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EXTRATING METHOD OF DEFORMED PART BY MICROTREMOR ON STONE WALLS OF JAPANESE TRADITIONAL CASTLE

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ABSTRACT: The non-destructive survey technique is required to estimate quantitatively the deterioration level of a stone wall at a traditional castle site. Microtremor measurement method is one of the non-destructive survey technique to estimate geotechnical characteristics of the ground. In this study, microtremors are measured at the stone wall of the Marugame castle, in order to evaluate vibration characteristics of deformed or non-deformed stone wall; the method to extract the deformation part of the stone wall is discussed based on the measurement results. The results showed that the value of H/V and H/H spectral ration increased with the increase of deformation of wall but also by the elevation of a measurement point. It was observed that the values of energy ratio were scattered widely. It is concluded that the H/H spectral ratio is a suitable index to indicated the deformation level of a stone wall. By setting the adequate threshold value, deformed walls were extracted roughly by the value of H/H spectral ratio at the Marugame castle.

Keywords: Microtremor measurement, stone wall, H/V spectral ratio, H/H spectral ratio, Japanese castle

1. INTRODUCTION

Japanese traditional castles have been often constructed at a crest of soil embankment. The wall face of the soil embankment was commonly protected with stones. These stone walls should be left for posterity as a part of cultural heritage.

However, stone walls deteriorated with ageing are affected sometimes seismic damage. For example, the stone walls of Sendai castle ruin and the Komine-Shirakawa castle ruin was collapsed by The 2011 off the Pacific coast of Tohoku Earthquake. Recently, stone wall of the Kumamoto castle was collapsed by The 2016 Kumamoto Earthquake.

In order to keep for posterity, a stone wall should be maintained according to its deterioration level. The deterioration level of a stone wall is ordinary judged based on visual observations in appearance condition.

In-situ tests such as boring and sounding test have been hardly used in survey of stone walls to avoid disturbance of a wall [1]. Especially the influence of in-situ tests for a stone wall which is collected in the cultural asset must be minimized from the viewpoint of cultural property protection. Therefore, the non-destructive survey technique is required to estimate quantitatively the deterioration level of a stone wall.

Microtremor measurement method is one of the non-destructive survey technique to evaluate vibration characteristics of the ground and structures [2],[3]. A predominant period is evaluated from spectrum of microtremor. S-wave response of the measuring target is estimated approximately based on the ratio of horizontal and vertical spectrum of the microtremor, H/V spectral ratio.

A few study on application of microtremor measurement method for evaluation of vibration

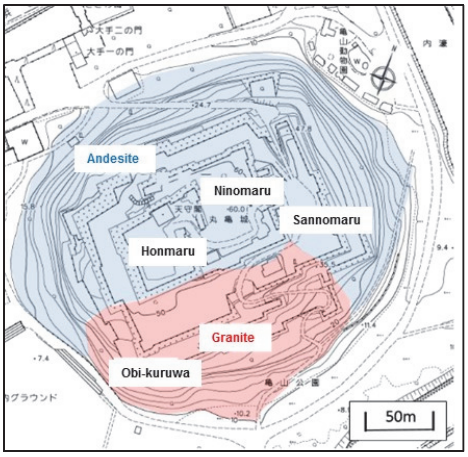


Fig. 1 The layout of the Marugame Castle plotted on geological map.

a) Swelling and opening (Sannomaru)　　b) Habaki stone wall (south-west part of Honmaru)

Fig. 2 Typical deformed stone wall a) and Habaki stone wall b)

characteristics of stone wall has been conducted, while the microtremor measurement method was sometimes applied to the evaluation of the ground and structures. For example, the microtremor measurement method was applied to the stone wall at the Kochi castle. The measurement results explained that the H/V spectral ratio was one of the deterioration
index of the stone wall [4]. However, the microtremor of stone walls with highly deformation has not been measured in the previous study.

In this study, microtremor measurement method is applied to the stone walls with highly deformation at the Marugame castle, Kagawa prefecture in Japan. The method to extract the deformation part of the stone wall is discussed based on the measurement results

2. OUTLINE OF MARUGAME CASTLE SITE

Figure 1 is the layout of the Marugame castle plotted on geological map [5]. The Marugame castle built in 1602, is located on the crest of Mt. Kameyama consisting of andesite and granite. The Marugame castle is composed of Honmaru (donjon), Ninomaru (first outer citadel), San-nomaru (second outer citadel) and Obikuruwa (outermost citadel). Each citadel is supported by a stone wall. The height of the whole stone wall is tallest in that of Japanese castle.

Figure 2 shows typical deformation of stone wall observed at the Marugame castle. Figure 2a shows swelling of a wall face and opening of the joint between stones. The reason of these deformations are estimated to earth pressure and rain water seepage. 'Habaki' stone wall was built at the foot of stone walls in order to restrain the deformation of the walls, as shown in Fig. 2b.

Figure 3 shows a schematic of a cross section of typical stone wall at the Marugame castle. A stone wall composed of a wall face stone, a cobble stone zone, backfill and bed rock. The width of the cobble stone zone is assumed to be 1 to 2 m approximately.

Figure 4 shows a measuring situation by MWS on the stone wall and MCS on the cobble stone zone.

3. MICROTREMOR MEASUREMENT

The location of microtremor meters, McSEIS-MT NEO made by OYO Corporation in Japan, are also shown in Figure 3. Microtremor meters were put

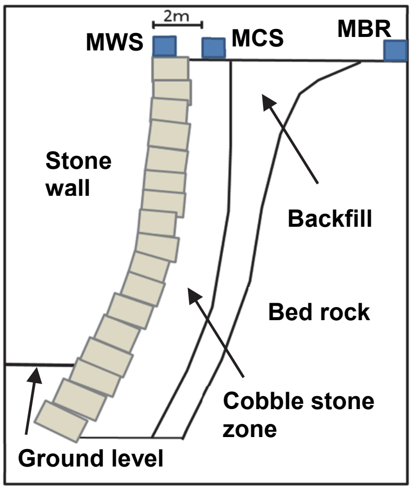


Fig. 3 Schematic of a cross section of a typical stone wall at the Marugame castle

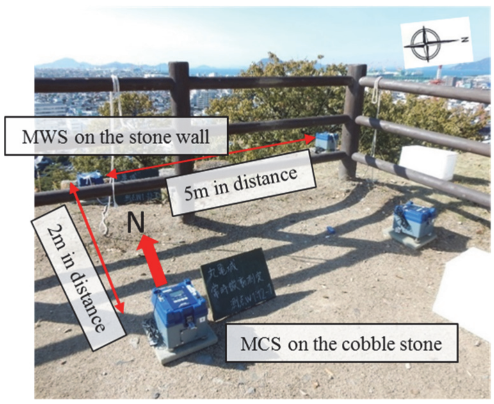


Fig. 4 Measuring by microtremors

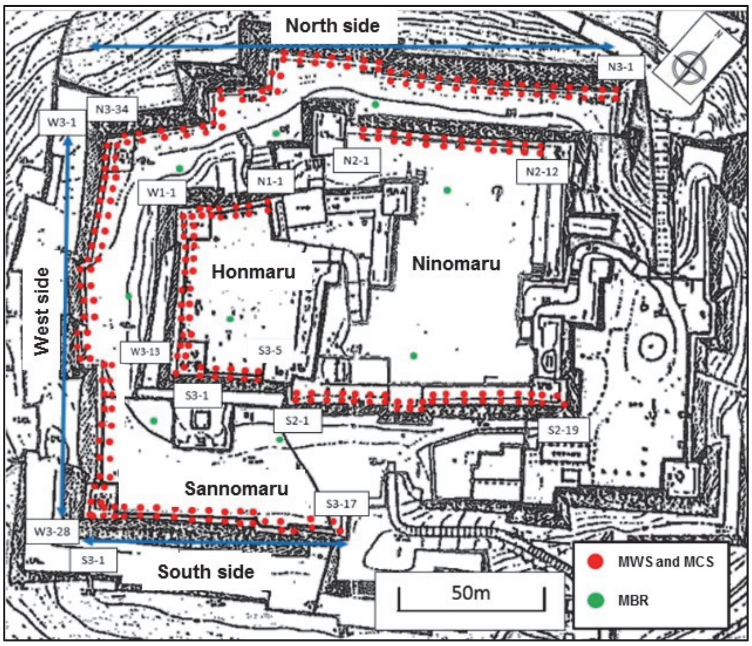


Fig. 5 Location of microtremor meters at the Marugame castle

directly on a wall face stone, a cobble stone and bed rock, which were named as MWS, MCS and MBR in this paper, respectively. The distance between MWS and MCS was 2 m approximately. MBR were typically put on the midpoint between a top of a wall and a toe of a wall behind in order to ensure to be reference point.

Figure 5 shows the planform of microtremor meters location. The numbers of MWS, MCS and MBR are 133, 131 and 9, respectively. The distances of each MWS and each MCS were 5 m approximately.

The data of microtremor were measured at MWS, MCS and MBR at the same time. The measurement time was about 1 hour to avoid effects of vibration of pedestrians.

Microtremors were measured at the geological cliff of the Sendai castle in previous study [6], which showed that the ground motion amplification of the perpendicular direction to the cliff was larger than that of the horizontal direction. Referring to the previous study, N-S direction of a microtremor meter was set to the perpendicular direction to a stone wall in this study, N-S component of microtremors was analyzed mainly in order to observe the motion in perpendicular direction to a stone wall.

4. MICROTREMOR MEASUREMENT RESULTS AND DISCUSSION

4.1 Analysis method of microtremor records

Microtremor records were used to analysis the vibration characteristics of Marugame castle. All

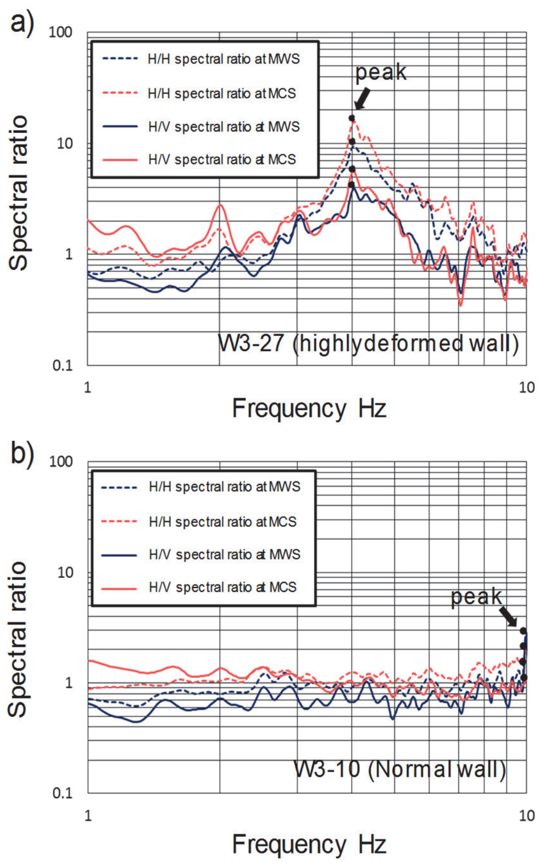
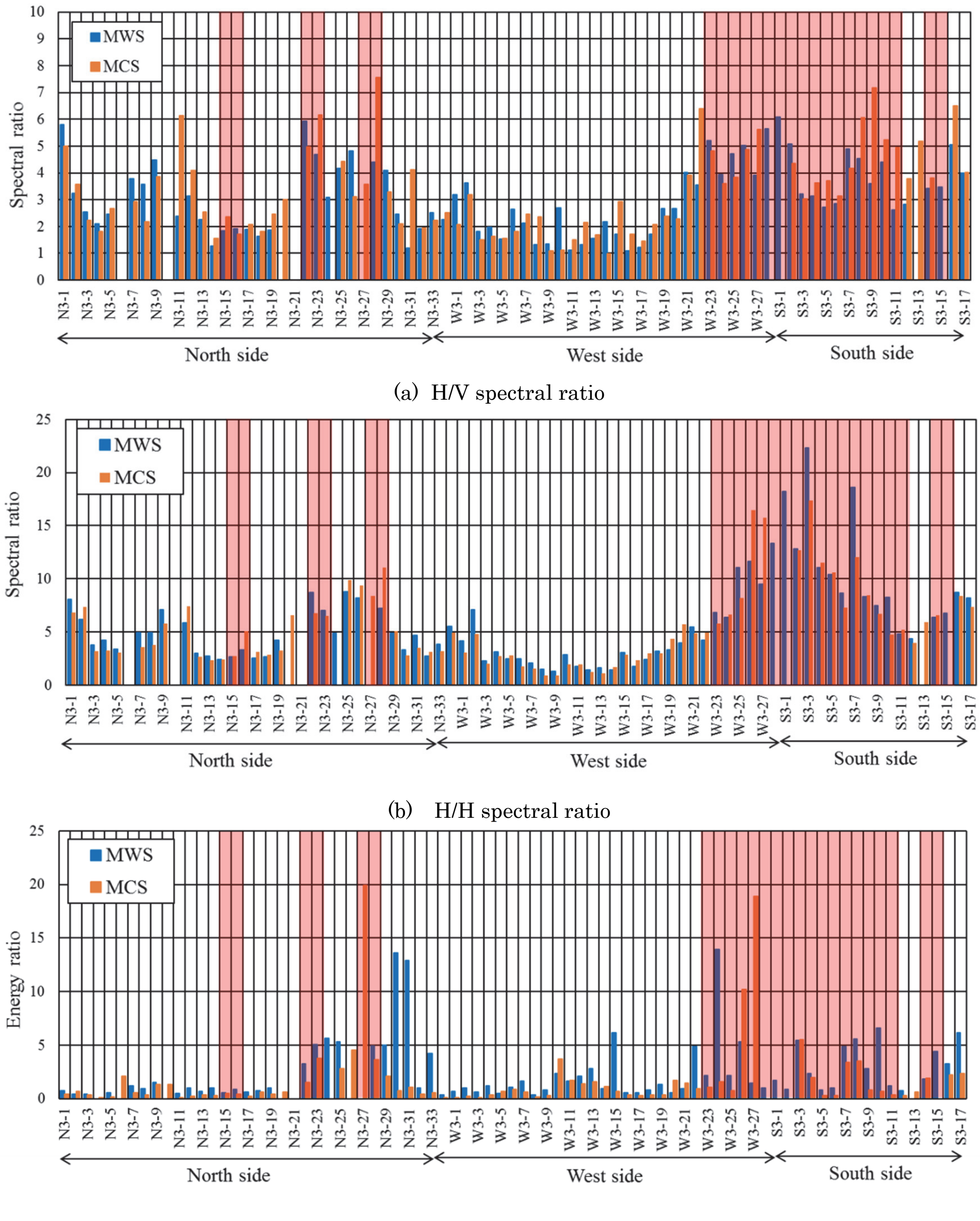


Fig. 6 Typical H/V and H/H spectral ratios obtained at W3-27 a) and W3-10 b)

microtremor spectrum (Fourier amplitude spectrum) were obtained in a frequency range of 1 to 10 Hz, then those were smoothed separately with Parzen window with a band width of 0.3 Hz. In order to found the normalized result explaining clearly the relationships between vibration characteristic and deformation of stone wall, three kinds of normalized result of microtremor records, as H/V spectral ratio, H/H spectral ratio and energy ratio were calculated based on the microtremor records.

4.1.1 H/V spectral ratio and H/H spectral ratio

H/V spectrum is a ratio of horizontal component and vertical component of a Fourier amplitude spectrum in perpendicular direction to a stone wall (NS component of a microtremor). The H/V spectral ratio is the H/V spectrum obtained at MWS or MCS normalized by the H/V spectrum obtained at MBR. The H/H spectral ratio, defined in this study, is horizontal component of a Fourier amplitude spectrum obtained at MWS or MCS normalized by



(a) H/V spectral ratio

(b) H/H spectral ratio

(c) Energy ratio

Fig. 7 Spectral ratio and energy ratio at Sannomaru horizontal component of a Fourier amplitude spectrum obtained at MBR in perpendicular direction to a stone wall.

Figure 6 shows typical spectral ratios of H/V and H/H obtained at 2 sites where the stone walls were judged to be largely deformed (W3-27) and be slightly deformed (W3-10) based on the visual observation in appearance condition. Black circles shown in Figure 6 indicate the peak values of the spectra. The peak values of spectral ratio were obtained in all observation points in the same manner.

4.1.2 Energy ratio

Yamauchi *et al.* [7] pointed out that the value of a Fourier amplitude which was obtained at unstable rock increased in all frequency range before the rock slid down. In order to clarify the increase of the amplitude values which were obtained at unstable stone of a stone wall, the value of energy was obtained by integration of Fourier amplitude spectra of 3 components, vertical and 2 horizontal components. Then the value of energy at MWS or MCS was normalized by the value of energy at MBR, which was defined as energy ratio in this paper.

4.2 Relationship between vibration value and deformed point

Figure 7 (a),(b),(c) show spectral ratios analyzed by three methods for MWS and MCS at the Sannomaru respectively. Measuring points covered with light red mean large deformed point of the stone wall by visual observation survey.

H/V spectral ratio is decreasing at N3-1~N3-14, N3-17~N3-20 and N3-29~W3-21 corresponding to small deformed parts, and increasing at other points corresponding to large deformed parts in Fig.7(a).

From difference of MWS and MCS, large spectral ratio is indicated energy ratio (Fig.7(c)), H/V spectral ratio (Fig.7(a)) and H/H spectral ratio (Fig.7(b)).

For H/H spectral ratio in Fig.7(b), the spectral ratio is small at N3-15 and N-3-16, but these is judged as a deformed part by observation survey.

And when it was judged from a relation between deformation of stone wall and spectral ratio, it can be estimated that H/H spectral ratio is estimated most.

4.3 Comparison of spectral ratios and energy ratio

The results of H/V spectral ratio and H/H spectral ratio are shown in Fig.6 and Fig. 7, respectively. The results measured at highly deformed site and small deformation site were

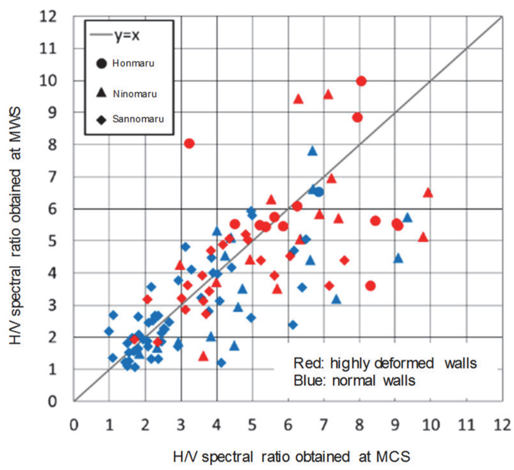


Fig. 8 H/V spectral ratio obtained at MWS and MCS

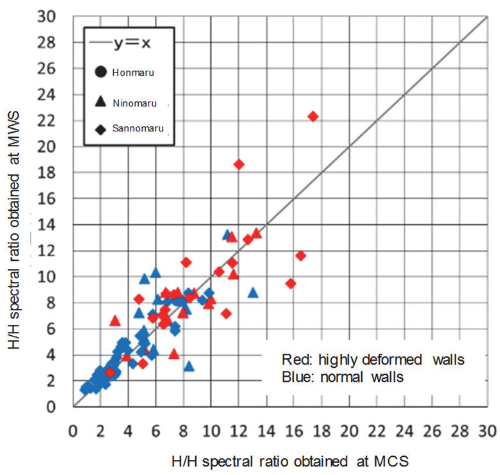


Fig. 9 H/H spectral ratio obtained at MWS and MCS

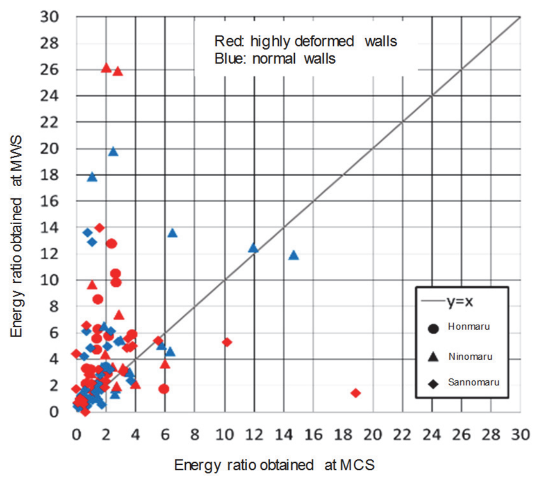


Fig. 10 Energy ratio obtained at MWS and MCS

plotted with red legend and blue legend, respectively.

The value of H/V spectral ratio obtained at highly deformed site was slightly larger than that at small deformation site, while the value scattered widely (Fig.8). A similar trend was observed also in the results of H/H spectral ratio (Fig.9). The variation of the value of H/H spectral ratio was smaller than that of the value of H/V spectral ratio (Fig.8 and 9). The values of H/V and H/H spectral ratio increased with the increase of deformation.

In addition, the value of H/V spectral ratio obtained at Honmaru was larger than those at Ninomaru and Sannomaru (Fig.8). The elevation of Honmaru is higher than those of Ninomaru and Sannomaru. Hence, the value of H/V spectral ratio was affected possibly by the effect of not only deformation but elevation of a measurement point.

On the other hand, the results of H/H spectral ratio were less affected by elevation of a measurement point. Therefore, H/H spectral ratio is assumed to be one of suitable index to extract highly deformed site.

The values of energy ratio obtained at all measurement points are shown in Fig. 10. The value of energy ratio obtained at MWS varies widely and is totally larger than that obtained at MCS. This trend explains the amplitude of micromotion at MWS is larger than that at MCS. The value of MWS which is remarkably large compared with the value of MCS might suggest existing of unstable stone in the stone wall. However, it is difficult to use the value of energy ratio for extraction of a deformed part of a stone wall.

4.4 Extracting method of a deformed stone wall by using H/H spectral ratio

As described above, the value of H/H spectral ratio was assumed to be one of an index to extract highly deformed site. The value of H/H spectral ratio was compared with the deformation state of a stone wall in order to conform the availability of this value.

Figure 11 shows the location of deformed stone wall. The 40 % of the whole stone walls was judged as highly deformed by visual observations.

Based on this rate, upper 40 % of the value of H/H spectral ratio was assumed to be obtained at the highly deformed wall. The lower threshold value of H/H spectral ratio including upper 40 % was obtained as 7.5 in cases of MWS and 7.0 in case of MCS, then the threshold value was set to 7.5 or 7.0 to extract highly deformed wall. Figure 11 also shows the distribution of the threshold value of H/H spectral ratio. The measurement points were classified into 3 types, both values over 7.5 at MWS and 7.0 at MCS (red circle), one value over 7.5 at MWS or 7.0 at MCS (yellow circle) and values under 7.5 at MWS or 7.0 at MCS (blue circle). The number of red circle, yellow circle and blue circle was 42, 19 and 65, respectively.

The deformed walls were observed at 31 sites in 42 red circles, 11 sites in 19 yellow circles and 15 sites in 65 blue circles. When the both value of H/H spectral ratio exceed 7.5 at MWS and 7.0 at MCS exceed 4.0, the stone wall under the measurement point was highly deformed with a probability of about 74 %. This result suggest the deformed walls

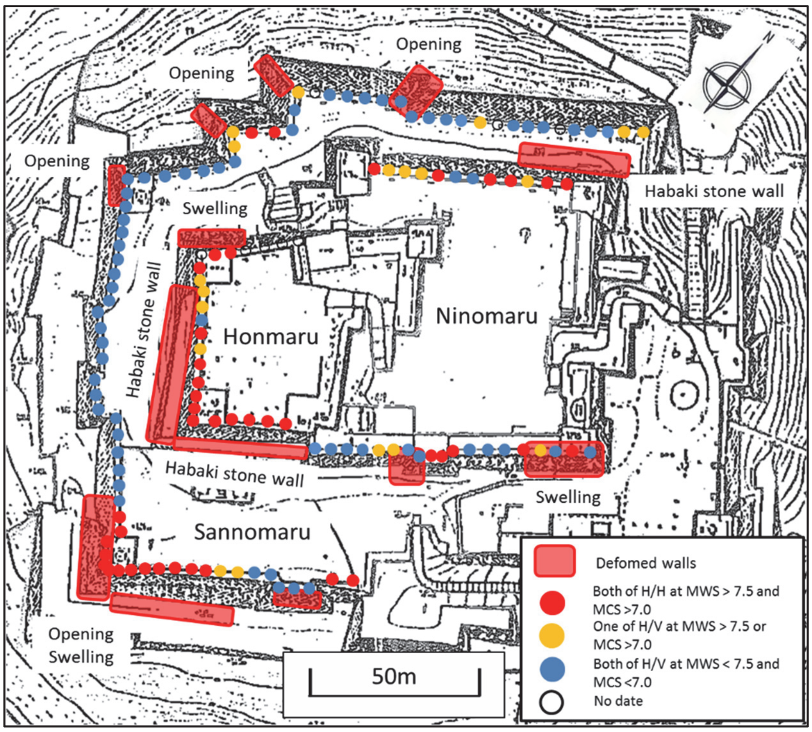


Fig. 11 Location of deformed wall and the distribution of the thresholded value of H/H ratio

are extracted roughly by the value of H/H spectral ratio and adequate threshold value. Further study is required to reveal the setting method of threshold value.

5. CONCLUSIONS

In this study, microtremors were measured at the stone wall of Marugame castle in order to evaluate vibration characteristics of deformed or non-deformed stone wall. The following conclusions could be derived from the results of the microtremor measurement.

1) The values of H/V spectral ratio scattered widely and slightly increased with the increase of the deformation. The value of H/V spectral ratio was also affected possibly by the effect of the elevation of a measurement point.

2) The values of H/H spectral ratio increased with the increase of deformation. In addition, the values of H/H spectral ratio were less affected by the elevation of a measurement point.

3) The H/H spectral ratio is a suitable index to indicate the deformation level of a stone wall. The deformed walls are extracted by the value of H/H spectral ratio and adequate threshold value at the Marugame castle. When the both values of H/H spectral ratio exceed 7.5 at MWS and exceed 7.0 at MCS, the stone wall might be highly deformed with a probability of about 74 %.

4) It is difficult to use the value of energy ratio for extraction of a deformed part of a stone wall because the value scattered widely.

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