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Characteristics of multi strike surface strength of stones, concrete and bricks used for historical structures since Meiji era in Japan

Abstract. Historical structures are part of the heritage humankind hands down to posterity. As records, they not only describe past construction technologies, but they also carry information about the social system and culture of their time. Many historical civil engineering structures constructed during and after the Edo era still remain in Japan. Some of these structures, such as the Yokosuka dry docks, played an important role in the fate of the nation (Shogaki, 2014). However, such sites have not been the subject of systematic geotechnical research or publicity. The strength of construction materials at historical sites built since the Meiji era was investigated using the rebound hammer test (JGS 2013) and evaluated with regard to construction age, facility use, and material. The tested materials were rocks (andesite, granite, and sandstone) at 10 sites, concrete at 6, and brick at 3.

Keywords: historical civil engineering sites, construction materials, Meiji era, rebound hammer test, strength.

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Introduction

Historical structures are part of the heritage that humankind passes on to posterity. As historical records, these structures do not only describe historical construction technologies, but also carry information with regard to the social structure and culture at the time of their construction. Many historical civil engineering structures constructed during and after the Edo era still exist in Japan. Some of these structures, such as the Yokosuka dry docks, played an important role in Japan's history (Shogaki, 2014). However, such sites have not received publicity nor have they been the subject of systematic geotechnical research, and very few systematic studies have been concerned with technical changes and the lost reality of historical civil engineering structures. Additionally, the cultural value of these structures has not been considered. Moreover, the restoration of historical structures is carried out with an incorrect perspective and research methodology regarding the conservation and repair work of historical civil engineering infrastructure. Evaluation and repair methods for the civil engineering heritage of each historical era are necessary, but not sufficient to study the progress of technology, including the complete understanding of technical documents.

The surface strength of concrete obtained from a rebound hammer test (RHT) is smaller than the concrete's interior strength. In this study, a new method of estimating the interior strength from the results of six hits at the same position is proposed. The strength of construction materials found at historical sites built since the Meiji era was investigated using the RHT and evaluated with regard to construction age, facility use, and materials.

Target site facilities and testing method

Figure 1 shows the site locations and Table 1 lists the site facilities dating back to 1884. The location of these facilities ranges from Otaru in Hokkaido to Misumi in Kumamoto prefecture, and most facilities are concentrated in the Kanto region. The RHT is specified by the Japanese Geotechnical Standards (JGS,

2013) as more than nine hits in an area of 15-50 cm, and the unevenness of the tested surface must be adjusted to less than 1 mm. However, the target facilities cannot allow multi-point measurements and surface processing because they are part of Japan's historical heritage and/or country-specific cultural properties. Therefore, in this study, the location representing the target material was determined visually and six hits were made at the same position. The strength (SR) values obtained from the RHT, with the exception of the measured values affected by unevenness, were averaged to obtain the mean value. The RHT was hit in the vertical direction of the measured surface and the SR was converted in the direction of the hit according to JGS (2013). The tested materials were rocks (andesite, granite, and sandstone) at 10 sites, concrete at six sites, and brick at three sites.

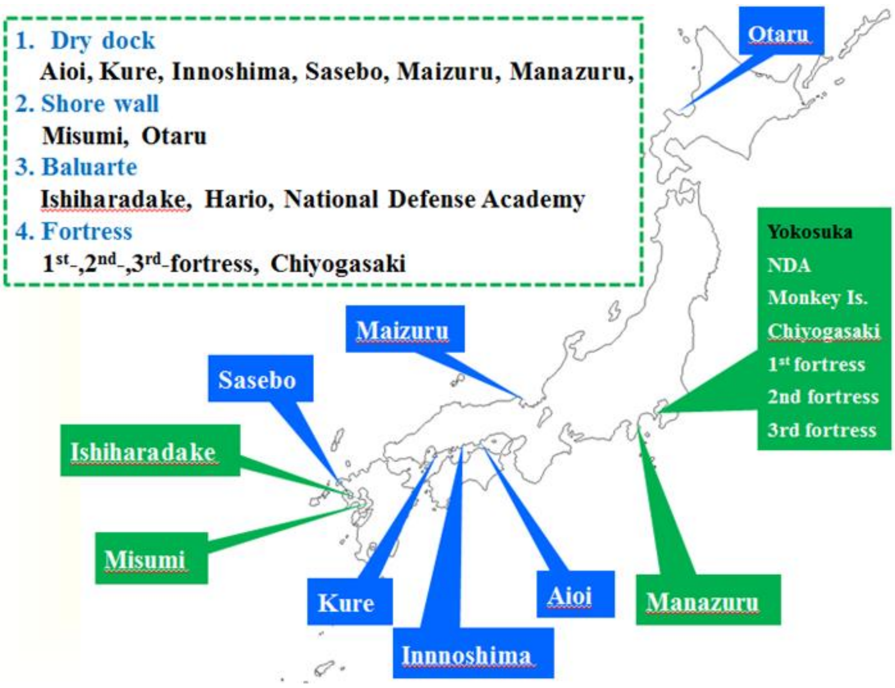

Figure 1. Site locations

Table 1

Outline of site facilities

Prefecture	No	Name of facility	Material	Construction year	Facility use
Kanagawa	1	Monkey turret	A,C,B	1884	Turret
Chiba	2	1st fortress	A,C,B	1890	Turret
Kanagawa	3	Chiyogasaki Turret	A,C,B	1895	Turret
Nagasaki	4	Ishiharadake Baluarte	A,C,B	1899	Fortress
Kyoto	5	Maizuru	granite	1901	dry dock
Hyogo	6	Aioi dock	sand stone	1912	dry dock
Kagawa	7	Innoshima dock	granite, C	1912	dry dock
Chiba	8	2nd fortress	concrete	1914	Turret
Kanagawa	9	3rd fortress		1921	Turret
Nagasaki	10	Hario sending station		1922	Sending station
Hokkaido	11	Otaru Canal	granite	1923	Revetment
Kanagawa	12	Building No.5	concrete	1955	Research Building
	13	4 Brigade		206	Student Building
	14	1 Brigade		2012	Student Building
	15	Student Cafeteria		2013	Canteen
	16	Public bath		2017	Bath
Hiroshima	17	Kure dock	granite	2017	keel blocks
Nagasaki	18	Sasebo dock	granite	2017	keel blocks
Kanagawa	19	Manazuru	andesite	Origin	quarry

A: andesite, C: concrete, B: brick

Method of estimating interior strength of concrete

The S_R values for concrete are plotted against the hits obtained from the Chiyogasaki turret, Hario sending station, Monkey turret, National Defense Academy, and third fortress, as shown in Fig. 2. The S_R increased as the number of hits increased until it became constant after several hits, regardless of the facility. The smaller S_R values at the first hit reflect the surface weathering, slack layer hardness of the surface, and unevenness. Fig. 3 shows the relationship between the ratio (S_R/S_R) of the mean value (S_R) (converged strength) to S_R, and the hits for the upper part of the third fortress' searchlight. The S_R/S_R values for the first hit were in the range of 1.2-1.8 and the mean value $(S_R/ S_R)_m$is 1.4. For the second and third hits, these values are 1.2-1.4 ($(S_R/ S_R)_m$=1.2) and 0.9-1.2 ($(S_R/ S_R)_m$=1.0), respectively. However, after four strikes, $(S_R/ S_R)_m$ was approximately equal to one. The converged strength was approximately equal to the inside strength of the concrete (Inaba and Shogaki, 2018). Therefore, more than four strikes were required to obtain the interior strength of the concrete. As shown in Fig. 3, $(S_R/ S_R)_m$ can be used as a modified value to obtain the interior strength by multiplying $(S_R/ S_R)_m$ with the S_R of each hit.

The $(S_R/ S_R)_m$ values for each hit were obtained from the observation station, artillery side, and searchlight facilities of the third fortress, and are listed in Table 2.

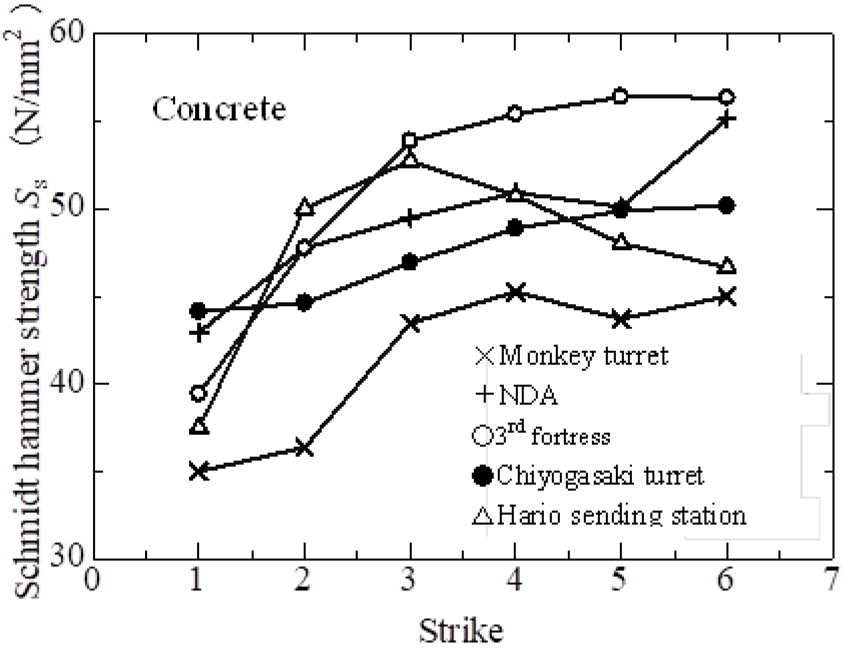

Figure 2. Relationship between S_R and hits

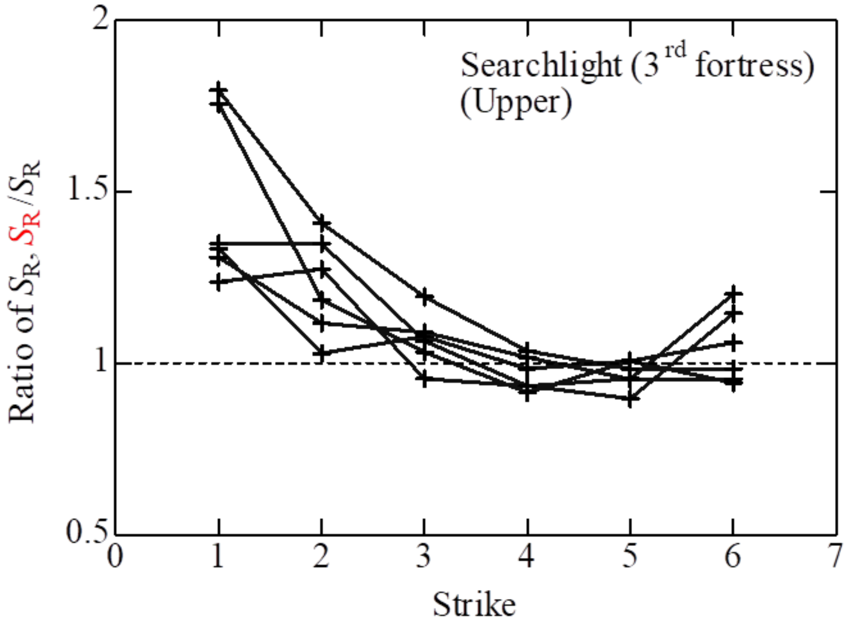

Figure 3. Relationship between S_R/S_R and hits (concrete)

Table 2

(S_R/ S_R)$_m$ for each hit (third fortress)

		Strike	1	2	3	4	5	6
Mean value of $\bar{S}_R/S_R$	Observation station	Upper	1.35	1.15	1.08	0.99	1.02	0.99
		Lower	1.50	1.21	1.05	1.06	1.09	0.96
	Artillery side	Upper	1.36	1.11	0.98	1.04	1.00	1.00
		Lower	2.09	1.53	1.15	1.07	0.96	0.97
	Searchlight	Upper	1.53	1.3	1.06	0.95	0.96	1.10
		Lower	1.32	1.07	1.08	1.00	0.98	0.95

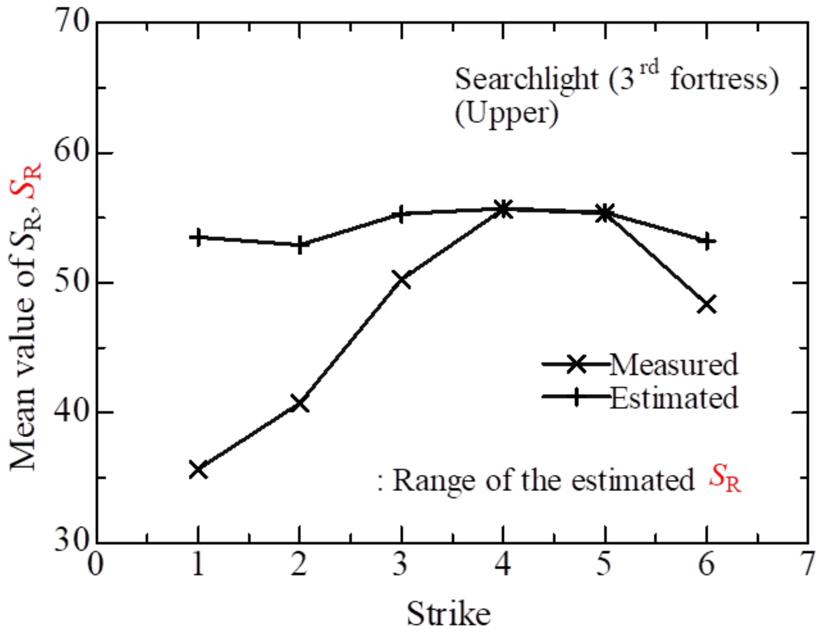

Figure 4. Measured and estimated S_R values

where "upper" and "lower" refer to the facilities' surface and underground structures, respectively. At 3-6 hits, the (S_R/ S_R)$_m$ became equal to one. The interior strength of the concrete can be estimated by multiplying the value in Table 2 with the S_R of each hit. As an example, for the searchlight obtained from Table 2, the measured and estimated S_R values of the concrete's interior strength were plotted against the hits as shown in Fig. 4. For up to three hits, the validity of the results with regard to the estimated interior S_R value can be understood visually. Moreover, a similar tendency has been confirmed for other facilities. Subsequently, the S_R values of the materials will be used to estimate the interior strength.

Changes in strength of concrete

The statistical values of S_R for concrete are shown in Table 3. The S_R, σ, and VS_R refer to the mean S_R value, standard deviation, and coefficient of variation, respectively. As shown in Table 3, the S_R values are plotted against the construction year from Fig. 5. The S_R values for the first fortress (+), the Monkey turret (×), Innoshima dry dock (▲), and Aioi dry dock (△), which are ports outside of the facilities' mainbody (+, ▲ and △) and the part of a weathered facilities (×), the S_R values were smaller than those of other facilities. With the exception of these facilities, the plots exhibited a trend of falling right, and the S_R values of older facilities are greater. The dotted line shown in Fig. 5 indicates the 1995 Southern Hyogo Prefecture Earthquake (1995SHPE), and the design changes to the structure is not influenced to the strength of the concrete.

Table 3

Statistical S_R values for concrete

Facility	Site	n (site)	S_R(N/mm^2)	σ	VS_R(%)
3rd fortress	Observation station	66(11)	54.1	8.8	16.3
	Artillery side	66(11)	50.0	10.4	20.8
	Searchlight	36(6)	50.0	10.5	20.9
	All	168(28)	51.6	9.7	18.7
Monkey turret	handhall	6(1)	15.9	2.8	17.3
	2nd Battery	19(3)	47.2	4.7	10.0
	1st Battery	21(3)	37.8	6.3	16.7
	3rd Battery	13(2)	38.7	6.3	16.3
	All	59(9)	38.8	10.4	26.8
1st fortress	All	89(15)	29.9	12.3	41.1
Chiyogasaki turret	All	204(34)	47.9	10.5	22.0
Ishiharadake Baluarte	All	18(3)	58.2	5.4	9.3
Aioi dock	All	11(4)	23.6	2.4	10.0
Innoshima dock	All	7(2)	31.3	18.2	58.0
Hario sending station	2nd tower	27(4)	40.6	7.8	19.2
	3rd tower	16(3)	50.0	8.9	17.8
	All	43(7)	44.5	9.1	20.3
NDA	1 Brigade	66(11)	39.6	12.3	31.0
	2 Brigade	30(5)	54.5	5.0	9.1
	Building No. 5	24(6)	39.9	11.1	28.0
	Public bath	6(1)	32.4	6.2	19.2
	Student Cafeteria	6(1)	35.6	3.8	10.6
	4 Brigade	30(5)	49.5	6.5	13.2
	All	138(23)	44.5	11.7	26.3

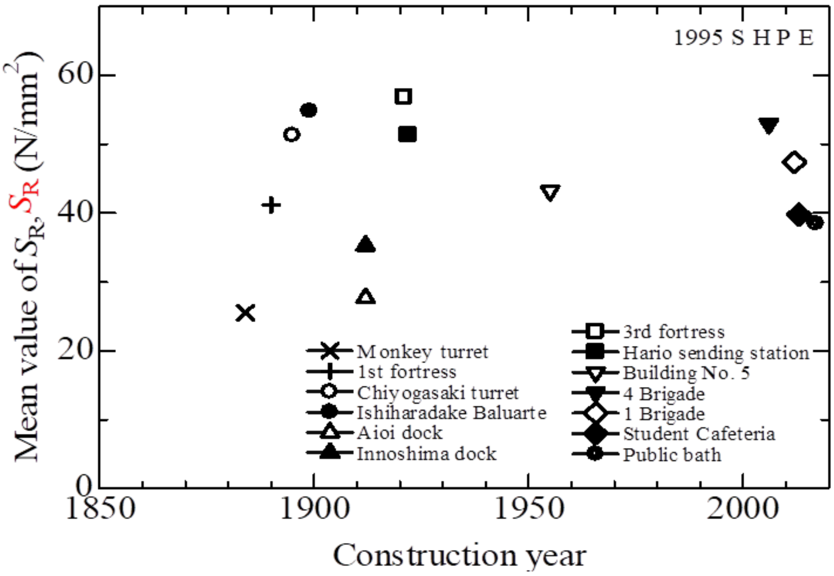

Figure 5. Relationship between S_R and construction year (concrete)

Table 4

Statistical SR values for stones

Facility	Site	Material	n (site)	S_R(N/mm^2)	σ	VS_R(%)
Monkey turret	Eletric lamps	andesite	31 (5)	54.6	8.8	16.2
	1st Barrack	andesite	17 (2)	56.4	9.8	17.3
	2nd Battery	andesite	14 (2)	53.8	9.3	17.4
	2nd Barrack	andesite	25 (3)	56.0	9.4	16.9
	3rd Battery	andesite	13 (2)	54.4	10.6	19.4
	Coast	andesite	31 (4)	60.9	12.0	19.7
	All	andesite	131 (18)	56.5	10.4	18.4
1st fortress	All	andesite	321 (54)	49.8	14.8	29.7
Chiyogasaki turret	All	andesite	87 (14)	58.4	10.5	18.0
Ishiharadake Baluarte	All	andesite	101 (20)	55.1	10.1	18.3
Manazuru	Seawall near 1st dock	granite	22 (4)	55.4	10.8	19.6
	2nd dock	granite	15 (3)	57.9	6.3	10.9
	3rd dock	granite	29 (5)	51.9	8.3	16.1
	Manazuru port seawall	granite	15 (3)	61.0	8.2	13.4
	All	granite	81 (15)	55.6	9.4	16.9
Aioi dock	All	sandstone	32 (11)	60.3	13.0	21.6
Innoshima dock	All	granite	23 (4)	55.2	10.9	19.7
Otaru	All	granite	36 (5)	61.1	8.5	13.9
Kure	Normal finish	granite	39 (10)	49.8	11.4	22.8
Kure	Mirror finish	granite	18 (4)	71.9	3.1	4.3
Sasebo	5th dock	granite	61 (10)	57.9	8.8	15.2
	6th dock	granite	24 (4)	63.3	8.4	13.2
	All	granite	85 (14)	59.4	9.0	15.1
Manazuru	All	andesite	456 (91)	37.9	15.9	42.0

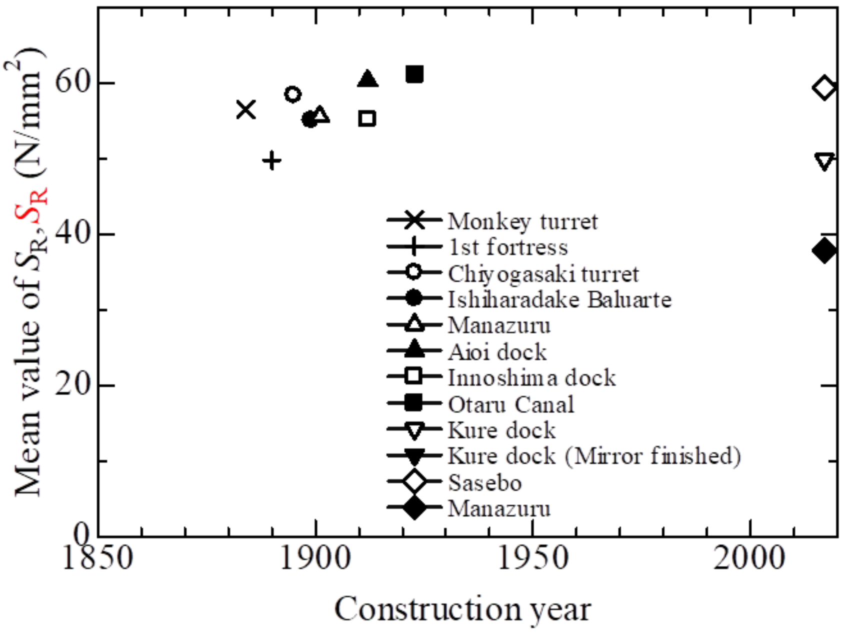

Figure 6. Relationship between SR and construction year(stones)

Table 5

Statistical SR values for bricks

Facility	Prefecture	Site	Material	n	S_R (N/mm^2)	σ	VS_R (%)
Monkey turret	Kanagawa	2nd Battery observation station	Brick	19 (3)	51.9	6.0	11.5
1st fortress	Kanagawa			54 (9)	51.0	13.1	25.7
Chiyogasaki turret	Kanagawa	All		144 (24)	48.7	10.5	22.9

Changes in strength of stones and bricks

The statistical S_R values for stones and the relationships between S_R and the construction years are shown in Table 4 and Fig. 6, respectively. The stones are classified as andesite, granite, and sand stone, as presented in Table 4. Additionally, the S_R values are also unrelated with the construction year, exception for Manazuru (◆), where S_R was smaller than that of other stones because the Manazuru stone (◆) includes the protein-clotting andesite. However, the S_R of stones used as construction materials had similar values. The granite at Kure (▼) was made the mirror finish. The plunger tip of the RHT is a curved surface, and the stone surface of the typical finishing was crushed unevenly by the hit of the RHT. The S_R increased as the contact area between the plunger tip and the stone increased. Moreover, the S_R coefficient of variation (VS_R) decreased from 4 % to 23%. The stone was used in the sewer wall of the old Kure Navy Factory dry dock, where the Yamato battleship was built.

The statistical S_R values of bricks are summarized in Table 5. The S_R is approximately 50 N/mm², regardless of the facilities and constructed years. The year of construction ranges within a period of 15 years from 1884 to 1899, when the manufacturing method and the quality of the bricks are already stable.

Conclusion

The conclusions drawn from this study are summarized as follows:

1. The strength of the concrete obtained from the first strike was smaller than that obtained with subsequent hits at the same position. The strength increased by increasing the number of hits until it became constant after several strikes. The converged strength approximated the interior strength. Using the first hit strength to estimate the inside strength is proposed as a new method of obtaining the interior strength.
2. The concrete strength of the third fortress varied by section, with the underground structure having lower strength than the part above the ground surface.
3. The strength of the concrete used in the facilities was not affected by the 1995SHPE, and the strength of older facilities was higher than that of new facilities.
4. The mean values and coefficient variations of the strength for stone and brick were not influenced by the age of construction or facility type.
5. The mirror-finished granite mean values and coefficient variations of strength were larger and smaller, respectively, in comparison with those of rough-finished stone.

References

1. Inaba, Y. and Shogaki, T. (2018): Concrete strength of the 3rd Meiji fortress, Proc.of the Technical research Presentation for the Kanto branch of the Japan Society of Civil Engineers, V-8, CDR, (in Japanese).
2. Shogaki, T. (2014): Geotechnical evaluations and preservation of Post-Edo period historical monuments in Japan. Geotechnical Engineering Magazine, Vol. 65, No.8, pp. 1-5 (in Japanese).
3. Japanese Geotechnical Society (2013): Method for rebound hammer test on rocks (JGS 3411-2012), (in Japanese).
4. Japanese Standards for Geotechnical and Geoenvironmental Investigation Methods-*Standards and Explanations*, pp. 433-447 (in Japanese).

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Жапонияда Мэйджи кезінен бастап салынған тарихи азаматтық құрылыс нысандарындағы құрылыс материалдарының беріктігі

Аңдатпа. Тарихи құрылымдар келешек ұрпаққа қалатын мұра болып табылады. Жазбалар ретінде олар өткен құрылыс технологияларын сипаттап қана қоймай, сонымен қатар өз заманының әлеуметтік жүйесі мен мәдениеті туралы ақпарат береді. Эдо дәуірінде және одан кейін салынған көптеген тарихи ғимараттар Жапонияда әлі де бар. Бұл құрылымдардың кейбіреулері, мысалы, Йокосуктың құрғақ доктары, ұлт тағдырында маңызды рөл атқарды (Шогаки, 2014). Алайда мұндай бөліктер жүйелі инженерлік-геологиялық зерттеулердің немесе жариялылықтың тақырыбы болған жоқ. Мэйджи дәуірінен бері салынған тарихи нысандардағы құрылыс материалдарының беріктігі джекаммер сынағымен (JGS 2013) зерттелді және құрылыс жасына, объект пен материалды пайдалануға байланысты бағаланды. Зерттелетін материалдар: 10 учаскедегі тау жыныстары (андезит, гранит және құмтас), 6-ға бетон және 3-ке кірпіш.

Түйін сөздер: тарихи азаматтық құрылыс нысандары, құрылыс материалдары, Мэйджи дәуірі, балғамен сынау, беріктік.

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Прочность строительных материалов на исторических объектах гражданского строительства, построенных со времен Мэйдзи в Японии

Аннотация. Исторические сооружения являются частью наследия, которое человечество передает потомкам. В качестве записей они не только описывают прошлые строительные технологии, но также несут информацию о социальной системе и культуре своего времени. Многие исторические строительные сооружения, построенные во время и после эпохи Эдо, все еще остаются в Японии. Некоторые из этих сооружений, например, сухие доки Йокосука, сыграли важную роль в судьбе нации (Shogaki, 2014). Однако такие участки не были предметом систематических инженерно-геологических исследований или огласки. Прочность строительных материалов на исторических объектах, построенных с эпохи Мэйдзи, была исследована с помощью испытания отбойным молотком (JGS 2013) и оценена с учетом возраста постройки, использования объекта и материала. Исследуемые материалы: горные породы (андезит, гранит и песчаник) на 10 участках, бетон на 6 и кирпич на 3.

Ключевые слова: исторические объекты гражданского строительства, строительные материалы, эпоха Мэйдзи, испытание отбойным молотком, прочность.

References

1. Inaba, Y. and Shogaki, T. (2018): Concrete strength of the 3rd Meiji fortress, Proc.of the Technical research Presentation for the Kanto branch of the Japan Society of Civil Engineers, V-8, CDR, (in Japanese).

2. Shogaki, T. (2014): Geotechnical evaluations and preservation of Post-Edo period historical monuments in Japan. Geotechnical Engineering Magazine, Vol. 65, No.8, pp. 1-5 (in Japanese).

3. Japanese Geotechnical Society (2013): Method for rebound hammer test on rocks (JGS 3411-2012), (in Japanese).

4. Japanese Standards for Geotechnical and Geoenvironmental Investigation Methods–Standards and Explanations, pp. 433-447 (in Japanese).

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