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Development and Application of Concrete Using Seawater and By-product Aggregates

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ABSTRACT

Authors developed concrete using seawater as mixing water. A combination of sea water, ordinary portland cement, ground granulated blast-furnace slag, fly ash, silica fume, and a special chemical admixture containing calcium nitrite was adopted to densify concrete. This concrete is hereafter referred to as “concrete with seawater”. This technology not only improves the performance of concrete but also shortens the material transportation process and reduces cost and CO2 emission from construction work by effective use of seawater when producing concrete in a region where fresh water is not readily available, such as isolated islands and coastal areas. Furthermore, authors developed methods of producing concrete using by-product aggregates such as large uncrushed concrete debris from the earthquake disaster or steel making slag. Especially when using large uncrushed concrete debris, pre-placed aggregate concrete method and post-packed concrete method were adopted to reduce processing time and cost by using as much uncrushed concrete debris as possible. This paper describes practical experiments to which we applied these production methods using seawater and by-product aggregates to build concrete blocks for ports and harbors and a pavement for a steel making plant.

INTRODUCTION

Treatment of large amounts of waste from the Great East Japan Earthquake Disaster has become a problem. This research focused on reutilization of concrete debris from concrete structures damaged by the earthquake. Fast and efficient processing is sought in the affected areas to reduce processing time and cost by using as much uncrushed concrete debris as possible. Additionally, it is expected that using seawater as the mixing water will shorten construction time and improve endurance by development of early and long-term strength. Thus, we developed methods of producing concrete using large uncrushed concrete debris and seawater, applying the pre-placed aggregate concrete method and the post-packed concrete method. This paper describes results of practical experiments applying these production methods to concrete blocks for ports and harbors.

Steel slag hydrated matrix (SSHM) is a technology that has been developed as a substitute for concrete using steel making slag, ground granulated blast furnace slag powder, and alkaline activator. SSHM, which enable to make efficient use of by-products from steel making plants, has been applied for artificial stone and non-reinforced concrete block for port and harbor. On the other hand, using seawater and special admixture which contains calcium nitrite make concrete denser to develop its early age strength and durability. Authors tried to apply SSHM by using seawater to a pavement in a steel making plant.

BLOCKS USING CONCRETE DEBRIS

Outline of production method. Large uncrushed concrete debris as coarse aggregate cannot be easily placed into a mixer, so we adopted two methods using separately mixed mortar.

The pre-placed aggregate concrete method or pre-packed concrete method is a method of placing grouting mortar from a grouting pipe inserted into formwork after placing of concrete debris. This method is applicable to structures of complicated shape because it is easy to confirm the situation of concrete debris prior to placing grouting mortar. The grouting mortar requires high segregation resistance and high fluidity. Figure 1 outlines the pre-placed aggregate concrete method using concrete debris.

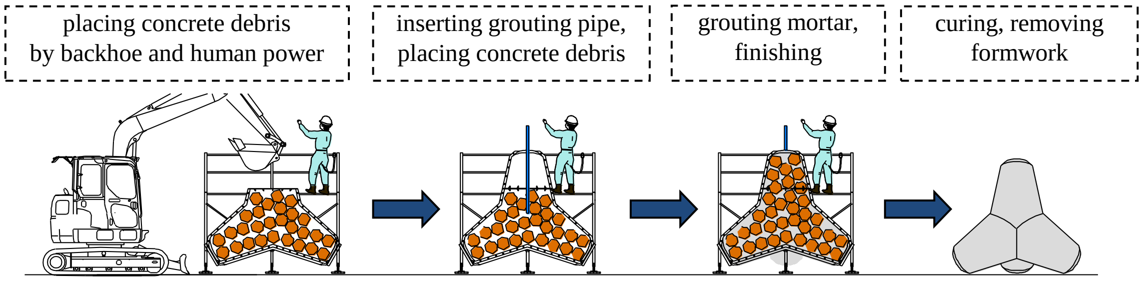


Figure 1. Pre-placed aggregate concrete method

In the post-packed concrete method, concrete debris is placed into mortar cast into formwork in advance. This method is applicable to structures of simple shape, like rectangular blocks because it is difficult to verify visually the filling situation of concrete debris in mortar cast in advance. However, relatively low fluidity mortar can be used, which simplifies this method. Figure 2 outlines the post-packed concrete method using concrete debris.

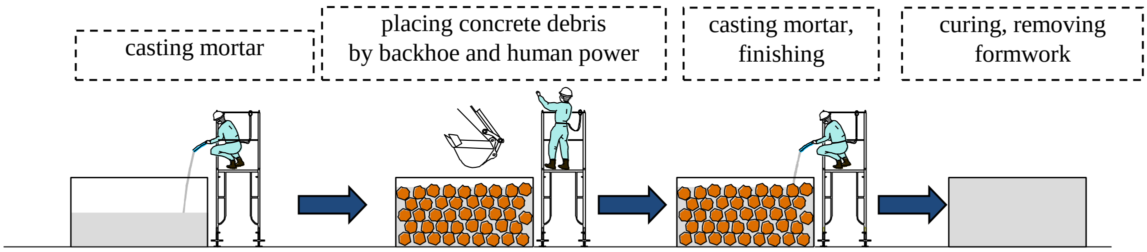


Figure 2. Post-packed concrete method

Object structure. Table 1 shows cases of the operations. Object blocks for ports and harbors are wave-dissipating blocks (25ton, height 3.3m x breadth 3.94m), foot protection blocks (40ton, height 1.5m x breadth 3.0m x length 4.0m) and retaining walls (height 3.0m x breadth 1.5m x length 5.0m), each of unreinforced concrete structure and design strength is 18N/mm2. The post-packed concrete method was adopted for the foot protection blocks, and the pre-placed aggregate concrete method for the wave-dissipating blocks and the retaining walls, whose filling situation of concrete debris cannot be confirmed later because of their complicated and narrow shapes. For comparison, the foot protection blocks and wave-dissipating blocks are also produced by mixing concrete using crusher-run (maximum size 40mm) made from concrete debris as coarse aggregate (hereinafter called recycled concrete). As binder materials, Portland blast furnace slag cement was used for each object. Additionally, fly ash (coal ash) which is produced by a coal power station for producing the retaining walls. The dedicated site plant was built to mix mortar and concrete.

Table 1. Object structure and production method

Object structure	Production method	Mixing water	Binder
Wave-dissipating blocks	Pre-placed aggregate concrete	Sea water / Fresh water	Portland blast-furnace slag cement
	Mixing concrete	Sea water	Portland blast-furnace slag cement
Foot protection blocks	Post-packed concrete	Sea water / Fresh water	Portland blast-furnace slag cement
	Mixing concrete	Sea water	Portland blast-furnace slag cement
Retaining walls	Pre-placedaggregate concrete	Sea water	Portland blast-furnace slag cement and coal ash

Materials and mix proportion. Concrete debris of size 200 - 500mm was used so that it could be carried by backhoe and handled by human power, and because it was necessary to minimize the crushing process to effectively reuse the huge quantity of concrete debris from the earthquake disaster. The origin of the concrete debris was concrete caissons damaged by the tsunami disaster, and then broken by concrete breakers. Figure 3 shows the concrete debris, and table 2 shows its properties. For reference, the quality of 'recycled aggregate class L' provided in the Japan Industrial Standards (JIS A 5023) is shown in table 2 adscript.

Figure 3. Concrete debris

Table 2. Properties of concrete debris

Parameter	Property	(Reference) Standard of Recycled Course Aggregate Class L (JIS A 5023)
Particular diameter (mm)	200 - 500	5 - 25
Density (g/cm^3)	2.37	—
Absorption (%)	7.18	7 or less
Compressive strength (N/mm^2)	37.2	—

Table 3. describes the materials used for the mortar and concrete. Portland blast-furnace slag cement type B was used as the cement. Seawater or fresh water was used as the mixing water of the mortar, and fresh water was used as the mixing water of the concrete. In order to suppress shrinkage cracks, expansive additive was used, and in order to ensure the integrity of mortar and concrete debris, foaming agent (aluminum powder) was used.

Table 3. Materials of mortar and concrete

Material	Description	Code	Abstract Specification
Water	Fresh water	W	Tap water
	Sea water		Density $1.03g/cm^3$,Chloride ion content 1.88%
Binder (B)	Portland blast-furnace slag cement type B	C	Density $3.04g/cm^3$
	Expansive additive	Ex	Calcium oxide type, Density $3.16g/cm^3$
	Coal ash	FA	Washed coal ash, Density $2.21g/cm^3$, Average particle size 28μm, Water content 18.2%
Coarse aggregate	Recycled crusher-run from concrete debris	G	Density $2.20g/cm^3$, Absorption 12.4 %, Particular diameter 40 mm or less
Fine aggregate	Crushed sand	S	Density $2.66g/cm^3$, Absorption coefficient 1.53%, F.M. 2.75
Admixture	Forming agent	AL	Specialty aluminum powder
	Super plasticizer	SP	Polycarboxylate type compound
	Air entraining agent	AE	Resinate type surface-activating agent

Table 4 shows the mix proportions of the mortar and concrete. The W/B of the mortar for the wave-dissipating blocks was 40.0%, and for the foot protection blocks it was 45.0%. The content of aluminum powder to satisfy the targeted expansive rate was $40g/m^3$. The content of expansive additive was $40kg/m^3$ replaced by cement for mortar based on standard usage.

Table 4. Mix proportions and properties of mortar and concrete

Type	Mixing Water	W/B (%)	S/B	s/a (%)	Unit weight (kg/m^3)							Flow Time (seconds)	Slump (cm)	Air Content (%)
					W	B			S	G	Al			
						C	Ex	FA						
Mortar for wave-dissipating blocks (pre-placed aggregate concrete)	Seawater	40.0	1.7	—	263	618	40	—	1119	—	0.04	58.3	—	10.0
	Fresh water	40.0	1.7	—	263	618	40	—	1119	—	0.04	49.2	—	10.7
Mortar for foot protection method (post-packed concrete)	Seawater	45.0	1.7	—	286	595	40	—	1080	—	0.04	33.0	—	9.0
	Fresh water	45.0	1.7	—	286	595	40	—	1080	—	0.04	31.4	—	9.7
Mortar for retaing walls (pre-placed aggregate concrete)	Seawater	40.0	1.4	—	284	600	40	71	995	—	0.04	47.5	—	8.9
Recycled concrete	Fresh water	54.7	—	46.4*	175	320	—	—	269	1303	—	—	11.0	5.6

* counting 35% of recycled crusher-run (particle diameter 5 mm or less) fine aggregate

Quality control. Table 5 shows the target performance of the mortar. According to the Standard Specification for Concrete Structure "Materials and Construction", the standard flow time (using a P-funnel) of the mortar for the pre-placed aggregate concrete should be taken as 16 - 20 seconds for a minimum coarse aggregate size of 15mm. However, in this case, the coarse aggregate size was 200 - 500mm, to the flow time was targeted at 30 - 60 seconds. The air content of the mortar was targeted at 8 - 12%, and the air content of concrete was targeted at 5.5 ± 1.5%, assuming the concrete blocks were subjected to freezing and thawing.

Table 5. Targeted performance of mortar

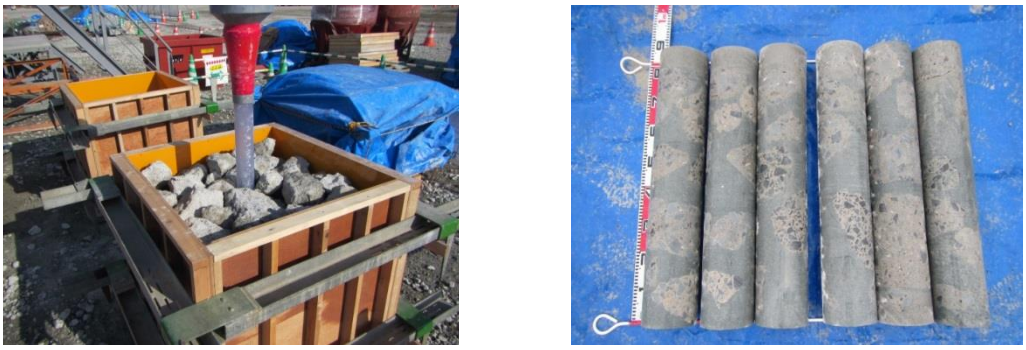
Test Item (Method)	Targeted Performance
Flow time (JSCE F 521)	30 - 60 seconds
Air content (JIS A 1128)	8.0 - 12.0 %
Bleeding ratio (JSCE F 522)	3 % or less at 3 hours
Expanding ratio (JSCE F 522)	2 - 5 %

Compressive strength was evaluated using two types of specimen. One was cast in a steel mold (φ150 x height 300mm) by the pre-placed aggregate and post-packed concrete methods using concrete debris of particle size about 40mm (hereinafter called φ150mm specimen, figure 4). The other type comprised core samples (φ150 x heights 300mm) of concrete blocks (cube 800mm on a side) made by the pre-placed aggregate and post-packed concrete methods using concrete debris of particle size 200 - 500mm (hereinafter called core specimen, figure 5).

(a) Pre-placed aggregate concrete

(b) Post-packed concrete

Figure 4. Casting of φ150 mm specimens



(a) Casting block (pre-placed aggregate concrete) (b) Sampling core

Figure 5. Manufacturing core specimens

Filling situations of mortar

Figure 6 shows situations of casting the products. Figure 7 shows the appearances of the products after formwork was removed. The mortar filled enough and no voids were found on the product surfaces as a result of controlled fluidity of mortar (flow time between 30 - 60 seconds).

(a) Wave-dissipating block (preplaced-aggregate concrete) (b) Foot protection block (post-packed concrete) (c) Retaining wall (preplaced-aggregate concrete)

Figure 6. Production procedures

(a) Wave-dissipating block (preplaced-aggregate concrete) (b) Foot protection block (post-packed concrete) (c) Retaining wall (preplaced-aggregate concrete)

Figure 7. Appearance of the products

Compressive strength. Figure 8 to figure 10 show the results of compressive strength tests. The compressive strength of the fresh-water-mixed concrete exceeded the design strength (18 N/mm^2) at 28 days. However, that of the sea-water-mixed concrete exceeded it at 7 days. At 28 days, the compressive strength of the wave-dissipating blocks (W/B 40.0%, sea-water-mixed) was 30N/mm^2 or over, and that of the foot-protection blocks (W/B 45.0%, sea-water-mixed) was 25N/mm^2 or over. Even in the case of added coal ash (retaining walls, W/B 40.0%, sea-water-mixed), the compressive strength at 35 days was almost equal to that of the case without coal ash (wave-dissipating blocks) at 28 days.

For both the wave dissipating block and the foot-protection block made from sea-water-mixed mortar, the compressive strengths were higher than for those made from fresh-water-mixed mortar. The strength increase was especially large at early age.
For recycled concrete, strength increase compared to that at 7 days was 1.5 times at 28 days and 2.0 times at 91 days. By contrast, strength increases of the pre-placed aggregate and post-packed concrete with sea-water-mixed mortar were lower: 1.2 - 1.3 times at 28 days and, 1.3 - 1.5 times at 91 days. The reasons of this are thought to be that the compressive strength of pre-placed aggregate and post-packed concrete using concrete debris of large size depends on the strength of the interface between the concrete debris and the mortar or that of the concrete debris itself, and the long-term strength increase of the sea-water-mixed mortar tends to be moderate, not showing a remarkable increase in early age.
For the φ150mm specimen with sea-water-mixed mortar, the strength increase compared to that of the fresh-water-mixed mortar tended to be higher than that for the core specimen. Furthermore, though the compressive strengths of the post-packed concrete for the φ150mm specimen and the core specimen are similar, for the pre-placed aggregate concrete, the strength of the φ150mm specimen was higher than that of the core specimen. It is thought that the quantity and location of concrete debris in the core specimens, and the randomness of strength of the concrete debris, influence the strength of the core specimen, because the size of the concrete debris (200 - 500mm diameter) is larger than the size of the core (150mm diameter).

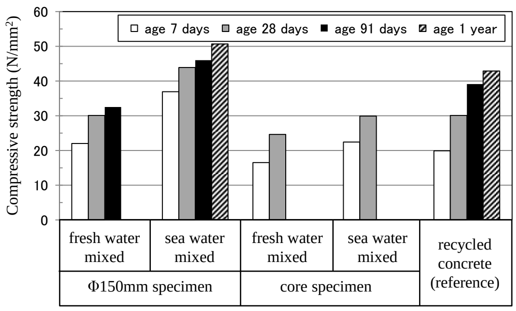


Figure 8. Compressive strength of wave-dissipating blocks (preplaced-aggregate concrete)

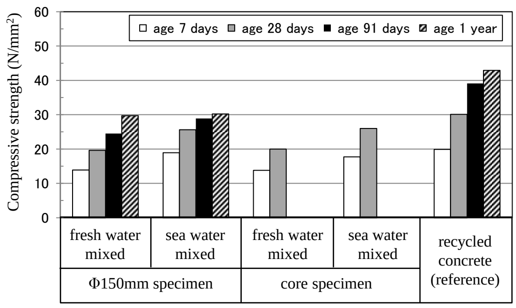


Figure 9. Compressive strength of foot protection blocks (post-packed concrete)

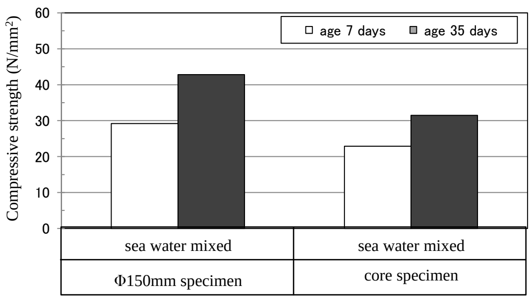


Figure 10. Compressive strength of retaining walls (preplaced-aggregate concrete)

A PAVEMENT USING STEEL MAKING SLAG

Experimental study. For pavement materials, Performances as workability, bending strength, durability and abrasion resistance required. Table 6. shows target qualities of SSHM on this experiment. Table 7. shows materials of SSHM. Portland cement was used as alkaline activator, and super plasticizer which has remarkable dispersibility was used for admixture for seawater-mixed SSHM. In addition, special admixture which contains calcium nitrite was used for a case of seawater-mixed SSHM. Table 8. shows test items. Behaviors of fresh concrete, bending and compressive strength of hardened concrete have been tested. Table 9 shows mix proportions and results of fresh concrete tests.

Table 6. Target Qualities

Item	Target value
Slump flow	50±10cm (Slump 21±2.5cm)
Air content	5.0±1.5cm
Bending strength (Age 7 days)	Specified strength 4.9N/mm^2 (Required strength 5.64N/mm^2)

Table 7. Materials of SSHM

Description	Code	Specification
Tap water	W	
Seawater		Cl^- content 1.88%
Ground granulated blast-furnace slag	BS	Density 2.86g/cm^3
Portland cement	NP	Density 3.15g/cm^3
Steel making slag fine aggregate	S	Density 3.78g/cm^3
Steel making slag coarse aggregate	G	Maximum diameter 25mm, Density 3.44g/cm^3
Special admixture for seawater-mixed concrete	AN	Contains calcium nitrite, Density 1.30g/cm^3
Super plasticizer	SP1	Contains polycarboxylate
	SP2	Contains polycarboxylate (For seawater-mixed SSHM)

Table 8. Test Items

Item	Standard	Specification
Slump and slump flow	JIS A 1101, JIS A 1150	
Air content	JIS A 1128	
Temperature		
Bending strength	JIS A 1106	100*100*400mm, seal curing
Compressive strength	JIS A 1108	φ100*200mm, seal curing

Table 9. Mixture Proportions and Results of Fresh Concrete Tests

	Mixing water	Water binder ratio (%)	Strength Index*	Unit weight (kg/m^3)						SP ((BS+NP) * %)	Slump flow (mm)	Air content (%)
				W	BS	NP	S	G	AN			
1	Tap water	31.6	4.32	180	363	207	1347	735	-	1.1	39.0	4.8
2	Seawater	31.6	4.32	180	363	207	1347	735	-	1.2	40.0	4.6
3	Seawater	31.6	4.32	170	363	207	1347	735	13	1.2	40.0	4.9

**(strength index) = (BS+2NP)/W*

Figure 11 and figure 12 show the results of compressive and bending strength respectively. Compressive strength increased by using seawater as mixing water, even more by adding special admixture. However, bending strengths of the cases using seawater and adding special admixture were approximately equal to the case using fresh water at the age 7 days. It is expected that using seawater and adding special admixture increase abrasion resistance, because higher compressive strength obtained, the higher abrasion resistance become.

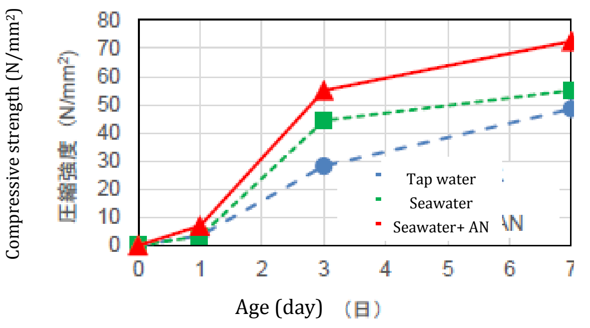


Figure 11. Compressive Strength

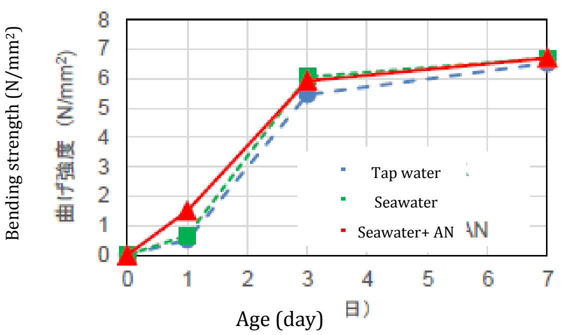


Figure 12. Bending Strength

Construction experiment

Authors applied seawater-mixed SSHM to a pavement in a steel making plant and evaluated quality and stability. The objective pavement was 25cm thick and 1000m^2 large in area.

Materials of SSHM were same as mentioned in **Table 7**. Seawater was obtained by pumping up from a sea bank in the steel making plant. Batch mixer was 1m^3 forced mixing, double-horizontal- axis type. Mix proportion of SSHM was revised as **Table 10.** because of a size distribution change of steel making slag aggregate.

Table 10. Mixture Proportions for the Pavement

	Mixing water	Water binder ratio (%)	Strength Index*	Unit weight (kg/m^3)						SP ((BS+NP) * %)
				W	BS	NP	S	G	AN	
1	Seawater	26.9	4.83	180	470	200	1330	660	-	0.5
2	Seawater	26.9	4.83	170	470	200	1330	660	13	0.5

**(Strength index) = (BS+2NP)/W*

Figure 13 shows the result of quality control test. Figure 14 shows situation of slump flow test, figure 15. shows situation of casting the pavement, and figure 16 shows appearance of the pavement after construction. According to the results, seawater-mixed SSHM satisfied target qualities of the pavement and caused neither surface cracking nor other defects.

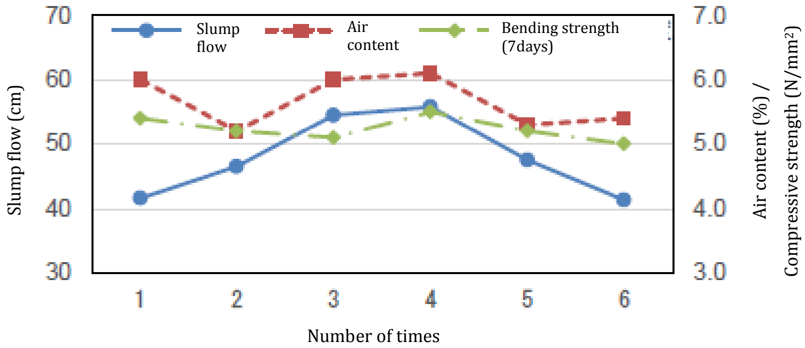


Figure 13. Result of Quality Control Test

Figure 14. Situation of the Slump Flow Test Construction.

Figure 15. Situation of Casting the Pavement

Figure 16. Appearance of Pavement After

SUMMARY

In this research, a technology of concrete using seawater and by-products (uncrushed concrete debris, steel making slag) has been established by the experimental study and the construction experiment. It is expected that using seawater shortens construction term and increases abrasion resistance because of development of compressive strength. Authors are going to expand the application of this technology to reinforced concrete structure.

ACKNOWLEDGMENTS

The practical experiment using concrete debris was conducted as “the application of the technology in the disaster relief work of northeast ports” publicly-offered by Tohoku Regional Bureau Ministry of Land, Infrastructure and Transport. Technical support by Nikki Kensetsu Co., ltd. and Fudo Tetra Corporation was necessary to conduct the experiment producing concrete blocks for ports and harbors.

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