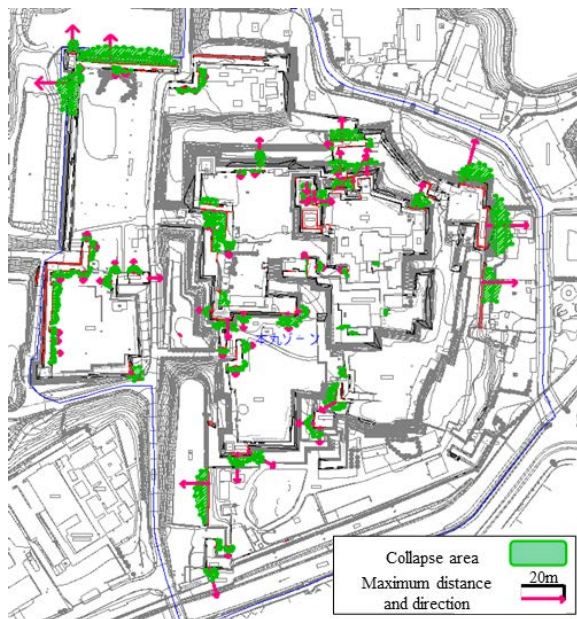


Fig. 8 Collapse area and Stone movements of damaged stone walls in the Honmaru area.

east-west direction. And it is confirmed that maximum movement distance is also longer than in these cases. It is estimated that ground vibrational characteristic under this site has a huge effect because stone walls almost construct equally in the direction of north, south, east and west.

Fig. 10 shows the relationship between the height of stone wall and maximum movement distance. It is confirmed that each parameter has almost linear relation in whole tendency. These

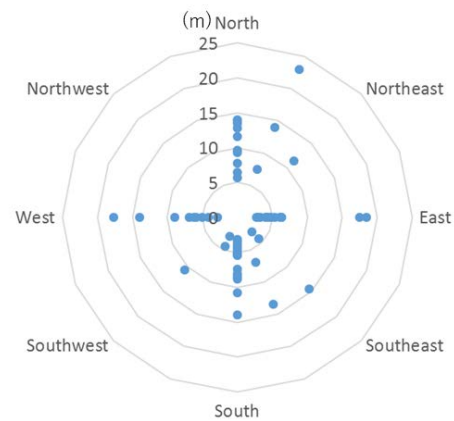


Fig. 9 Relationship between maximum distance and direction.

results indicate that the more ground investigation of this field will be important on the foundation ground of stone wall and strength of embankment for reconstruction in near future.

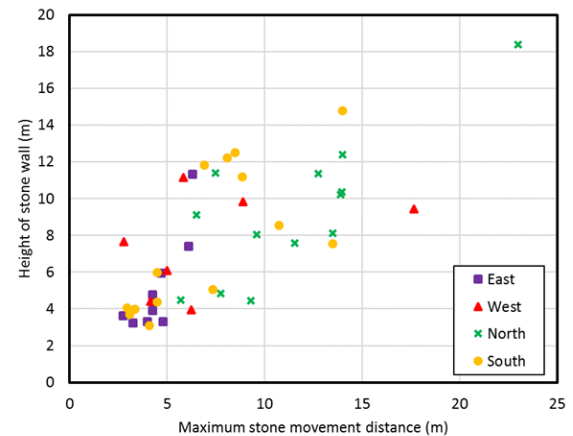


Fig. 10 Relationship between maximum stone movement distance and height of stone wall.

4.2 Surface wave exploration

Surface wave exploration was carried out by using the high precision surface wave exploration equipment (McSEIS-SXW) in order to discuss on influence a compaction or depth of surface layer for the damage of stone walls. Vibration by hammering interval was 2m and geophone interval was 2m as receiving points. In total 24 seismograph sensors were used. To make good surface connection, the geophones were properly installed in the ground.

Fig. 11 shows survey lines of Surface wave exploration at Heizaemon-maru of Kumamoto Castle. 6 measuring lines are located in a reticular pattern. Fig. 12 shows situation of surface wave

prospection at line 6 of Heizaemon-maru.

Fig. 13 shows the distribution of analyzing results of S-wave velocity at line 2 and 4. It is estimated that Aso-4c layer with under $V_s=240\text{m/sec}$ V_s and Aso-4s layer with $V_s=240\text{--}300\text{m/sec}$ locate with indeterminate undulation across a depth of about 8m.

Fig. 14 shows the distribution of N-value calculated from V_s . N-value is calculated by the following equation [8].

$$N = (V_s/97)^{0.314} \quad (1)$$

here,

N: N-value by the standard cone penetration test

V_s : Surface wave velocity by surface wave prospecting (m/sec)

There is the loosen embankment layer that N-value is about 2 above a depth of 2m. Aso-4c layer has N-value that is from 2 to 8 above a depth of 8m. And Aso-4s extends with N-value from 10 to 25 under the Aso-4c layer.

This result indicates that these soft ground gives amplification of vibration with earthquake for buildings and structures.



(a) Northern part of castle tower (b) Hooate gate (c) Northern part of Nagatsubone tower

Photo 1 Damaged stone wall and embankment in Kumamoto Castle

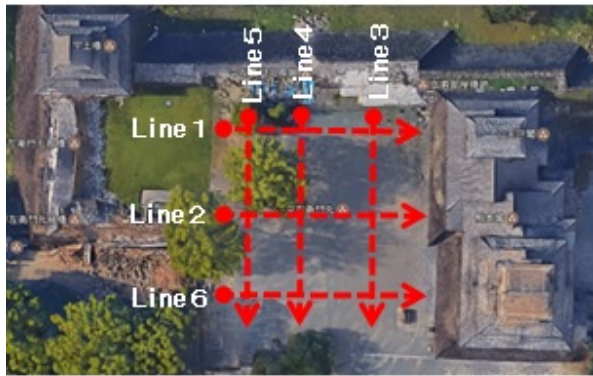


Fig.11 Survey lines of Surface wave exploration at Heizaemon-maru



Fig.12 Situation of Surface wave exploration at line 6

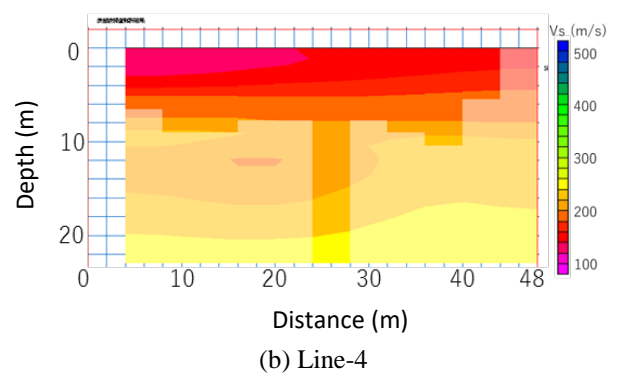
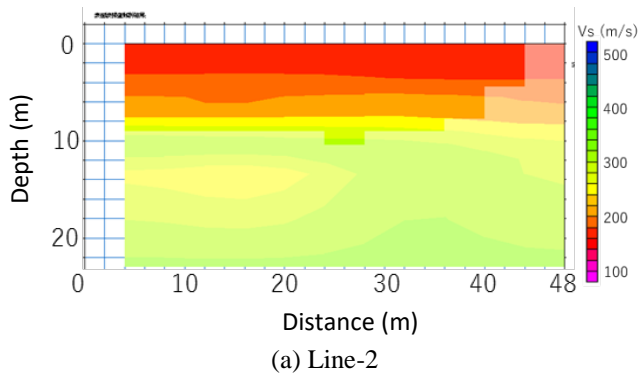


Fig. 13 Distribution of surface wave velocity V_s

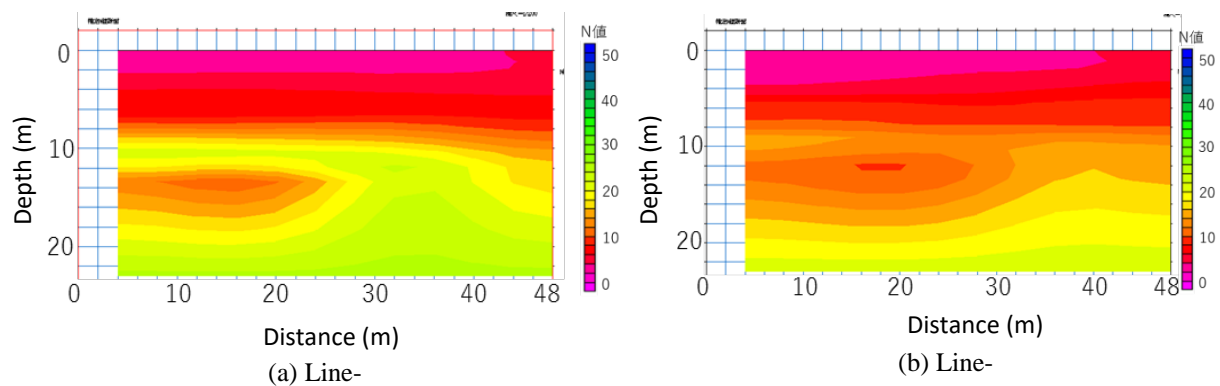


Fig. 14 Distribution of N-value

5. CONCLUSION

The 2016 Kumamoto earthquake caused huge damages for several structures in Kumamoto Castle. These structures almost have high value as cultural assets with past time of about 400years. Hundreds of stone walls and embankments were also damaged or collapsed with the massive earthquake.

This investigation carried out with the limited information of ground and geology under the Kumamoto Castle because the boring survey has minimally suppressed due to subsistent as a cultural asset before the earthquake. Therefore, the collection of past limited boring data, site investigation and the method of estimation on geological structure and soil characteristic were combined, and the following results were clarified in this study.

1) There were more cases that stone walls collapsed in north-south direction compared with the cases in east-west direction. This result indicates that the more ground investigation of this field will be important on the foundation ground of stone wall and strength of embankment for reconstruction in near future.

2) It is clarified that the Kumamoto Castle was constructed on the Aso-4 centered volcanic soil layers with low N-value. This result indicates that these soft ground gives amplification of vibration with earthquake for buildings and structures.

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