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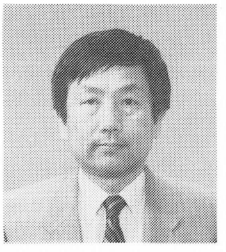
STUDIES ON CONCRETE QUALITY CHANGE AND RELATED FACTORS BASED ON DATA ANALYSES

(Translation from Proceedings of JSCE, Vol. 408, V-11, Aug. 1989)



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SYNOPSIS

The objectives of this study are to analyze factors which are considered to affect concrete quality change and to develope adequate concrete quality control system based on data analyses. The data used in this study are mainly those of the concrete placed in expressway construction works and commonly ready-mixed concrete placed all over Japan.
Through a lot of data analyses, it became evident that concrete qualities become deteriorative and multifarious with range throughout Japan due to producing equipment, quality control system, aggregate condition, regional difference and so on. Comments are also made on those particular factors in order to more reasonable concrete quality control system.

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1. INTRODUCTION

Reacent years, many studies have been reported about the problems of early deterioration or durability decline on concrete structures. As for main reason for this decline, it could be stated that the material to be used and construction methods had become multifarious with the progress of construction works in Japan. Especially, as for the aggregate resources for concrete, though the supply of high quality river aggregate (river sand and gravel) has been decreasing and the kinds of aggregate have been multifarious. Therefore it should be guessed that the concrete qualities (compressive strength, drying shrinkage, freeze-thaw resistance and so on) have also become multifarious. Nevertheless, there are few researches from the viewpoint of studying the relation between the quality of aggregate or the quality control (hereafter QC) and that of concrete at the national scale.

Ready-mixed concrete was merchandised in November 1949, and JIS (Japanese Industrial Standards) A 5308 "Ready-Mixed Concrete" [1] was enacted in November 1953. Moreover, it was the first time that QC of concrete was enacted in the Japan Society of Civil Engineers (JSCE) standard "Standard Specification for Design and Construction of Concrete Structures " (revised edition in 1957) [2]. After that, with the increase of construction works accompanied with the high development of Japan, ready-mixed concrete industry has made remarkable advances. Ready-mixed concrete plants have greatly increased in number all over Japan. The number of factories as of March 1988 is 5354 (the number of JIS plant is 3868, 72.2 % of a whole), and the volume of concrete produced in a year is 17800 milion m^3. Therefore production of the concrete by the field plant is limited only under special conditions.

Nowadays, in the case of the concrete construction works, ready-mixed concrete have been commonly used. QC of concrete is extremely dependent on the manufacturing control of ready-mixed concrete. However, the quality standard of JIS Ready-Mixed Concrete is prescribed at the unloading position. So, manufacturing process which includes the chain from selection of materials, determination of mix proportions, mixing to transportation is being trusted to suppliers by self-imposed restraint controls. Naturally, quality difference of manufactured concrete could be happened depending on the difference of QC systems among the each ready-mixed concrete plants. On the other hand, in the case of NIHON DORO KODAN (Japan Highway Pablic Corporation, hereafter KODAN), the flow of QC system (from start of concrete investigation before order of works, execution control tests under construction works, to finish of inspection after completion of works) should be done consistently. Then the both concrete manufactured by the ready-mixed concrete plants and by the field plants have been controled for the construction by the same specifications [4]~[6]. In these specifications the methods were standardized how to control the concrete qualities and how to inspect these qualities. Judging from these matters, these concretes have been produced and have been maintaining almost constant quality level.

From the above facts, the objectives of this study are to analyze factors which are considered to affect concrete quality changes and to develope adequate concrete QC system based on data analysis. The data used in this study are mainly those of the concrete placed in expressway construction works of KODAN and commonly ready-mixed concrete placed all over Japan [7]~[12].

2. CONTENTS OF THE INVESTIGATION

2.1 Investigation of Concrete Tests

An investigation of Concrete Tests (hereafter Investigation Ⅰ) [12] is the result which was tested on many kinds of concretes (indoor tests, 75 test reports reported by KODAN organizations all over Japan from 1971 to 1985, hereafter CONCRETE TESTS). The contents of investigation are qualities of materials, mix proportions, results of mix design (compressive strength test) and so on. These results have a very wide domain because the data includes low quality aggregate so far not used for actual construction works.

2.2 Investigation of the Concrete placed in Highway Construction Works of KODAN

Investigation of the concrete placed in highway construction works of KODAN (hereafter Investigation Ⅱ) [12] is aimed at the concretes which were placed in highway construction works of KODAN (hereafter KODAN CON).

In this investigation the following concretes were contained [7];

(a) The concrete which was used for construction works of the Meishin Expressway constructed in 1958～1965 when the ready-mixed concrete plants were not so popular (the first expressway in Japan, hereafter MEISHIN)

(b) The concrete which was used for construction works of the Tomei Expressway constructed in 1965～1969 when the aggregate resources started to be multifarious (hereafter TOMEI)

(c) The concrete which is used for construction works of the nationwide highways constructed in 1972～1985 (completion of works in each year, hereafter COMPLETION EACH YEAR).

The data of Investigation Ⅱ did not show the change of concrete quality data at the same construction site because the construction sites have been changed yearly. But because these works are nationwide, these data can be treated equally as random sampling data from all over the country.

The methods of the investigation were based on the way to collect the past data and "the reports of placed concrete" which were drawn up after completion of works [6]. The contents of the investigation were the outline of construction, qualities of materials, mix proportion, result of mix design, specified mix, results of control tests and so on. The number of investigated mix proportions are 19 mixes shown in Table 1. The notations shown in ( ) of this table are the names which are standardized by the KODAN specifications [4]～[6]. For example, in the case of "A_{1-1}", "A" means the type of structures that the concrete placed, the first suffix "$_1$" means the maximam size of coarse aggregate or the type of structures and the second suffix "$_{-1}$" means the type of cement.

2.3 Investigation of the Ready-mixed Concrete

An investigation of the ready-mixed concrete (hereafter Investigation Ⅲ) [12] is aimed at the data on the nationwide ready-mixed concrete plants which were mainly located along the expressways of KODAN under plan, construction or operation. This investigation was conducted in 1978 (hereafter REMI CON '78) and 1986 (hereafter REMI CON '86) [8]～[11].

The method of the investigation was formed by questionnaires. REMI CON '78 was asked the 500 selected plants in June 1978, and got the answer from 432 plants (9.0 % of total number 4808 of ready-mixed concrete plants, 16.4% of total number 2554 of JIS ready-mixed concrete plants) until August 1978. REMI CON '86 was asked selected plants in July 1986, and got the answer from 560 plants (about 10 plants each prefectures, refer to Fig. 1). The investigation were based on the way to select the class of Concrete 1(A_{1-1}), 4(B_{1-1}), 6(B_{2-1}), 9(C_{2-1}), 13(P_{2-2}), 15(T_{1-1}), 16(X_{1-1}) and 18(H_{1-1}) from Fig. 1 in order to contrast the KODAN CON and to represent the whole concrete for civil engineering works. And on these

Table 1 Investigated Concrete (Investigation Ⅱ)

Item / Class of concete (Concrete)	Type of Concrete structure 1)	Condition of mix proportion: Strength at 28 days f_{ck28} (kgf/cm²) 2)	Slump SL (cm) 2)	Air A (%) 2)	Maximum size of coarse aggregate G_M (mm)	Type of cement 3)	Unit cement content C (kg/m³) 4)	Type of chemical admixture 5)	Mix pro-portion-ing strength f_{c28} (kgf/cm²)	'82-'83 Comple-tion of works: Number of data n	Avarege of placed concrete (m³)
1 (A_{1-1})	G	300	8±2.5	4±1	20,25	N	(320),320,350,380	w, aw	356	42	372
2 (B_{0-1})	S	240	8±2.5	4±1	20,25	N	(300),300,300,320	w, aw	284	285	2067
3 (B_{0-2})	S	240	8±2.5	4±1	20,25	H	(300),300,300,320	w, aw	284	11	1177
4 (B_{1-1})	R	240	8±2.5	4±1	20,25	N	(290),280,300,320	w, aw	284	327	6171
5 (B_{1-2})	R	240	8±2.5	4±1	20,25	H	(290),280,300,320	w, aw	284	27	3327
6 (B_{2-1})	K	240	8±2.5	4±1	40	N, B	(280),270,280,300	w, aw	284	242	4153
7 (B_{2-2})	K	240	8±2.5	4±1	40	H	(280),270,280,300	w, aw	284	2	106
8 (C_{1-1})	C	180	8±2.5	4±1	20,25	N, B	(240),230,240,250	w, aw	219	191	1191
9 (C_{2-1})	C	180	8±2.5	4±1	40	N, B	(240),230,240,250	w, aw	219	241	1463
10 (D_{1-1})	D	—	—	—	40	N, B	(215),210,210,220	—	—	31	2270
11 (N_{1-1})	N	180	20±2.5	4±1	20,25	N, B	(—),280	w, aw	180	11	1330
12 (P_{1-2})	P	450	7±1.5	4±1	20,25	H	(450),440,470,500	w, aw	522	0	0
13 (P_{2-2})	P	400	7±1.5	4±1	20,25	H	(400),400,430,460	w, aw	464	97	2428
14 (P_{3-2})	P	350	7±1.5	4±1	20,25	H	(350),350,380,410	w, aw	406	130	962
15 (T_{1-1})	T	180	15±2.5	4±1	40	N, B	(270),270,270,280	w, aw	219	61	16165
16 (X_{1-1})	W	225	15±2.5	4±1	40	N, B	(370),370	w, aw	267	9	579
17 (Y_{1-1})	W	300	15±2.5	4±1	20,25	N, B	(370),370	r, ar	356	128	2567
18 (H_{1-1})	H	Flex. 45	1.5±1	4±1	40	N,H,M,P	(320),300,320,350	w, aw	Flex. 50	25	4357
19 (H_{2-1})	H	Flrx. 45	5±1.5	4±1	40	N,H,M,P	(350),310,330,350	w, aw	Flex. 50	27	1983

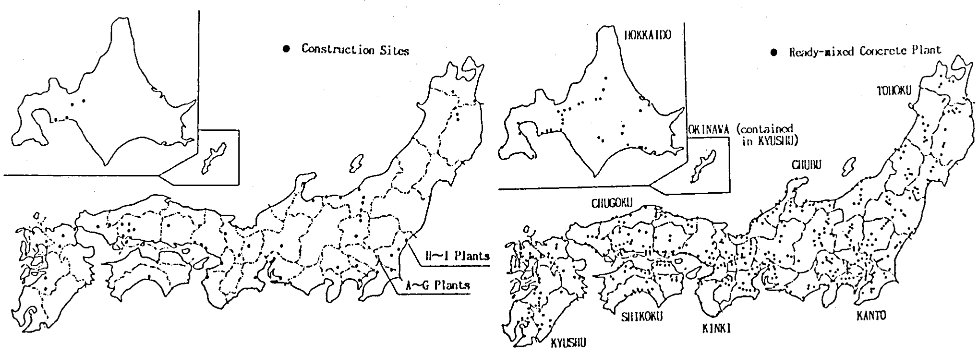
Note 1) G : Deck slab of composite beam bridge, S : Deck slab of general bridge, R : Reinforced concrete structure
K : Foundation of substructure (footing) , C : Plain concrete structure, D : Levelling concrete
N : Fill of pneumatic caisson, P : Prestressed concrete structure, T : Tunnel lining,
W : Foundation of substructure (Underwater concrete), H : Cement concrete pavement slab

Note 2) The value at placing point. The placing point means where concrete is placed within the forms before compacting by vibration.

Note 3) N : Ordinary portland cement, H : High-early-strength portland cement, B : B types of portland blast-furnace slag cement, M : Moderate-heat portland cement, P : Pavement cement

Note 4) (320) : Unit cement content until contracted works in 1977 (example 320 kg/m³)

Note 5) w : Standard types of water-reducing agents, aw : Standard types of air-entraining and water-reducing agents,
r : Retarding types of water-reducing agents, ar : Retarding types of air-entraining and water-reducing agents,
The amount of chemical admixture = (Standard amount of standard types or retarding types of water-reducing agents) + (Amount of air-entraining agents coforming to required air)



(a) Investigation Ⅱ (compression of works in 1982~1983) (b) Investigation Ⅲ

Fig. 1 Investigation Points

Standard Goods the quality of materials, mix proportion, result of mix design, specified mix, result of control tests were investigated.

2.4 Investigation of daily control tests

An investigation of daily control tests (hereafter InvestigationⅣ) is aimed at the daily control test data on the concrete placed in JOBAN Expressway construction works of KODAN (13 works, hereafter DALY CONTROL TESTS). Concrete plants are 9 plants located in KANTO district (A~I plants in Fig. 1, the term of September 1980~ April 1985). The contents of investigation were the daily fluctuations of grading of aggregates, surface moisture, batching value, compressive strength and so on.

2.5 Method of analysis

All gathered data were inputted into the Computer ACOS-650 in the Laboratory of KODAN. These data were checked in order to remove the mistakenly filled out data and the calculation mistakes such as W/C ratio, etc.. After this data processing

3. Investigation results and Consideration

3.1 The placed concrete volume of the concrete classes (Investigation Ⅱ and Investigation Ⅲ)

From the result of Investigation Ⅱ, comparisons of the numbers and placed volume of the concrete classes were made. The case of completion of works in 1982 ~1983 (COMPLETION '82~'83, see Fig. 1) are shown in Table. 1 (as an example). On batching plants in the case of completion of works in 1982 the numbers of ready-mixed concrete plants are 143 (97.9 % of a whole, JIS plants are 138 and non JIS plants are 5) and field plants are 3, in the case of completion of works in 1983 the numbers of ready-mixed concrete plants are 123 (98.4 % of a whole, JIS plants are 119 and non JIS plants are 4) and field plants are 2. From this investigation, the placed concrete volume in a year is about 3 millions m^3.

The order of the number of concrete data are concrete 4(B_{1-1}), 2(B_{0-1}), 6(B_{2-1}), 9(C_{2-1}), 8(C_{1-1}), 14(P_{3-1}), 17(Y_{1-1}), 13(P_{2-2}), 15(T_{1-1}) and the order of the number of placed concrete volume are concrete 4(B_{1-1}), 6(B_{2-1}), 15(T_{1-1}), 2(B_{0-1}), 9(C_{2-1}), 17(Y_{1-1}), 13(P_{2-2}), 8(C_{1-1}). Concrete 4(B_{1-1}) which is used for the common RC structures is the most representative concrete. Besides, in the case of investigation Ⅲ, it is also shown the similar tendency. The general quality of these data is compressive strength (age 28 days) f_{c28} = 186~508 kgf/cm^2, slump SL = 3.0~21.3 cm and air content A = 3.0~4.7 %. The date represent the frequencies of the appearance of the concrete for the road construction works.

Therefore, from now on, an examination will be done about the materials and the concrete of concrete 4(B_{1-1}, in the case of JIS Ready-Mixed Concrete, standard Goods corresponds to this).

3.2 The Materials to be used (Investigation Ⅱ and Investigation Ⅲ)

(1) Cement

Comparing the qualities of cements used in the period of MEISHIN and TOMEI, the specific gravity of cement has been changed from 3.15 to 3.16 since 1972~1975. There is no fluctuation in the fineness value and the compressive strength have been increased by 40 kgf/cm^2 (see Fig.2).

(2) The change of the kinds of aggregate

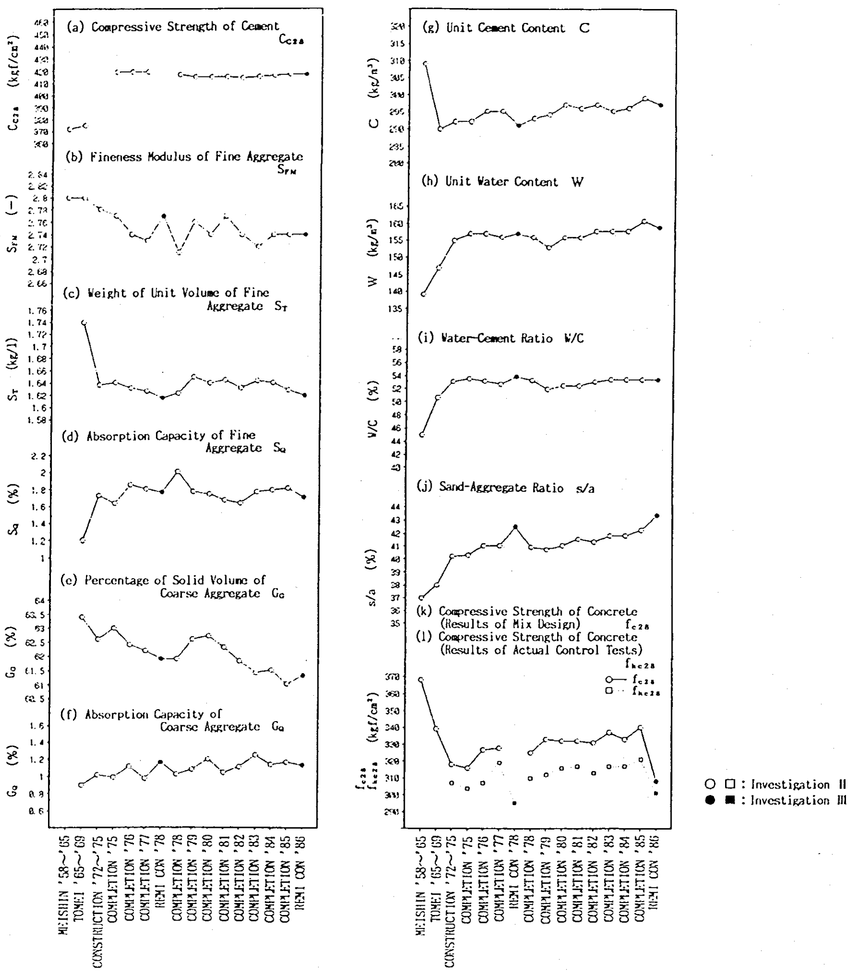


Fig. 2 Changes in qualities of the materials to be used and concretes (Investigation II and Investigation III)

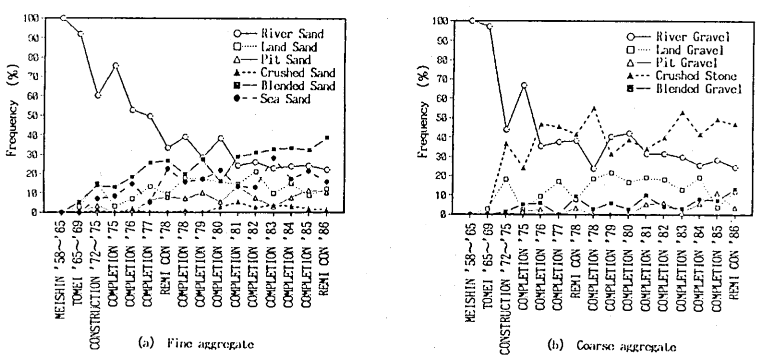


Fig. 3 Changes in kinds of aggregates (Investigation II and Investigation III)

The change of the kinds of aggregate is shown in Fig. 3. In the case of MEISHIN, aggregates used were all river sand and gravel. After about early 1960's, economical development of Japan and expansion of construction enterprise caused the exhaustion of the high quality river aggregates. Since 1966 the Ministry of Construction started actively to give administrative guidance on the regulations of using river gravels and the conversion to use crushed stones. But in the case of TOMEI, only land aggregate, blended sand with pit sand et al. were used because it was blessed with the resources of river sand and gravel. In the early 1970's, the construction of highway had been expanded all over Japan. The aggregate qualities became multifarious under the social conditions on aggregate for concrete. In the case of fine aggregate, the rate of land sand, pit sand, sea sand or these blended sand to be used became high. In the late 1970's,in accordance with the decrease in rate of river sand, that of blended sand increased. Since then this trend has been progressing. On the other hand, in the case of coarse aggregate, accompanying with the decrease in rate of river gravel,that of crushed stone increased. Also land gravel and pit gravel had been used. In the late 1970's, the rate of river gravel and that of crushed stone were reversed. From the early 1980's, it seemed that the rate of river gravel and land gravel tend to decrease and that of crushed stone tends to increase. In Fig. 3, these trends are shown evidently. Seeing the case of REMI CON '86, in the case of fine aggregate, in contrast to the ratio of river sand dropped to 21.8 %, that of blended sand and sea sand rose to 38.9 % and 15.4 % respectively. In the case of coarse aggregate, the rate of river gravel and crushed stone are 24.5 % and 46.7 % respectively. That of crushed stone increased (see later Table 4).

Comparing the fine aggregate with the coarse aggregate, with the decrease in resources of river sand and gravel, in the case of the coarse aggregate, mainly crushed stone and land gravel have replaced river gravel. On the other hand, in the case of the fine aggregate, first blended sand, and the individual sands (such as pit sand, land sand, sea sand) have replaced river sand. As for the reason why the rate of blended sand became high, the followings are given:
If individual sands are used, qualities of these sands (grading, particle shapes, chloride content et al., instead of river sand) have often caused problems. The adjustment of grading is more difficult than that of coarse aggregate, and crushed sand which is by-product of crushed stone should be utilized effectively et al..

Like this, with decrease of river sand and gravel, the aggegate resources have became multifarious, especially in the case of fine aggregate this multifarious trend is remarkable, and the rate of blended sand is most high.

(3) Change of Qualities of Aggregate

With the stated changes on aggregate resources, the qualities of aggregate have changed as shown in Fig. 2. Comparing with the time when river sand and gravel were mainly used in MEISHIN and TOMEI, the aggregates to be used have become multifarious since 1972. In the case of fine aggregate, fineness modulus, solid volume percentage, mass of unit volume and specific gravity become small, and absorption capacity become large. And, in the case of coarse aggregate, mass of unit volume, fineness modulus and solid volume percentage become small, and absorption capacity and specific gravity become large and big. Without specific gravity of coarse aggregate, all qualities become deteorated. In other words, these qualities have changed into the bad side that drying shrinkage (unit water content) of concrete increase or compressive strength, Young's modulus and freeze-thaw resistance decrease [13].

Then, after the early 1970's, as long as the average values are compared each other, the qualities have a little tendency toword deterioration, but almost remain on the same level. As mentioned above, followings could be summarized: The fine aggregates which have good quality and can be used individually have decreased. The fine aggregates are supplemented their deteriorations of qualities by using blended sands. And, the coarse aggregates are supplemented their deterioration of quality by using crushed stone which have the angular shapes (particle shapes are inferior), but have almost good qualities of aggregate. However, as the aggregate to be used have became multifarious, the distribution range of aggregate have became wide.

(4) Qualities of each kind of aggregates

The qualities of each kind of aggregates, in the case of REMI CON '86, are shown in Tables 2 and 3, respectively.

In the case of fine aggregate, river sand which is seemed to have good quality tents to have good trend generally, but absorption capacity is large, together with land sand, and the decline of qualities of aggregate is recognized. Comparing with river sand, land sand and pit sand, the specific gravity, mass of unit volume and solid volume percentage of sea sand are low (quality is bad) and absorption capacity, finess modulus and loss in washing test are also low (quality is good). In the case of crushed sand, specific gravity and mass of unit volume are large, and absorption capacity is low (qualities of aggregate are good), but finess modulus and loss in washing test are large (unit water content increase). In the case of blended sand the next features is recognized that a

Table 2 Quality of Fine Aggregate (Investigation Ⅲ)

Kinds of aggregate \ Item		Fineness modulus S_{FM} (−)				Loss in washing test S_A (%)				Percentage of solid volume S_O (%)				Weight of unit volume S_T (kgf/l)				Specific gravity S_H (−)				Absorption capacity S_Q (%)			
		$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}
	River Sand	2.78	0.11	2.99	2.34	1.5	0.6	2.8	0.1	64.3	2.0	71.6	57.8	1.637	0.061	1.840	1.450	2.59	0.03	2.71	2.52	1.79	0.58	3.58	0.65
	Land Sand	2.73	0.11	3.00	2.45	1.3	0.6	2.8	0.2	65.1	2.3	70.2	60.8	1.658	0.075	1.860	1.520	2.59	0.04	2.75	2.52	1.82	0.65	3.26	0.50
	Pit Sand	2.74	0.15	2.91	2.04	1.7	0.5	2.6	0.6	64.7	1.8	69.4	60.7	1.638	0.054	1.780	1.540	2.57	0.02	2.62	2.52	1.66	0.39	2.73	1.04
	Sea Sand	2.70	0.09	2.88	2.50	1.1	0.5	2.5	0.3	61.9	2.1	67.9	57.0	1.588	0.068	1.800	1.420	2.56	0.03	2.68	2.52	1.65	0.37	2.80	1.11
	Crushed Sand	2.80	0.07	2.92	2.74	1.8	1.7	4.8	0.2	64.6	4.3	72.5	58.6	1.685	0.127	1.920	1.570	2.64	0.06	2.73	2.56	1.33	0.65	2.30	0.46
Blended Sands	River+Land	2.72	0.10	2.85	2.50	1.5	0.5	2.9	0.3	63.8	1.8	67.3	60.0	1.616	0.053	1.730	1.505	2.58	0.02	2.65	2.54	1.74	0.44	2.93	1.02
Blended Sands	River+Pit	2.80	0.10	2.97	2.53	1.4	0.6	2.4	0.2	63.5	2.1	66.2	58.2	1.604	0.054	1.680	1.430	2.57	0.03	2.62	2.52	1.69	0.60	2.38	0.13
Blended Sands	River+Sea	2.77	0.11	3.05	2.57	1.4	0.4	2.0	0.4	63.8	1.8	67.2	61.1	1.634	0.053	1.745	1.520	2.60	0.03	2.64	2.54	1.59	0.39	2.35	1.04
Blended Sands	River+Crushed	2.78	0.07	2.89	2.62	2.3	0.9	4.7	1.1	64.8	2.5	68.9	61.5	1.665	0.066	1.760	1.550	2.61	0.03	2.65	2.57	1.75	0.49	2.75	0.83
Blended Sands	Land +Pit	2.71	0.11	2.94	2.45	1.6	0.5	2.6	0.7	64.5	2.1	68.7	61.6	1.625	0.060	1.745	1.530	2.57	0.02	2.61	2.54	1.96	0.57	3.12	1.29
Blended Sands	Land +Sea	2.79	0.10	2.89	2.60	1.5	0.5	2.1	0.9	64.4	1.4	66.4	62.9	1.632	0.044	1.690	1.573	2.58	0.04	2.64	2.54	1.90	0.52	2.79	1.29
Blended Sands	Land +Crush	2.71	0.11	2.89	2.42	1.9	0.9	3.7	0.8	63.5	1.5	65.9	60.8	1.629	0.054	1.710	1.557	2.61	0.04	2.68	2.55	1.64	0.40	2.34	0.83
Blended Sands	Pit +Sea	2.76	0.11	2.90	2.57	1.7	0.4	2.1	1.0	63.2	2.5	69.0	59.6	1.586	0.071	1.730	1.470	2.55	0.02	2.60	2.50	1.85	0.37	2.60	1.30
Blended Sands	Pit +Crushed	2.67	0.18	2.99	2.30	1.9	0.8	3.8	0.4	63.3	1.9	67.9	59.9	1.625	0.056	1.759	1.530	2.61	0.03	2.65	2.57	1.57	0.34	2.14	1.10
Blended Sands	Sea +Crushed	2.72	0.10	2.90	2.34	1.9	0.9	4.5	0.4	62.8	1.6	65.9	58.8	1.598	0.057	1.768	1.480	2.59	0.06	2.82	2.54	1.57	0.39	2.25	0.73
Blended Sands	Total	2.73	0.11	3.05	2.30	1.7	0.7	4.7	0.2	63.6	2.0	69.0	56.2	1.617	0.058	1.768	1.430	2.59	0.04	2.82	2.50	1.71	0.46	3.12	0.13
Total		2.74	0.11	3.05	2.04	1.5	0.7	4.8	0.1	63.8	2.3	72.5	56.2	1.621	0.070	1.920	1.420	2.56	0.04	2.82	2.50	1.72	0.50	3.58	0.13

Notes : Number of data is Table 4. $\bar{x}$: Average value, x_σ : Standard deviation, x_{max} : Maximum value, x_{min} : Minimum value

Table 3 Quality of Coarse Aggregate (Maximam size 25mm, Investigation Ⅲ)

Kinds of aggregate \ Item		Percentage of solid volume G_O (%)				Weight of unit volume G_T (kgf/l)				Specific gravity G_H (−)				Absorption capacity G_Q (%)				Content of soft particle G_Y (%)				Soundness G_D (%)			
		$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}	$\bar{x}$	x_σ	x_{max}	x_{min}
	River gravel	63.5	1.4	67.7	60.4	1.655	0.048	1.827	1.549	2.64	0.04	2.80	2.49	1.24	0.54	3.56	0.48	1.9	1.3	7.4	0	4.8	0.3	14.8	0.3
	Land gravel	64.0	1.5	68.2	60.0	1.652	0.049	1.810	1.540	2.62	0.04	2.73	2.52	1.49	0.72	3.63	0.30	2.7	2.6	19.3	0	4.6	2.4	11.2	0
	Pit gravel	63.9	1.8	66.6	60.3	1.647	0.047	1.715	1.550	2.60	0.01	2.65	2.59	1.11	0.39	1.73	0.45	2.4	1.4	4.5	0.1	4.4	1.8	9.0	1.0
	Crushed stone	59.1	1.3	63.4	56.1	1.580	0.060	1.770	1.460	2.70	0.09	3.05	2.52	1.00	0.55	2.74	0.25	1.2	1.3	8.1	0	3.7	2.0	12.6	0
Blended gravels	River+Land	62.8	1.2	64.1	61.4	1.636	0.039	1.678	1.570	2.64	0.03	2.68	2.60	1.33	0.33	1.66	0.90	2.0	1.2	4.3	1.1	4.5	1.7	6.7	1.5
Blended gravels	River+Pit	63.9	1.2	65.5	62.7	1.665	0.021	1.690	1.640	2.64	0.03	2.68	2.61	1.45	0.65	2.42	1.10	2.7	1.2	4.4	1.9	5.3	3.6	10.3	1.8
Blended gravels	River+Crushed	62.0	1.3	64.6	58.5	1.627	0.037	1.678	1.545	2.65	0.03	2.70	2.60	0.88	0.27	1.58	0.42	1.6	1.2	3.9	0	4.0	1.9	6.7	0.3
Blended gravels	Land +Crushed	62.1	1.4	64.4	60.1	1.625	0.041	1.705	1.560	2.65	0.02	2.68	2.60	1.05	0.38	1.77	0.64	2.1	1.2	3.8	0	4.8	2.3	8.4	1.4
Blended gravels	Pit +Crushed	60.7	1.3	62.3	58.1	1.588	0.036	1.620	1.510	2.64	0.01	2.66	2.62	0.83	0.20	1.18	0.50	1.5	1.2	3.3	0	3.4	1.7	6.9	1.7
Blended gravels	Sea +Crushed	60.4	2.4	62.1	58.7	1.615	0.036	1.640	1.589	2.69	0.04	2.72	2.66	0.56	0.21	0.70	0.41	0.8	0.4	1.0	0.5	3.0	0.8	3.5	2.4
Blended gravels	Total	62.0	1.5	65.5	58.1	1.624	0.040	1.705	1.510	2.65	0.03	2.72	2.60	1.04	0.38	2.42	0.41	1.8	1.3	4.7	0	4.2	2.1	10.3	0.3
Total		61.3	2.5	68.2	58.1	1.616	0.063	1.827	1.460	2.67	0.08	3.05	2.49	1.13	0.57	3.63	0.25	1.7	1.6	19.3	0	4.2	2.3	14.8	0

Note : Number of data is Table 4.

blend of sea sand (in order to adjust mainly the chloride content) caused consequently the increase of mass of unit volume (improvement of quality is caused), and a blend of crushed sand caused the increase of specific gravity and loss in washing test et al.. Comparing the quality of river sand with that of TOMEI (almost river sand was used, see Fig. 2), it is noticed that all the items of quality areon the bad side and even in the case of river sand the qualities turn deteriorative.

In the case of coarse aggregate, when the quality of crushed stone is compared with river gravel, land gravel and pit gravel, mass of unit volume and solid volume percentage are low and shape of particles is bad, but specific gravity, absorption capacity, soundness and soft particles are low, and quality of aggregate becomes good. As compared with the individual of crushed stone, the blended gravel which is blended with crushed stone have a large mass of unit volume and a large solid volume percentage, and qualities become improved. Comparing the quality of river gravel with that of TOMEI (almost river gravel was used, see Fig. 2), specific gravity is low and absorption capacity is large, and qualities are on the bad side. As river sand, even in the case of river gravel the qualities turn deteriorative.

3.3 Concrete (Investigation Ⅱ and Investigation Ⅲ)

(1) Change of qualities of concrete

Comparing also with the case of concrete $4(B_{1-1})$, the change of qualities of concrete is shown in Fig. 2. With the change of the aggreates to be used, the unit water content increases by 20 kg/m^3 more than that of MEISHIN, and also increases by 10kg/m^3 more than that of TOMEI. And the sand-aggregate ratio increases by 4 % more than that of MEISHIN, and also increases by 2 % more than that of TOMEI. After the early 1970's, the former increases by 1～2 kg/m^3 and the latter increases by 1～2 %, and the trend of slight increase is recognized. As discussed above, this reason was that:
As the river sand and gravel which have good shape of perticles have decreased, the crushed stone and sea sand which have angular and flat shape of perticles have increased and the fine and coarse aggregates became multifarious. And in order to get the same workability of concrete, it is needed that unit water

Table 4 Combinations of Fine Aggregate and Coarse Aggregate (Investigation Ⅲ)

Coarse Aggregates \ Fine Aggregates		River Sand	Land Sand	Pit Sand	Sea Sand	Crushed Sand	Blended Sands											Total
							River+ Land	River+ Pit	River+ Sea	River+ Crushed	Land + Pit	Land + Sea	Land + Crushed	Pit + Sea	Pit + Crushed	Sea + Crushed	Sub-total	
River Gravel		93 (16.9)	9 (1.6)	2 (0.4)	1 (0.2)	1 (0.2)	9 (1.6)	7 (1.3)	8 (1.5)	4 (0.7)	0	0	0	1 (0.2)	0	0	29 (5.3)	135 (24.5)
Land Gravel		4 (0.7)	38 (6.9)	2 (0.4)	0	0	9 (1.6)	1 (0.2)	0	1 (0.2)	5 (0.9)	3 (0.5)	1 (0.2)	1 (0.2)	0	0	21 (3.8)	65 (11.8)
Pit Gravel		0	0	20 (3.6)	0	0	0	0	0	0	0	0	0	0	0	0	0	20 (3.6)
Crushed Stone		17 (3.1)	14 (2.5)	22 (4.0)	82 (14.9)	6 (1.1)	8 (1.5)	5 (0.9)	5 (0.9)	5 (0.9)	16 (2.9)	3 (0.5)	13 (2.4)	11 (2.0)	14 (2.5)	36 (6.5)	116 (21.1)	257 (46.7)
Blended Gravels	River+ Land	0	0	0	1 (0.2)	0	5 (0.9)	0	0	0	0	0	0	0	0	0	5 (0.9)	6 (1.1)
	River+ Pit	0	0	0	0	0	0	4 (0.7)	0	0	0	0	0	0	0	0	4 (0.7)	4 (0.7)
	River+ Sea	0	0	0	0	0	0	1 (0.2)	0	0	0	0	0	0	0	0	1 (0.2)	1 (0.2)
	River+Crushed	5 (0.9)	3 (0.5)	5 (0.9)	1 (0.2)	0	11 (2.0)	2 (0.4)	5 (0.9)	4 (0.7)	0	0	0	1 (0.2)	1 (0.2)	1 (0.2)	25 (4.5)	39 (7.1)
	Land +Crushed	1 (0.2)	3 (0.5)	2 (0.4)	0	0	2 (0.4)	0	0	0	1 (0.2)	0	4 (0.7)	0	0	0	7 (1.3)	13 (2.4)
	Pit +Crushed	0	0	4 (0.7)	0	0	0	3 (0.5)	0	0	0	0	0	0	1 (0.2)	0	4 (0.7)	8 (1.5)
	Sea +Crushed	0	0	0	0	0	0	0	1 (0.2)	0	0	0	0	0	0	1 (0.2)	2 (0.4)	2 (0.4)
	Subtotal	6 (1.1)	6 (1.1)	11 (2.0)	2 (0.4)	0	18 (3.3)	10 (1.8)	6 (1.1)	4 (0.7)	1 (0.2)	0	4 (0.7)	1 (0.2)	2 (0.4)	2 (0.4)	48 (8.7)	73 (13.3)
Total		120 (21.8)	67 (12.2)	57 (10.4)	85 (15.4)	7 (1.3)	44 (8.0)	23 (4.2)	19 (3.5)	14 (2.5)	22 (4.0)	6 (1.1)	18 (3.3)	14 (2.5)	16 (2.9)	38 (6.9)	214 (38.9)	550 (100)

Note : Upper side : Number of Concrete Plants, Lower side : Constitution Ratio (%)

content increases and sand-aggregate ratio also increases.

Though compressive strength changes as mix proportioning strength changes, it remains on the almost same level. With this trend, there are almost no fluctuations also in the water-cement ratio. The unit water content and the unit cement content are slitely increased.

(2) Qualities (kinds) of Aggregate and Qualities of Concrete

Table 4 shows the combinations of fine aggregate and coarse aggregate to be used (the examples from REMI CON '86). There are great differences among ready-mixed concrete plants concerning their aggregate conditions. The order of numbers of combination is that:
river sand and river gravel = 16.9 %, sea sand and crushed stone = 14.9 %, land sand and land gravel = 6.9 %, blended sand (sea sand and crushed sand) and crushed stone = 6.5 %, pit sand and crushed stone = 4.0 %, pit sand and pit gravel = 3.6 %, river sand and crushed stone = 3.1 %, blended sand (land sand and pit sand) and crushed stone = 2.9 %, etc..
The maximum number of combination is blended sands and crushed stone (21.1 %).

As a whole, there are a large number of combinations that the production areas

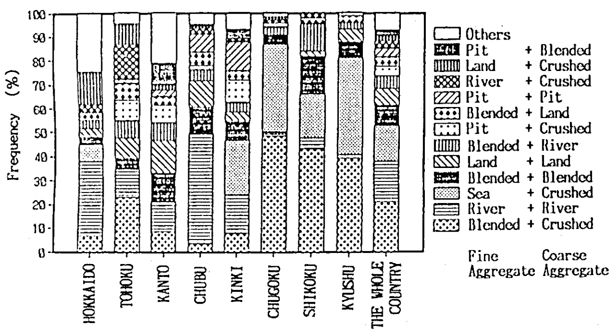


Fig.4 Combinations of fine aggregate and coarse aggregate at diffrent districts (Investigation Ⅲ)

Table 5 The kinds of Aggregate and Concrete Qualities (Ready-mixed Concrete corresponds to Concrete 4(B_{1-1}), Investigation Ⅲ)

Case	Coarse Aggregate	Fine Aggregate	Number of data n	Maximum Size of Coarse Aggregate G_M (mm) $\bar{x}$	x_σ	x_{max}	x_{min}	Unit Cement Content C (kg/m³) $\bar{x}$	x_σ	x_{max}	x_{min}	Unit Water Content W (kg/m³) $\bar{x}$	x_σ	x_{max}	x_{min}	Water-Cement Ratio W/C (%) $\bar{x}$	x_σ	x_{max}	x_{min}	Sand-Aggregate Ratio s/a (%) $\bar{x}$	x_σ	x_{max}	x_{min}	Compressive Strength at mix design f_{c28} (kgf/cm²) $\bar{x}$	x_σ	x_{max}	x_{min}
1	Gravel	Normal		25								145				55				38							
2	River	River	93	25	0	25	25	288	13	318	259	152	6	164	136	52.8	2.1	56.9	47.9	42.1	2.0	47.3	36.9	305	15	362	278
		Blended	29	25	1	25	20	291	14	318	266	153	7	169	141	52.4	1.9	56.0	49.0	41.7	2.0	45.4	36.6	299	14	331	273
	Land	Land	38	25	0	25	25	287	15	315	255	150	5	160	140	52.3	2.3	56.0	47.0	41.8	1.9	45.4	37.4	304	18	360	260
		Blended	21	25	2	25	20	293	13	317	272	153	8	162	143	52.4	2.1	57.0	49.0	42.5	2.0	46.9	37.5	303	11	323	283
	Pit	Pit	20	25	0	25	25	292	12	317	274	152	4	159	146	52.1	1.8	54.9	47.3	41.3	1.8	45.2	38.1	316	17	353	289
	Crushed	River	17	24	2	25	20	306	12	326	275	163	6	176	149	53.3	1.0	55.0	50.9	43.4	2.2	46.7	37.3	314	21	355	276
		Land	14	24	2	25	20	295	17	324	263	159	7	169	143	53.9	2.3	58.4	50.0	44.0	2.0	46.1	40.1	308	14	343	291
		Pit	22	22	3	25	20	292	23	325	243	161	6	169	148	55.3	2.9	62.1	50.0	44.4	1.6	47.6	40.6	313	16	349	284
		Sea	82	20	1	25	20	315	12	340	272	169	5	182	147	53.8	1.5	58.4	50.0	44.6	1.1	46.9	41.0	305	15	337	263
		Blended	116	21	2	25	20	306	15	343	255	166	7	182	143	54.2	1.9	60.0	49.0	44.8	1.6	49.5	38.5	310	17	362	280
	Blended	Pit	11	25	0	25	25	278	16	300	256	153	6	163	148	55.3	1.8	57.4	52.9	42.8	1.5	45.7	41.1	310	19	352	292
		Blended	48	24	2	25	20	290	14	322	262	157	7	170	141	54.0	1.7	58.4	49.8	42.8	2.4	48.1	36.9	309	13	333	285
	Total	Total	550	23	2	25	20	297	18	343	243	159	10	182	136	53.5	2.2	62.4	47.0	43.3	2.3	49.5	35.5	308	16	362	260

Case 1) : The value from Table C 4.8.1 in Standard Specification for Design and Construction of Concrete Structures, Part 2 (Construction). Sand (fineness modulus = about 2.80) of ordinary gradations as aggregates.
Case 2) : The value from Investigation Ⅲ. In the case of maximum size of coarse aggregate=20・25mm, Slump=8cm and n>10.

for fine aggregate is the same as that for coarse aggregate. However, as for crushed stone, there are various combinations because it is used widely throughout Japan. So, it ranks 1/2 of a whole (see Fig. 4).

Therefore, in order to consider the infuluence of fine and coarse aggregate to concrete quality, the relationships between the each kinds of coarse aggregate and mix proportions or compressive strength are shown in Table 5. The concrete made up of crushed stone needs more unit cement content, unit water content and water-cement ratio than that made up of river gravel, land gravel and pit gravel. The reason for this is as follows:
Because the particle shapes of crushed stone is angular and flowability is inferior, unit water content to get the required slump is needed much more value. But because the cohesion between the surface of aggregate and cement paste is good, and comparing with river gravel, it has good qualities of aggregate such as specific gravity, absorption capacity and so on. Even if the water-cement ratio is large, required strength can be fulfiled [13], [14].

Furthermore, as for the concrete made up of crushed stone, comparing the relationship between the kinds of fine aggregates and mix proportions (or compressive strength), it is shown that the different kinds of fine aggregates influence to mix proportion and compressive strength greatly. The average value of unit water content of sea sand is higher by 10 kg/m^3 than that of land sand, unit cement content is also higher by 20 kg/m^3 than that and water-cement ratio is lower by 0.3 % than that. But compressive strength is lower by 3 kgf/cm^2 than that. In the case of blended sand, there is no constant trend. But, in the case of sea sand, blending tends to cause high strength although it has low unit cement content. It is understood that blending may causea improvement of quality.

Consequently a regional difference of concrete has arisen (see Fig.5) [9], [11]. In the region where the sea sand and crushed stone are used, unit water content and unit cement content are high, but on the other hand strength index is low and compressive strength is low as well. Where, strength index is defined by (b/W)

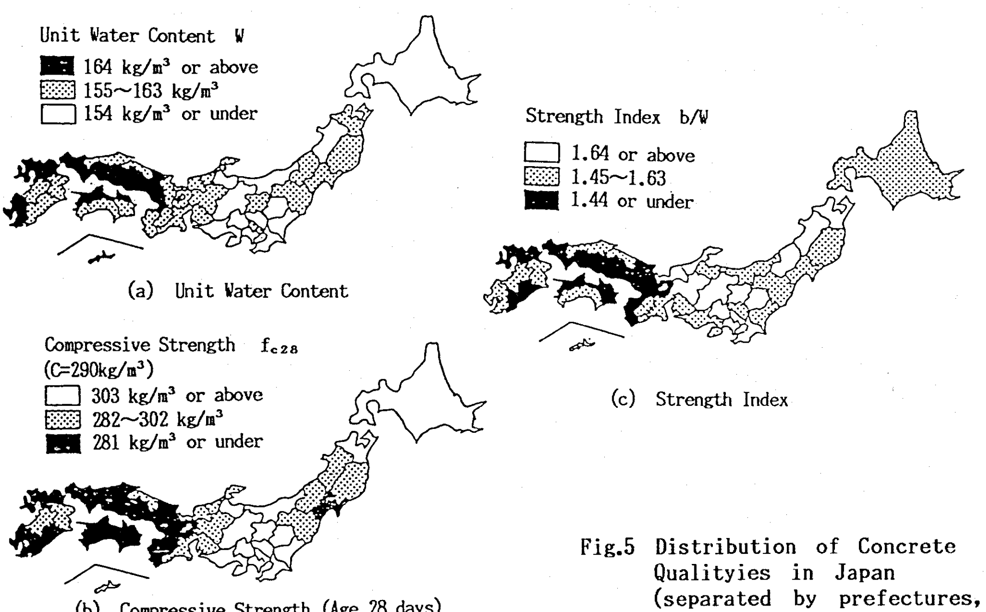


Fig.5 Distribution of Concrete Qualityies in Japan (separated by prefectures, Investigation III)

which is adopted from an equation [11], [12]:

$$f_{c28} = a + b\cdot(C/W)$$

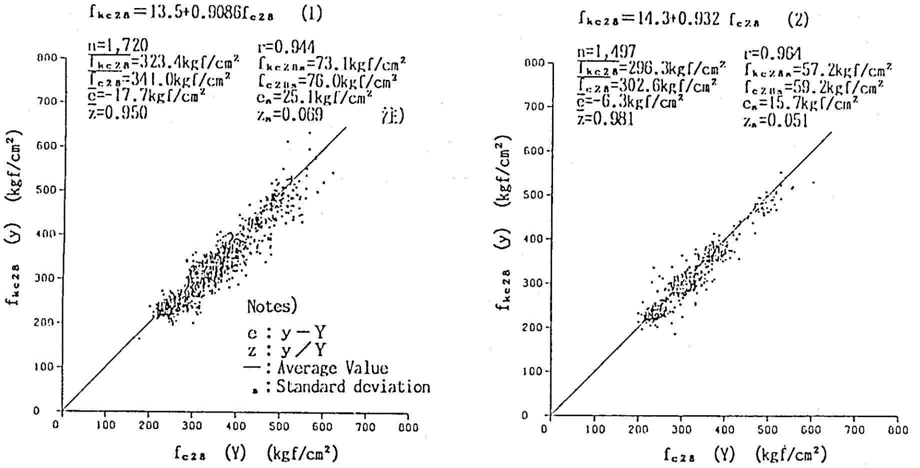
When approximate values of sand-aggregate ratio and unit water content (which have been given in Table C4.8.1 of "Standard Specification for Design and Construction of Concrete Structures" [2]) are compared with the present, it is shownthat unit water content is low by 7 kg/m³ and sand-aggregate ratio is low by 4%.Considering the kinds of combination of aggregate are numerous, the author proposes revising the approximate values and correction values. The values in Table 5 are proposed as standard ones, and also the values in Table 10 of the reference [12] are proposed as correction ones.

3.4 QC and Quality of Concrete (Investigation I ~ Investigation IV)

(1) Relation between compressive strength of the actual control test results (actual results of shipment) and compressive strength of the mix design results (trial mixtures results)

From Fig. 2 (k) and (l), searching for the relation between average value f_{KC28} of compressive strength of the actual control test results (actual results of shipment of REMI CON) f_{KC28}' and the compressive strength of the mix design results (trial mixtures results, tested in the test room) f_{c28}, in the case of KODAN CON, the former is lower by 3~7 % (average value) than the latter. When this relation is searched in representive COMPLETION '82~'83 (see Fig. 6(a) and equation (1)), there is the high correlation between f_{kc28} and f_{c28} (correlation coefficient r = 0.944, standard error e_s = 25.1 kgf/cm²). The value $z = f_{kc28}/f_{c28}$ is in the range of 1.20 ~0.67, and the strength is low by 5.0 % (average value, 17.7 kgf/cm²).

On the other hand, in the case of REMI CON, when this relation is also searched in representive REMI CON '86 (see Fig. 6(b) and equation (2)), there is the high correlation (r = 0.964, e_s = 15.7 kgf/cm²). The average value of strength is low by 6.3 kgf/cm² (1.9 %), and that value is smaller by 11 kgf/cm² than KODAN CON. However, from Fig. 2, in spite of almost same qualities of the materials to be used and almost same water-cement ratio, both f_{kc28} and f_{c28} are lower than KODAN



(a) KODAN CON (Investigation II) (b) REMI CON (Investigation II)

Fig. 6 Relation between f_{kc28} and f_{c28}

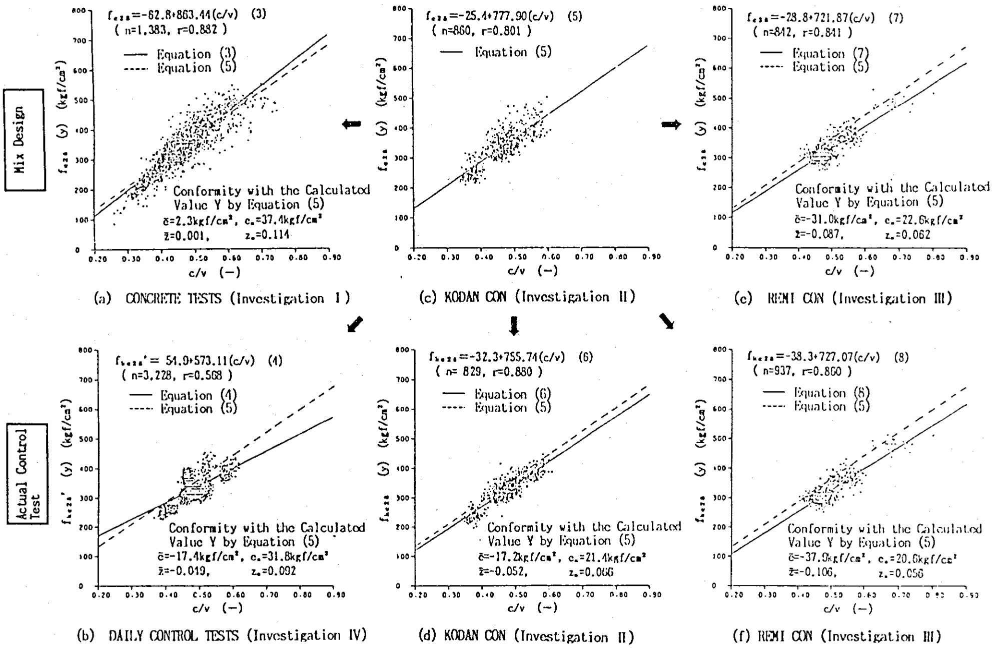


Fig. 7 Relation between compressive strength and cement-void ratio

Con and the tendency is different. The reason for this will be considered in the following section.

(2) Influence of QC against Quality of Concrete

From the results of Investigation I ~ IV, Fig. 7 shows the relations between compressive strength f_{kc28} (or f_{c28}) and cement-void ratio c/v in the case of the concrete in which ordinary portland cement, maximum size of coarse aggregate = 20 or 25 mm and air-entraining and water-reducing agents are used. All of them are closely correlated. In the case of the mix design results, KODAN CON is almost equal to the indoor test results of CONCRETE TESTS (Investigation I), but the compressive strength of KODAN CON is higher by 31 kgf/cm^2 (8.7%) in average than that of REMI CON (Investigation III). In the case of the actual control test results, the compressive strength of KODAN CON is lower by about 5 % (DAILY CONTROL TESTS = 4.9%, KODAN CON = 5.2%) than that of the mix design results but REMI CON is lower by 10.6% (average value 38 kgf/cm^2) than that, and the amount of drop is considerable.

As for the reason for this, it is judged that concrete quality at shipment is determined by the differences of quality variations (drop) of manufacturing facilities and quality control conditions against the strength of mix design that is essentially what is true concrete quality. Giving concrete examples, there are differences of mixing efficiency of mixers [15], differences of curing conditions, differences of grading of aggregate, errors in correction of over and under particle-size, mixture of farmful amount of mud and dust in aggregates, errors in correction of surface moisture, use of sludge water or not, variation of concrete temperature (weather conditions), transport method, variation of transport time, residual substance of sludge water, etc., slump and air content

Table 6 Ready-mixed Concrete Plants (Nomber of Investigated Plants= 243)

No	Mainly pointed out matters or advised matters	Number of matters (frequency) amount (%)
1	Badness of maintenance and cleaning in various places of plant	167 (68.7)
2	The remainder aggregates at belt conveyor, turnhead and batching hopper	115 (47.3)
3	Unpreparedness of shed of stock yard	78 (32.1)
4	Inadequate drainage at stock yard and plant yard	71 (29.2)
5	Insufficient height of partition wall of colgate silo and stock yard	58 (23.9)
6	Lack of test implements and equipments	53 (21.8)
7	Lack of testers	49 (20.2)
8	Unpreparedness or unsuitable position of belt comveyor cleaner	44 (18.1)
9	Unpreparedness of cover of belt conveyor	42 (17.3)
10	Leakage of mixing water and chemical admixtures from batching hopper, etc.	39 (16.0)
11	Lack of volume and number of stock yard, colgate silo	34 (14.0)
12	Unreasonable indication of kinds of aggregate and cements	30 (12.3)
13	Unreasonable grading and particle shape of aggregate, insufficiency of washing	29 (11.9)
14	Number shortage on correction of surface moisture of aggregate	23 (9.5)
15	Remaining concrete inside mixer, leakage from gate	21 (8.6)
16	Unpreparedness or unsuitable position of monitor television	17 (7.0)
17	Certain action of monthly quality control and daily control tests	17 (7.0)
18	Badness of batching equipments	17 (7.0)
19	Unpreparedness of prevention equipment for overweighing chemical admixtures	14 (5.8)
20	Uses of sludge water	12 (4.9)

also drop. Therefore at the stage of mix design it is supposed that there are many cases that the specified mix of REMI CON was determined from actual results of shipment without actual mix design (trial mixtures tested in test room). The ratio is 27% of a whole according to questionnaires (REMI CON '78).

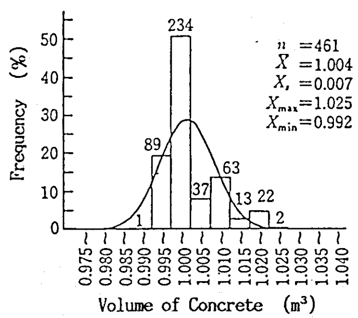


Fig. 8 Concrete Volume (Investigation Ⅲ)

Table 6 shows the main matters which are advised the inspected supplier's plants on improvement of manufacturing facilities and the method of quality control at inspection of plants in 1983～1985 [3]. The matters pointed out are influencing items on quality variation of aggregate, influencing items on quality variation because of bad facilities, influencing items on quality variation because of bad control, etc.. Like this, manufacturing techniques of JIS Ready-Mixed Concrete have made great advandes during last 40 years, but under the present situation there are many cases that quality control system includes some problems for steady manufacturing. Then, from Fig. 2 (j), in the case of the mix proportion of REMI CON, sand-aggregate ratio is larger than that of KODAN which decided the most suitable sand-aggregate ratio by test mix, in spite of almost same water-cement ratio. This tendency is recognized generally, and this fact became a factor increasing the unit water conent. Moreover, Fig. 8 shows the concrete volumes (average value of each plants) which are calculated from the specific gravity of materials, speciffied mix and air content of actual results of shipment. Because the method to calculate the mix peoportions does not standardized in JIS, the range of concrete volume is 0.992～1.025 m^3 and it is generally over 1 m^3, and this volume error (mix proportion error) bring about more error to batching error.

Judging from above mentioned facts, the qualities of ready-mixed concretes are varied according to the system of inspection and advice by purchaser (supervisor), manufacturing facilities of plants, the system of quality control, the calculating method of mix proportion, the situation of aggregate, weather condition, regional character et al.. Therefore it is considered that the great differences among plants have arisen due to these factors.

4. CONCLUSIONS

As the results of this study the followings are obtained:

(1) As for the aggregate resources for concrete in Japan, the high quality river sand and gravel have been decreasing, and the kinds of aggregates have become deteriorative and multifarious. This trend is especially remarkable on fine aggregates.

(2) Nowadays, in Japan, the representative aggregates which are used in the concrete are blended sand as fine aggregate and crushed stone as coarse aggregate. The ratio of concrete which use this combination of aggregates is the most highest one. The crushed stone concrete accounts for about 1/2 of a whole.

(3) The qualities of ready-mixed concretes are greatly influenced by aggregates to be used. The regional differences of concretes have arisen.

(4) It is generally recognized that the compressive strength of concrete at shipment (actual concrete test results) is lower than that of concrete at mix design (trial mixtures), the tendency that arise strength drop is recognized as a whole. It is considered that the amount of drop depends on system of quality control. In the case of excellent quality control the average amount of drop is about 5% and in the case of common quality control it is about 10%.

(5) According to the system of inspection and advice by purchaser (supervisor), manufactuting facilities of plants, the system of quality control, the calculating method of mix proportion, the sutuation of aggregate, weather condition, regional charactor et al., the qualities of ready-mixed concretes are varied among plants.

This study is a part of docter dissertation by which the author received his Doctor of Engineering degree from the University of Tokyo in June 1988.

ACKNOWLEDGEMENT

The author would like to express his deepest appreciation to Dr. k. Kobayashi, Professor of the University of Tokyo, for his helpful suggestion. The author would like to thank the members of Engineering Department of Head Office of KODAN, Laboratory of KODAN, Experiment Section of 10 Construction Bureau of KODAN, The Laboratory of Cement Association of Japan and the ready-mixed concrete plants in the whole Japan. Finally all supporters of this study should be gratefully acknowledged.

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