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EMBANKMENT MATERIAL CHARACTERISTICS AT AGRICULTURAL RESERVOIR DAMAGED BY THE 1983 MIDDLE JAPAN SEA EARTHQUAKE IN AOMORI PREFECTURE

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ABSTRACT: We used a geographic information system to reconsider factors leading to damage of agricultural reservoirs in Aomori Prefecture during the 1983 Middle Japan Sea Earthquake considering damaged reservoirs, topographical and geotechnical conditions, embankment and foundation ground materials, and reservoir ledgers. Results implicated the combined materials of embankments and foundations in damage to the reservoirs. The percentage of damage occurrence being attributable to sandy soil material was particularly high, and it was caused by the influence of liquefaction.

Keywords: Agricultural reservoir, Geographic information system, Buffer range,
The 1983 Middle Japan Sea Earthquake, Aomori Prefecture

1. INTRODUCTION

Earth dams of less than 15 m embankment height are classified as agricultural reservoirs of small earth dams for irrigation by agricultural land improvement project design guidelines1). Of Japan's approximately 170,000 agricultural reservoirs, about 1,800 agricultural reservoirs are in Aomori Prefecture, where our university is located2). But the construction age and foundation ground materials remain unclear. Agricultural reservoirs are concentrated in northwestern regions where the Iwaki River flows through the Tsugaru plain, and the eastern region has many rivers flowing into the Pacific Ocean (refer to Fig. 1). Since the agricultural reservoirs were constructed, many earthquakes broke out and many disasters occurred every time in Japan. Reportedly, damage to agricultural reservoirs was investigated in earnest after the 1939 Oga earthquake4). Damage from cracking and settlement was sustained by more than 100 agricultural reservoirs in Aomori Prefecture during the 1983 Middle Japan Sea Earthquake. The percentage of damage occurrence in cases where the embankment and foundation ground materials of agricultural reservoirs were sandy soil was particularly high. Therefore, investigation of topographical and geotechnical conditions around the damaged agricultural reservoirs is expected to be an important for assessing the earthquake resistance of each structure5). In addition, danger attributable to slope damage, spillway cracking, and similar factors was found in about 20% of 1300 agricultural reservoirs surveyed in a simultaneous investigation (2013–2014) conducted in

Aomori Prefecture[2]. The report was reconsidered to compare the existing agricultural reservoir distributions, embankment material characteristics and other factors using a geographic information system (GIS) with the agricultural reservoirs damaged in Aomori Prefecture during the 1983 Middle Japan Sea Earthquake.

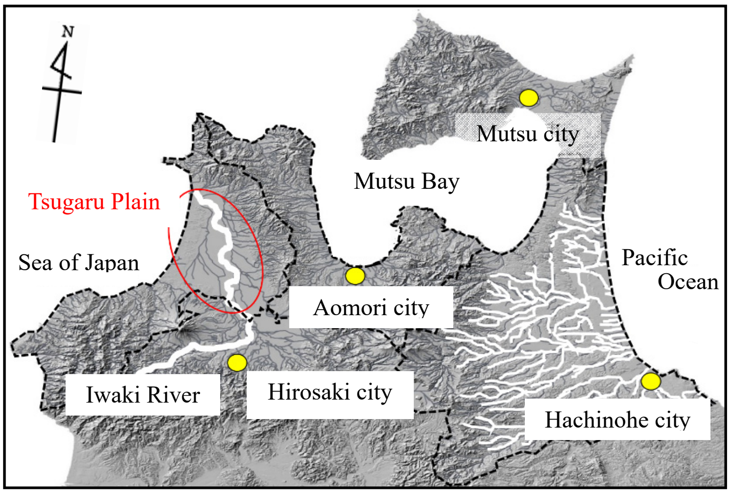

Fig. 1 Geographic map in Aomori Prefecture
[Reference 3) with partial revision]

2. EMBANKMENT MATERIAL AND FOUNDATION GROUND MATERIAL CHARACTERISTIC OF AGRICULTURAL RESERVOIR BY GIS

Figure 2 shows a ground surface geological classification map in Aomori Prefecture. The un-solidified sediment of an alluvium in the northwestern region with Iwaki River flowing through the Tsugaru Plain, the sand-fill area between Mt. Byobu on the western side of the Tsugaru Plain and the Sea of Japan and the volcanic rock sediment including loam and pumice on the eastern side with many rivers flowing into the Pacific Ocean, are accumulated.

Figure 3 shows the presumed seismic intensity distribution[7] and damage distribution map of agricultural reservoirs[8] on a ground surface geological classification map shown in Fig. 2 in the 1983 Middle Japan Sea Earthquake. It indicates the seismic intensity $V^- – V^+$ at the Tsugaru Plain area stretch

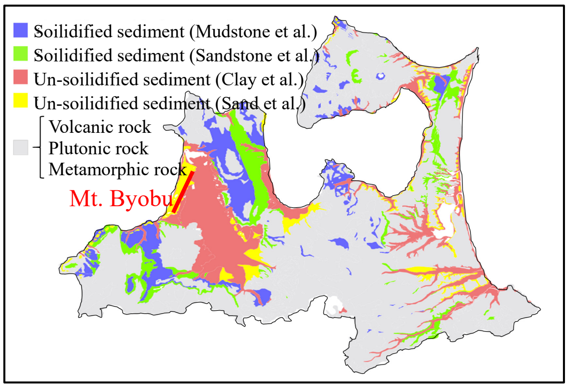

Fig. 2 Ground surface geological classification map [Reference 6) with partial revision]

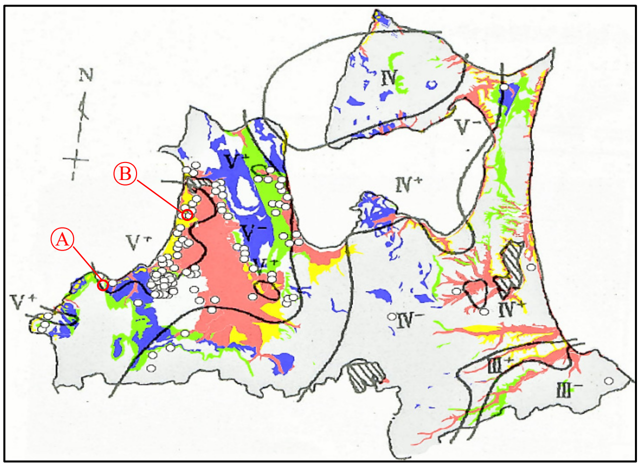

Fig. 3 Presumed seismic intensity distribution and damage distribution map of reservoirs [Reference 6) with partial revision]

and shows that about 70% of damaged agricultural reservoirs are distributed throughout the northwestern region. It particularly shows the seismic intensity V^+ at the sand-fill area between Mt. Byobu on the western side of the Tsugaru Plain and the Sea of Japan. The damaged agricultural reservoirs around the sand-hill area tended to be concentrated. Consequently, influences of the surrounding topography and geological condition including the strength of seismic intensity, might be related to the damage factor sustained by agricultural reservoirs.

Photo 1 shows the example of an agricultural reservoir damaged by the 1983 Middle Japan Sea Earthquake at location Ⓐ indicated in Fig. 3[9)]. Because the cracks on the embankment occurred and the sticking block slid down, it was assumed that the ground surface geological feature was in the area where grain particles were large as sandstone in (semi) solidified sediment.

Photo 2 shows the example of a large sand boil in a paddy field damaged by the 1983 Middle Japan Sea Earthquake at location Ⓑ indicated in Fig. 3[9)]. Damage done by sand boil was reported around this area where the ground surface geological feature was sand-fill. We inferred that a main factor of damaged agricultural reservoir was liquefaction of the foundation ground.

Photo 1 Cracks on the embankment and sliding of the sticking block [Reference 9)]

Photo 2 Large sand boil [Reference 9)]

Figure 4 shows a cross section of Kasube-numa Reservoir damaged by the 1983 Middle Japan Sea Earthquake at location Ⓑ indicated in Fig. 3[8)]. Under this damage condition, as the settlement of upstream side of embankment and 2 – 3 axial cracks on crest occurred, about 1.5m of crest settlement was reported[8)]. From the soil boring log shown in Fig. 5, because this reservoir had both the embankment material and foundation ground material of sandy soil, we inferred liquefaction once more as the main cause of damage.

Figure 6 shows a construction age distribution map of agricultural reservoirs as a percentage of the number of all reservoirs. Because approximately half of these data were unclear (+), we assumed these data to be old and that the reservoirs would not be in operation. In fact, agricultural reservoirs constructed before the Edo Period (●) including the Unclear Period (+) were numerous in the northwestern region of Tsugaru area. However, new agricultural reservoirs (○・■・▲) constructed after the Meiji Period are distributed widely throughout the eastern region facing the Pacific Ocean. After development of new paddy fields in the early stage started at an alluvial plain (Tsugaru Plain) with the Iwaki River, it might be inferred that the plowed-land development in the eastern region advanced with modern construction technology and widening influence of farm machinery to enter the Meiji Period. A change was apparent in the development of a new paddy field in Aomori Prefecture[11)].

Figure 7 shows a form distribution map of agricultural reservoirs by the percentage to the number of total reservoirs. Although about 60% of these data were unclear (+), the percentage of agricultural reservoirs with valley-type form was slightly greater than those with saucer-type form. Additionally, the agricultural reservoirs with saucer-type form are be distributed over both sides of east and west of the Tsugaru Plain. Agricultural reservoirs with valley-type form are distributed along a boundary line with the diluvial upland in the east and widely in a mountainous area of the eastern region facing the Pacific Ocean side.

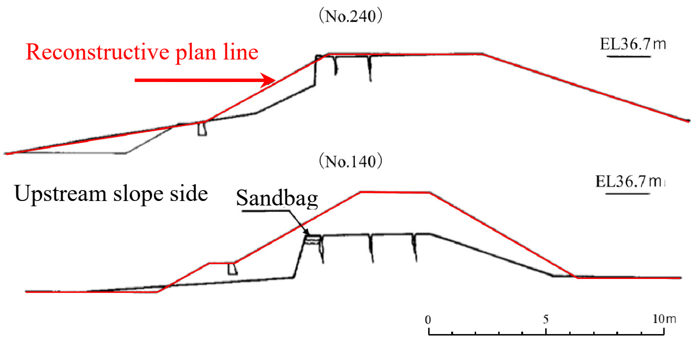

Fig. 4 Cross section of damaged Kasube-numa Reservoir [Reference 8) with partial revision]

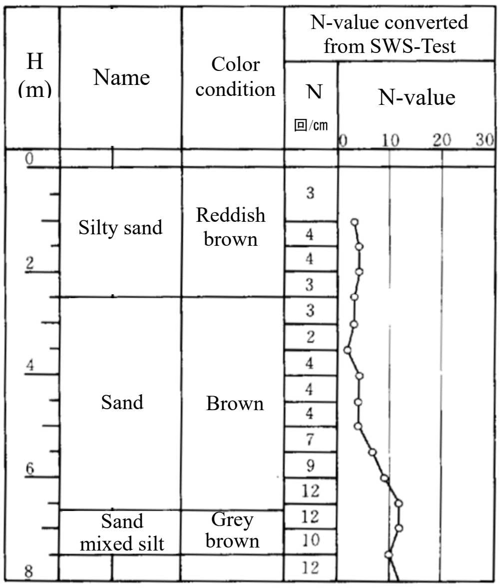

Fig. 5 Soil boring log (No.140) of Kasube-numa Reservoir [Reference 8) with partial revision]

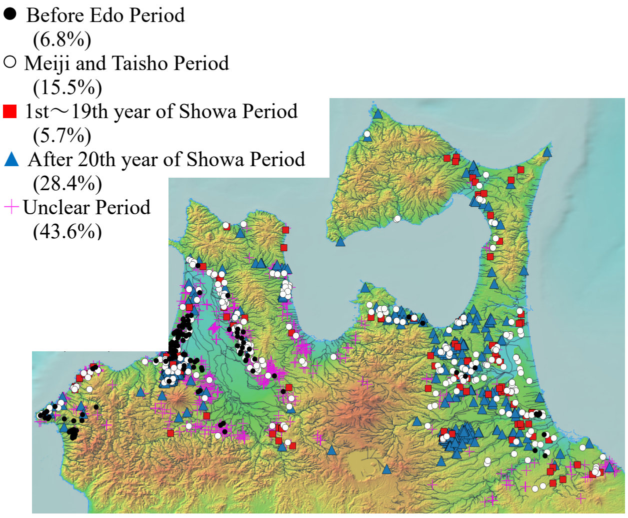

Fig. 6 Construction age distribution map [Reference 10) with partial revision]

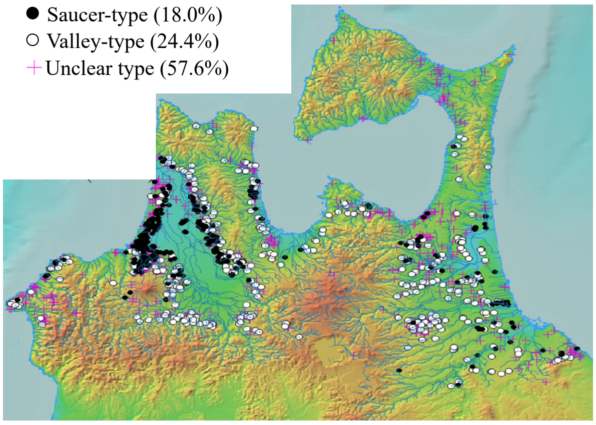

Fig. 7 Form distribution map of reservoirs [Reference 10) with partial revision]

Figure 8 shows an embankment material distribution map of agricultural reservoirs as a percentage to the total number of reservoirs on the ground surface geological classification map indicated in Fig. 2. Agricultural reservoirs with clay embankment material (●) are distributed widely throughout all of Aomori Prefecture, but agricultural reservoirs with sand embankment material (○) are distributed widely throughout the northwestern region and done in the sand-fill area in the Sea of Japan side of the Tsugaru Plain and sandstone facing Mutsu Bay. Furthermore, agricultural reservoirs with sand embankment material account for about 20% of the whole. The possibility of damage exists at those places even when examined based on a seismic hazard of the past[5), 9)].

Figure 9 shows a foundation ground material distribution map of agricultural reservoirs by the percentage to the number of total reservoirs on the ground surface geological classification map indicated in Fig. 2. Although high-precision investigation is difficult to conduct according to the foundation ground material of agricultural reservoirs, it is often almost the same material as the embankment material in comparing with Fig. 8. Much of the embankment material had probably been used as foundation ground material around the agricultural reservoirs. Therefore, as foundation ground materials of agricultural reservoirs with sand embankment materials might consist of sandy sediment by a high probability, there would be fear of influence of liquefaction of foundation ground materials from now on.

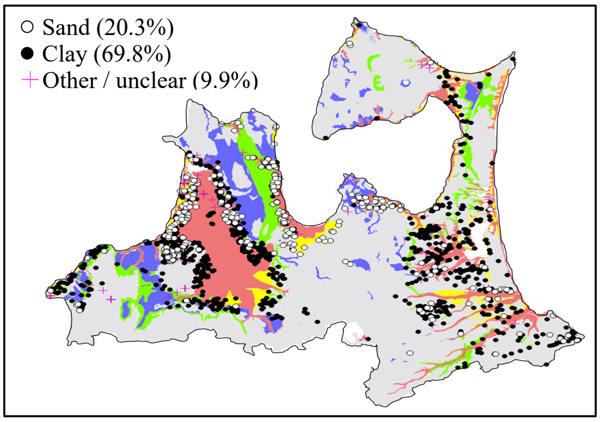

Fig. 8 Embankment material distribution map [Reference 6) with partial revision]

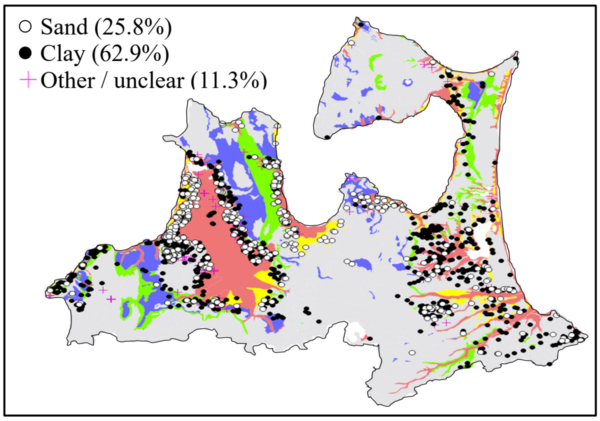

Fig. 9 Foundation ground material distribution map [Reference 6) with partial revision]

Figure 10 shows each material combination with the embankment material (sand or clay) and foundation ground material (sand or clay) as a percentage of all reservoirs. Although the material combination (a) by which both the embankment material and foundation ground material are clay is about 60%, the material combination (b) with sand–sand is also about 17%. Investigation of these combination percentages in other prefectures from basic documents must be done to elucidate the leakage damage occurrence attributable to embankment materials and to assess liquefaction damage exacerbated by the foundation ground material.

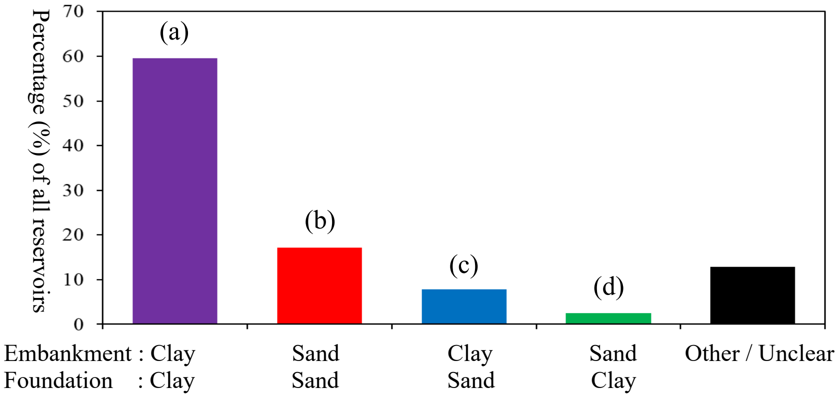

Fig. 10 Each material combination with the embankment and foundation ground

Figure 11 shows the construction age distribution maps of each material combination as a percentage of all agricultural reservoirs, and the percentages of the respective material combinations in respective age periods are also indicated in Fig. 11. In Fig. 11(a) indicating the clay–clay material combination of embankment material and foundation ground material, many agricultural reservoirs constructed before the Edo Period (●) including the unclear period are situated in western regions, and reservoirs constructed after the Meiji Period (○) are widely distributed throughout the eastern region. In Fig. 11(b) indicating the sand–sand material combination of embankment material and foundation ground material, the agricultural reservoirs constructed both before the Edo Period and after the Meiji Period are situated around the Tsugaru Plain in the northwestern region, and the percentage (about 15%) of agricultural reservoirs constructed only in this age before the Edo Period was lower than that (about 19%) after the Meiji Period in this only age after the Meiji Period. In Fig. 11(c) indicating the clay–sand material combination of embankment material and foundation ground material, the percentage (about 10%) of reservoirs constructed only in this age before the Edo Period is large in being different from other cases except for Fig. 11(d) which the number of reservoirs is few, and these reservoirs are around the Tsugaru Plain in the western region. Because the foundation ground material was not actually investigated and recorded in the agricultural reservoir ledger, it was often judged from the surrounding topography and geotechnical conditions. The recognition of safety for leakage prevention to reservoirs constructed the embankment using the clay soil before the modern age, however, would be higher than we expected, even if the surrounding ground was the sandy soil material. The number of embankment materials in Fig. 11(d) constructed by sandy soil with a possibility of the leakage is usually small, although the foundation ground material is clay. Consequently, because it is generally easy for fill material to treat sandy soil, the percentage of reservoirs constructed before the Edo Period scarcely shows high technical capabilities of civil engineering works.

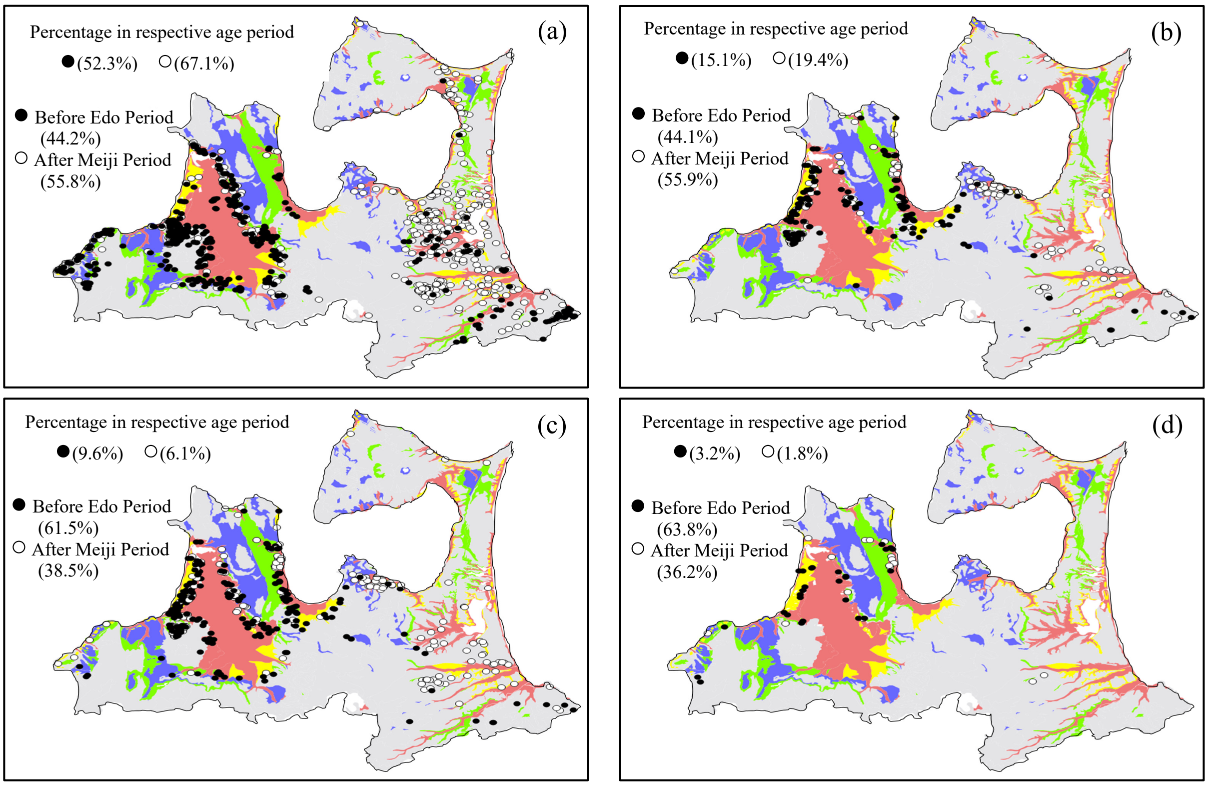

Fig. 11 Construction age distribution map of each material combination [Reference 6) with partial revision]

Figure 12 shows the agricultural reservoirs (○) damaged in the 1983 Middle Japan Sea Earthquake and existing agricultural reservoirs (●) with the respective material combinations indicated in Fig. 10. In Fig. 12(a) indicating the clay–clay material combination of embankment material and foundation ground, although existing reservoirs with the combination in Fig. 12(a) agree with damaged reservoirs in the eastern area of the Tsugaru Plain, they tend to have a low degree of agreement at those in the sand-hill area around concentrating particularly on the western area of the

Tsugaru Plain and sandstone around facing Mutsu Bay. In Fig. 12(b) indicating the sand–sand material combination of embankment material and foundation ground, the existing reservoirs by the combination in Fig. 12(b) agree with damaged reservoirs in eastern and western area of the Tsugaru Plain and sandstone around facing Mutsu Bay, and they do also with the damage reports4), 5), 8), 9) in the those days when both the embankment material and foundation ground material were sandy soil. In Fig. 12(c) indicating the clay–sand material combination of embankment material and foundation ground, although the existing reservoirs by the combination in Fig. 12(c) agree with damaged reservoirs in eastern and western areas of the Tsugaru Plain, they do not agree with those at the northern edge area of the Tsugaru Plain and sandstone around facing Mutsu Bay. Detailed investigations seem necessary for future studies because the possibility exists that Fine Fraction Content (F_C) value of an embankment material authorized as a clay soil by location was high12). In Fig. 12(d) indicating the sand–clay material combination of embankment material and foundation ground, although it is difficult to estimate these values because existing reservoirs with that combination in Fig. 12(d) are few, the continuous verification by GIS is necessary because the possibility exists that including great damage by a pore water pressure rise in the embankment constructed by a sand material.

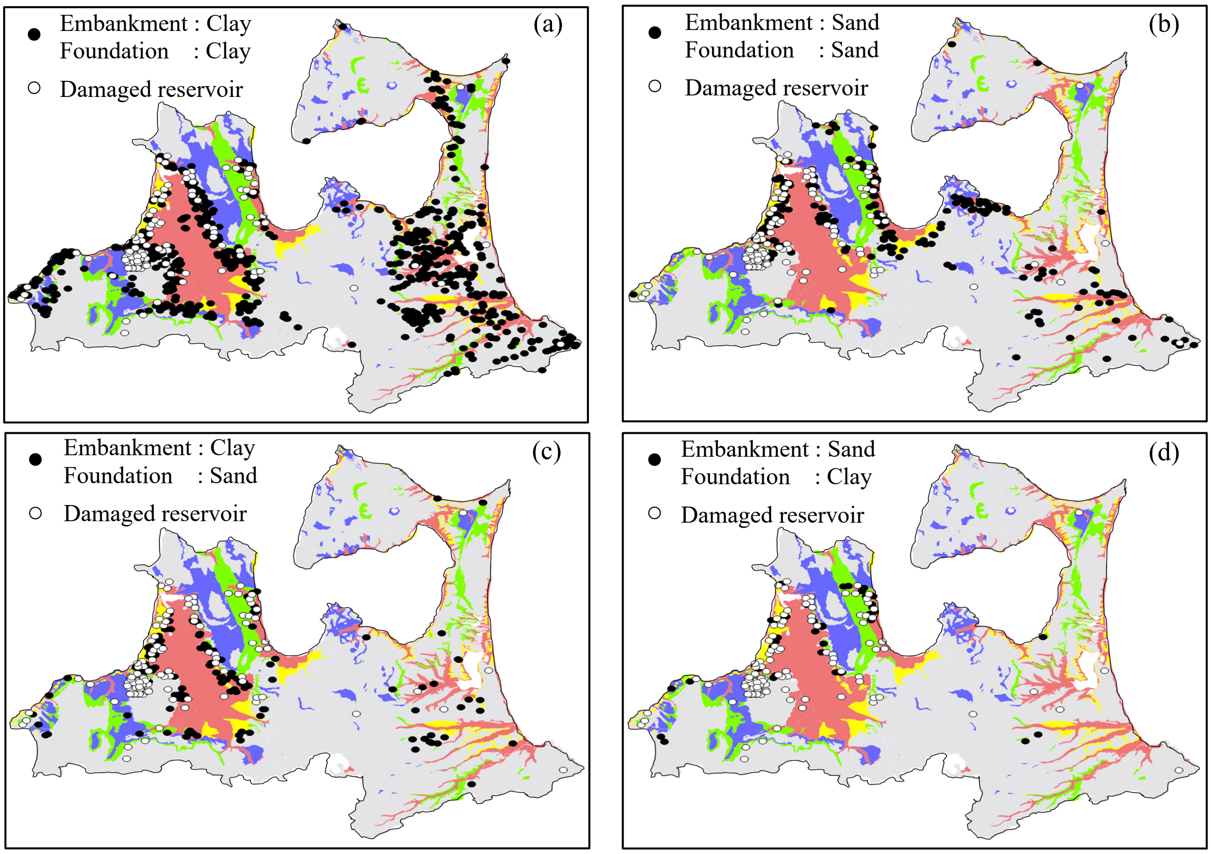

Fig. 12 Damaged agricultural reservoirs and the existing agricultural reservoirs with respective material combination [Reference 6) with partial revision]

Figure 13 shows relations between the buffer radius and buffer range with each material combination when a buffer range is set up at some distance [R (buffer radius) = 100, 250, 500, 750, 1000, 1500, 2000 m] from the center of damage to a reservoir (refer to Fig. 14) for quantitative consideration of the degree of agreement with relations between the agricultural reservoir portions damaged in the 1983 Middle Japan Sea Earthquake and the existing agricultural reservoir portions for each material combination indicated in Fig. 12. These percentages in the buffer range with sandy soil embankment material [(b), (d)] tended to be larger than those with clay soil embankment material [(a), (c)]. The percentage in the buffer range for cases with the sand–sand (b) and clay–sand (d) foundation ground material on bound of R = 1000 m and the percentage in the buffer range for cases with the clay–clay (a) and sand–clay (c) on bound of R = 1250 m, tended to reverse. On carrying out the detailed future investigations of foundation ground material, the impact statement precision can be improved by using the buffer radius (R). We could suppose the damage in the past and the factors such as wide or narrow areas.

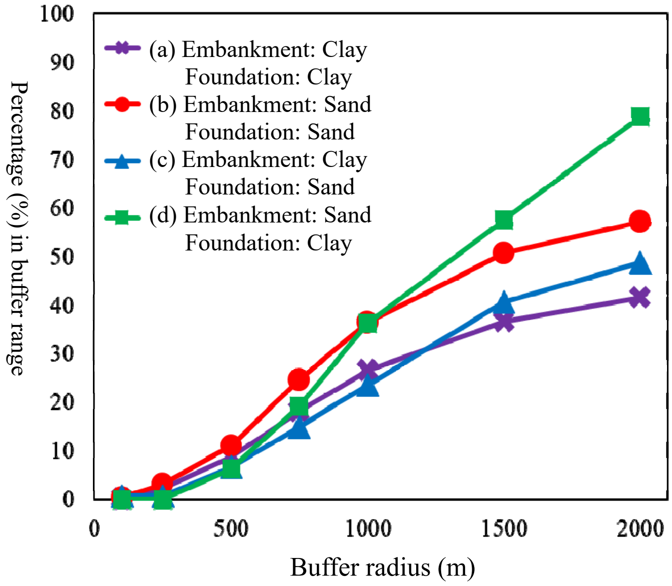

Fig. 13 Percentage in buffer range of damaged reservoir with each material combination

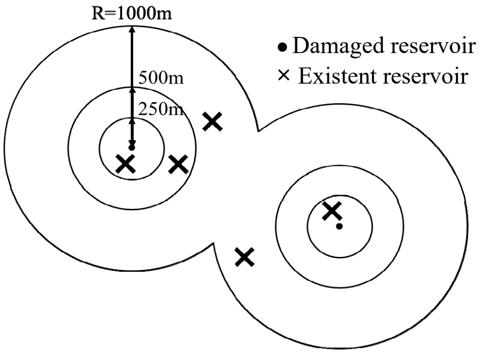

Fig. 14 Example of buffer range

3. CONCLUSIONS

This report presented reconsideration of the damage factors affecting agricultural reservoirs in Aomori Prefecture during the 1983 Middle Japan Sea Earthquake by GIS using the topographical and geotechnical condition and the embankment and foundation ground materials from reservoir ledgers. Many damage agricultural reservoirs in Aomori Prefecture during the 1983 Middle Japan Sea Earthquake were in the northwestern region with the Iwaki River Basin, and they was concentrated particularly around the sand-fill area along the Sea of Japan side on boundary of Mt. Byobu at the western side of the Tsugaru Plain. Therefore, the possibility of main cause of the damage factor could be reconfirmed as liquefaction of the foundation ground material.

From the findings presented above, the damage factor of agricultural reservoirs in Aomori Prefecture on the 1983 Middle Japan Sea Earthquake was considered to cause from material combinations of embankment and foundation ground used for reservoir construction. Particularly, results indicated that the percentage of damage occurrence using a sandy material was high, and this was regarded as deriving from liquefaction induced in a sandy soil layer.

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