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ACCURACY OF MEASURING AND FEEDING EQUIPMENTS OF AGGREGATES IN CONTINUOUS MIXERS FOR CONCRETE

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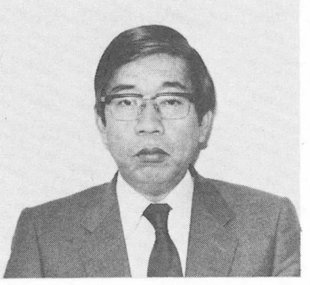
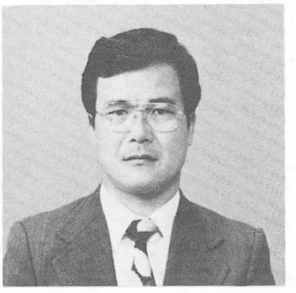

Noriaki NISHIZAWA Hirotomo YOSHIDA Yukikazu TSUJI

SYNOPSIS

Aggregates are continuously measured by volume in a continuous mixer. For controlling and determining the quantities of fine and coarse aggregates, devices such as counters and cut gates are employed. This paper presents the accuracy of measuring and feeding equipment of aggregates in the continuous mixer. A residual aggregate in the container and the operation of cut gate in an aggregate feeder of the continuous mixer do scarcely affect the quantity of aggregate, and the accuracy in measuring and feeding aggregate is within the required tolerances. With one measuring and feeding equipment, coarse aggregates with maximum size of 40 mm can be dispensed within ±3 percent of the amount required. The effects of surface moisture content and bulking factor of the fine aggregate, and grading of the fine and coarse aggregates on the quantities of aggregates supplied by the continuous mixer are also experimented.

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1. INTRODUCTION

One of the most important problems concerning the usage of continuous mixers in the production of concrete is whether or not, the continuous mixer is capable to measure and feed a certain designated quantity of aggregate within a required tolerance. Since the materials are measured by volume in most of the commonly used continuous mixers, changes in the dispensed aggregate quantities due to the surface moisture and their grading have been pointed out as important problems. However, experimental results concerning the effect of these factors on the measurement and feed of aggregates have been scarcely reported. In particular, testing results on the performance of aggregate measuring and feeding devices set beneath containers from a full state to an empty state have not yet been obtained.

The quantity of aggregate batched is independent of the residual volume of aggregate in the container. The variation in the measured quantity of aggregate, when the continuous mixer is operated from a full stored state to an empty state has been scarcely experimented. When using continuous mixers for the production of concrete, it is very rare to change its mix proportion frequently. However, when it is necessary to change this mix proportion, the aggregate feeder cut gates, which are measuring devices connected to setting dials, must be operated up and down. Apart another problem not discussed yet is whether or not a two line aggregate feeding system is indispensable in order to secure the prescribed accuracy, when aggregates of large particle size are used. Whenever a calibration of the measuring device is carried out, it is usual to measure and dispense fine and coarse aggregates individually. However, in reality, fine and coarse aggregates are fed simultaneously. Apart another problem not investigated by experiments is whether or not the quantity of aggregate during the calibration of the measuring device and the quantity of aggregate during the actual operation of the continuous mixer, are different from each other.

In this paper, experimental results concerning the measuring and feeding accuracy of aggregates in continuous mixers are reported, which help to

Table 1 Details of continuous mixers and supplementary equipment

		Series1	Series2		
		CM250	CM250-A	CM250-B	Supplementary equipment
Mixing capacity (m^3/hr)		25	25	25	——
Number of counts per minute		231	167	153.7	245
Velocity of belt feeder (m/min)		24.47	20.44	18.82	11.75
Movement of aggregate (m/100 counts)		10.59	12.24	12.24	4.80
Width of cut gate (mm)	fine	161	161	161	——
	coarse	217	217	217	173
Volume capacity of container (m^3)	fine	4.6	4.6	4.6	——
	coarse	4.6	4.6	4.6	2.0
	cement	1.4	1.4	1.4	——
	water	1.4	1.4	1.4	——
	admixture	0.3	0.3	0.3	——

understand better their operational problems. This experiment was performed as one of activities of the Subcommittee on Recommendations for Mixing Concrete in Site in the Japan Society of Civil Engineers (JSCE).

2. OUTLINE OF THE EXPERIMENTS

The experiments were organized in two series. Series 1 was carried out in Mie Ube Nama-concrete Industry Co.,Ltd. in February 1984, and Series 2 in Sugiue Engineering Co.,Ltd. in March of the same year.

The layout of the continuous mixer, measuring hopper and other equipments used for Series 1, is explained in Fig. 1. In Series 2, two continuous mixers, which were of the same type as the one used in Series 1, were adopted in order to establish the difference of performance between two mixers of the same type. A supplementary measuring and feeding equipment to be used exclusively for aggregates was accommodated in combination of the continuous mixer in order to set up a two line feeding system. Details of these equipments are summarized in Table 1.

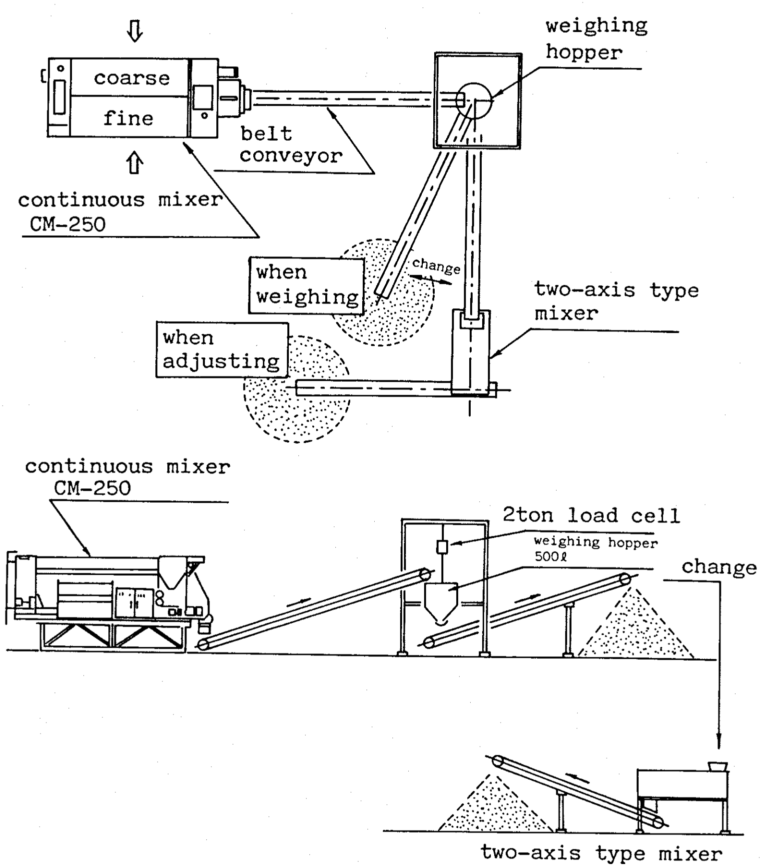


Fig. 1 Layout of a continuous mixer, weighing hopper and other equipments used for Series 1

For the continuous mixers, the mixing capacity of 25m^3/h was selected because of its popular usage. The capacity of the storage container for both fine and coarse aggregates was 4.6m^3 and the aggregates were discharged on a belt feeder set beneath the storage container.

The quantities of the aggregates were controlled and determined by calibrated cut gate openings adjusted by setting dials. The velocity of the belt feeder was about 20m per minute, and was different for each of the continuous mixers depending on the decreasing motor ratio. The width of the cut gate was 161 mm for fine aggregates and 217 mm for coarse aggregates. Openings and areas of the cut gates corresponding to various positions of the setting dials are tabulated in Table 2 as an example.

Table 2 An example of openings and areas of cut gates versus values of setting dials in a continuous mixer

Value of setting dial	Opening of cut gate (mm)	Area of cut gate (cm²)	
		fine aggre.	coarse aggre.
3	32.27	51.96	66.81
4	44.84	72.19	92.82
5	57.40	92.42	118.83
6	69.97	112.66	144.84
7	82.54	132.89	170.85
8	95.11	153.12	196.86
9	107.67	173.35	222.88
10	120.24	193.58	248.89

A vibrator was attached to the exterior surface of the fine aggregate container in order to facilitate the discharge of the aggregates. The vibrator was operated in connection with the belt feeder even when the coarse aggregates themselves were discharged. The frequency of the vibrator was 3450vpm., and the amplitude 2.1 mm.

The volume of the weighing hopper was 500 liters, the scale reading capacity of the digital type load cell was 2 ton with a minimum of 1 kgf.

Aggregates were generally shoveled into the storage container, but occasionally a belt conveyor was used in case of continuous feeding.

In the majority of the experiments, the continuous mixer was operated during a specified period to measure and dispense the aggregates into the weighing hopper, after which the quantity of aggregate was weighed by a load cell. The sequence was continued since when the storage container was full of aggregate until it was empty. The operation time of the mixer was measured by a counter set in a meter (see Table 1).

In Series 1, the mixer was stopped by every 100 counts, and the weight of the aggregate in the weighing hopper was measured by the load cell. Measurement was continued up to four batches, namely 400 counts of the meter, after which the gate of the hopper was opened to discharge the aggregates weighed accumulately. In Series 2, this operation was done every 150 to 400 counts. This testing method has been rarely adopted, nevertheless it may be the most severe one for obtaining the accuracy of measurements and feeding of ingredients of concrete by means of a continuous mixer.

In the two series, the experimental factors were the type, grading and surface moisture content of the fine aggregates and the type and grading of the coarse aggregates. In the same way as for the grading of the aggregates, values such as the weight per unit volume, the solid volume percentage of bulk aggregate, and the fineness modulus were measured separately in order to select an appropriate parameter which would have the best correlation with the quantity of dispensing aggregate. Physical properties of the aggregate are shown in Table 3.

Table 3 Physical characteristics of aggregates

Series	Kind	Specific gravity	Absorption (%)	Weight of unit volume (kgf/l)	Solid volume percentage (of bulk aggregate) (%)	Fineness modulus
1	River sand	2.60	1.68	1.62	63.5	2.77
	River sand	2.59	1.66	1.56	61.4	2.64
	Pit sand	2.58	1.76	1.58	62.5	2.84
	Crushed sand	2.80	1.50	1.73	62.8	2.50
	River gravel	2.64	0.81	1.58	60.1	6.69
	Pit gravel	2.61	0.83	1.60	61.9	7.11
	Crushed stone	2.65	0.60	1.56	59.3	6.30
	Crushed stone	2.65	0.56	1.60	60.6	6.38
	Crushed stone	2.65	0.54	1.59	60.3	6.57
	Crushed stone	2.66	0.54	1.66	62.7	7.25
2	Sea sand	2.52	2.10	1.22	48.4	1.71
	Crushed sand	2.58	2.49	1.59	63.3	2.42
	Blended sand	2.56	1.60	1.39	54.3	2.57
	River sand	2.61	1.30	1.48	56.7	2.24
	Crushed stone 2005	2.66	2.60	1.50	56.4	7.17
	Crushed stone 4020	2.63	2.26	1.50	57.0	7.91
	Crushed stone 4005	2.66	2.29	1.55	58.2	7.43

In the case of the fine aggregates, adjustments of the surface moisture content were done by blending with oven-dry fine aggregates and water. These were dried in a dryer from an asphalt mixing plant. The blending was performed by a two-axis type mixer in the case of Series 1 and a continuous mixer in Series 2. these mixers were also used for adjusting the grading of the aggregates.

3. MEASUREMENT ACCURACY AND BATCH QUANTITY

In most of the cases of Series 1, the continuous mixer was operated to feed the aggregates to the weighing hopper and measure the cumulative weight of the aggregates every 100 counts up to 400, after which, the aggregates were discharged from the hopper. This operation was carried out continuously beginning when the container was full with aggregates until it was empty. The minimum measure of the load cell was 1 kgf. Although the quantities of the sample per 100 counts varied with the different values of the setting dial, weights of the sample were approximately 45 kgf to 130 kgf for fine aggregates and 85 kgf to 215 kgf for coarse aggregates. These measured values were arranged in every 100, 200 and 400 counts. Average values x and coefficients of variation v of these values are tabulated in Table 4.

The cases in which the weight of sample per 100 counts is small compared with the accuracy of the measuring apparatus, correspond to the cases in which the

Table 4 Feeding quantities of aggregates for Series 1

(1) Fine aggregate

Number of specimen	Kind	Surface moisture content (%)	Setting dial			State in container	100 counts			200 counts			400 counts		
			D 1	D 2	D 3		x(kgf)	v(%)	n	x(kgf)	v(%)	n	x(kgf)	v(%)	n
No.1		0.4		5			114.3	2.72	29	228.6	2.44	14	457.2	2.01	7
2		3.4	3				48.8	2.68	50	97.6	2.54	25	195.6	2.43	12
3		3.6		5			86.9	1.29	34	173.8	1.00	17	347.6	0.62	8
4		3.2			7	full	132.7	0.77	18	265.5	0.74	9	531.4	0.58	4
5	River	5.6	3			↓	43.5	3.39	20	87.0	3.33	10	173.9	3.47	5
6		5.8		5		empty	84.1	2.76	25	168.6	2.49	12	337.1	2.50	6
7		5.8			7		124.1	1.46	20	248.2	1.30	10	496.5	1.17	5
8		3.0		5			91.8	1.87	40	183.6	1.74	20	367.2	1.73	10
9		5.9		5			86.3	1.91	40	172.6	1.88	20	345.1	1.80	10
10	Pit	3.1		5			82.7	1.08	40	165.5	0.98	20	331.0	0.93	10
11	Crushed	6.3		5			89.3	2.64	44	178.6	2.51	22	357.1	2.38	11
12	Pit	3.2		5		supplied	83.4	2.07	56	166.8	2.01	28	333.5	1.96	14

(2) Coarse aggregate

Number of specimen	Kind	Surface moisture content (%)	Setting dial			State in container	100 counts			200 counts			400 counts		
			D 1	D 2	D 3		x(kgf)	v(%)	n	x(kgf)	v(%)	n	x(kgf)	v(%)	n
No.1			4				88.0	1.60	43	176.0	1.23	21	351.9	1.12	10
2	River			5			123.2	1.47	31	246.6	1.34	15	493.9	1.22	7
3					7		185.1	1.00	25	370.5	0.88	12	741.0	0.81	6
4	Pit			5			111.0	1.29	49	222.1	1.22	24	444.1	1.13	12
5			4			full	90.2	1.23	29	180.4	0.77	14	360.7	0.63	7
6		air-dry	4			↓ empty	87.9	1.19	40	175.9	1.02	20	351.7	0.77	10
7		state	4				83.5	1.27	40	167.1	1.11	20	334.1	1.00	10
8	Crushed		5				89.7	2.70	50	179.4	2.36	25	359.3	2.13	12
9				7			154.9	2.50	27	310.2	1.96	13	622.0	1.27	6
10					9		213.6	2.19	20	425.2	2.00	10	850.4	1.71	5
2-1	River			5		supplied	129.7	2.34	76	259.8	2.30	38	519.5	2.30	9

(3) Fine and coarse aggregate

Number of specimen	Kind	Surface moisture content (%)	Setting dial			State in container	100 counts			200 counts			400 counts		
			D 1	D 2	D 3		x(kgf)	v(%)	n	x(kgf)	v(%)	n	x(kgf)	v(%)	n
No.20	Pit sand River gr	3.1 air-dry		5 5		full → empty	217.6	1.50	38	435.3	1.48	19	871.2	1.50	9

values of the setting dial, and hence, the openings of the cut gate are small compared with the size of the aggregates (see Table 2). In these cases, the coefficient of variation is generally large. In particular, the coefficient of variation is very large when the number of the setting dial is 3 for fine aggregates, and is 5 for coarse aggregates with maximum size of 40 mm. Further,

Table 5 Feeding quantities of aggregates for Series 2

(1) Fine aggregate

Number of specimen	Kind	Surface moisture content (%)	Dial	State in container	Σ (kgf)	n	x (kgf)	σ_{n-1} (kgf)	V (%)	Mixers	Batched quantity (counts)
1-0-A	Sea	oven-dry	3.94	full ↓ empty	4862.9	12	135.1	0.981	0.73	A	300
2-BP-A		1.5	5.70		2853.2	8	178.3	0.874	0.49	A	200
2-BP-A		1.5	7.00		1774.4	4	221.8	0.842	0.38	A	200
3-P-A		6.8	5.70		4019.9	10	134.0	1.339	1.00	A	300
4-P-B		6.5	6.30		3709.4	8	154.6	1.084	0.70	A	300
5-P-B		6.3	6.30		3520.4	11	160.0	2.176	1.36	B	200
5-0-A	Crushed	oven-dry	3.71		4100.0	10	136.7	1.258	0.92	A	300
7-P-A	Blended	6.1	5.38		1471.1	7	140.1	1.109	0.79	A	150
8-P-B		4.6	5.98		4759.3	20	158.6	2.411	1.52	A	150
9-P-B		6.1	6.32		3627.5	14	172.7	1.832	1.06	B	150
25-P-A	River	8.0	5.40		3200.6	11	132.3	1.839	1.39	A	200
25-P-B		8.0	6.30		3369.0	10	168.5	2.259	1.34	B	200
7-P-A'	Blended	6.1	5.38	supplied	3896.0	19	136.7	1.577	1.15	A	150
9-P-B'		6.1	6.32		2090.5	8	174.2	1.321	0.76	A	150
28-P-B	River	8.0	6.30		3422.0	10	171.1	1.313	0.77	B	200
18-P-A	Sea	5.8	5.70	supplied up-down of cut gate	1394.4	5	139.4	1.339	0.96	A	200
			7.00		1747.0	5	174.7	1.036	0.59	A	200
19-P-B		5.8	5.50		1346.2	5	134.6	1.077	0.80	A	200
			6.30		1567.4	5	156.7	1.185	0.76	A	200
24-P-B		5.9	5.50		1394.1	5	139.4	1.311	0.94	B	200
			6.30		1621.8	5	162.2	1.965	1.21	B	200
27-P-B	River	8.0	5.50		1399.8	5	140.0	1.522	1.09	A	200
			6.30		1681.3	5	168.1	1.005	0.60	A	200

(2) Coarse aggregate

Number of specimen	Kind	Surface moisture content (%)	Dial	State in container	Σ (kgf)	n	x (kgf)	σ_{n-1} (kgf)	V (%)	Mixers	Batched quantity (counts)
9-G-A	Crushed 2005	air-dry state	4.94	full ↓ empty	1633.0	5	130.6	0.878	0.63	A	250
10-G-B			5.16		1392.0	5	139.2	0.447	0.32	A	200
11-G-A	Crushed 4020		4.11		855.0	4	55.3	0.239	0.43	sup.	400
12-G-B			4.70		1239.0	5	61.9	1.055	1.70	sup.	400
14-G-A	Crushed 4005		7.50		1651.0	5	220.1	1.263	0.57	A	150
17-G-B			7.84		1408.0	4	237.0	1.409	0.60	A	150
13-G-A			(4.11,4.94)		2081.0	5	208.1	1.294	0.62	A+sup.	200
15-G-B			(5.16,4.95)		2757.0	6	229.8	0.935	0.41	A+sup.	200
9-G-A'	Crushed 2005	air-dry state	4.94	supplied	1621.0	5	129.7	1.060	0.82	A	250
10-G-B'			5.16		1388.0	5	138.8	0.748	0.54	A	200
22-G-A"	Crushed 4005		7.50		2355.0	7	224.3	1.145	0.51	A	150
13-G-A'			(4.11,4.94)		2074.0	4	207.4	0.750	0.36	A+sup.	200
22-G-A	Crushed 4005	air-dry state	6.00	supplied up-down	1623.0	7	154.6	1.782	1.15	A	150
			7.50		2323.0	7	221.2	1.739	0.79	A	150

it is general that the coefficient of variation for fine aggregates is larger than the one for coarse aggregates.

When the batched quantity increases as the count is increased from 100 to 200, and from 200 to 400, the coefficient of variation decreases. However, this tendency was not so clear as shown in Table 4. Since the weight of the sample per 400 counts corresponds to at least 200 kgf, the large minimum measure of the weighing apparatus can not be the reason for a large variation in measuring and dispensing aggregates. Therefore, the reasons may be that the value of the setting dial was small compared with the particle size of the aggregates and that the measurement were performed every 100 counts by operating and stopping the continuous mixer intermittently. Especially, the experiments of Series 1 were carried out at a low ambient temperature and the freezing of the surface moisture water in the fine aggregates may be one of the reasons for the large variation of the measured values. This conclusion may be reasonable considering that the coefficient of variation obtained in Series 2 which was performed at the end of March is at most 1.7% (see Table 5). In this case the quantity of sample considered as one batch is the weight of aggregate determined from every 150 counts up to every 400 counts. The figures shown in Table 5 are values converted to 100 counts.

4. FEEDING QUANTITY WHEN THE RESIDUAL CONTENT OF THE AGGREGATES ARE DIFFERENT IN THE CONTAINER

Examples of a sequence in feeding quantities of the aggregates from full stored state to empty state of the container are shown in Fig. 2 and Fig. 3. For both fine and coarse aggregates, there are few cases which have the constant trends of smaller residual contents of aggregate in the container corresponding to larger quantities or smaller quantities of sample.

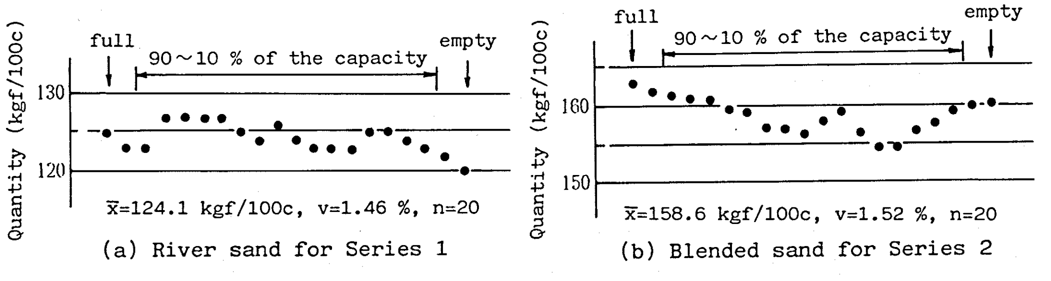


Fig. 2 Feeding quantities of fine aggregate versus residual content in the container

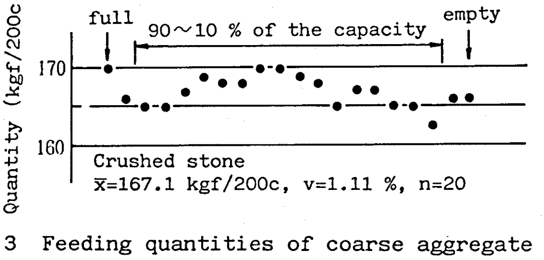
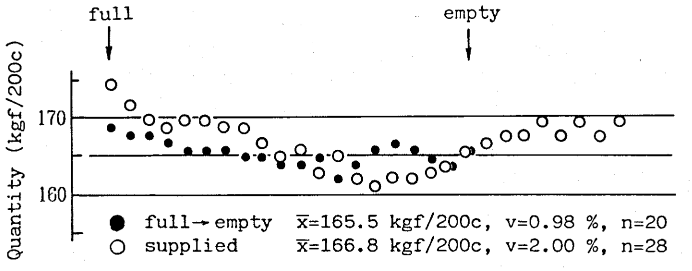
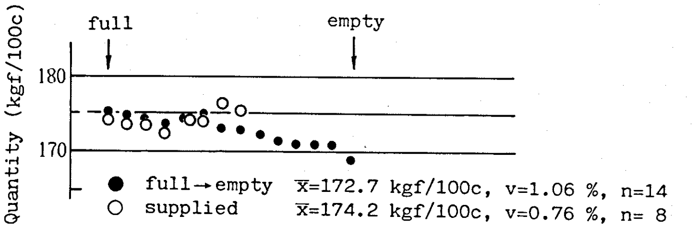


Fig. 3 Feeding quantities of coarse aggregate versus residual content in the container

Discussing the batched quantities more in detail, there are many cases in which the batched quantities decrease as the residual content decreases as shown in Fig. 2(a) and Fig. 3, when the storage container is almost full or almost empty. However, there are some cases such as shown in Fig.2(b) in which the batched quantities increase as the residual content decreases when the residual content of aggregate is almost zero.



(a) Pit sand, setting dial at 5



(b) Blended sand, setting dial at 6.32

Fig. 4 Feeding quantities when residual content of aggregates are different in the container

Table 6 Feeding quantities in cases of supplied continuously in the container and of a full to empty state of the container

Series	Specimen		full → empty (1) $\bar{x}$ (kgf/100c)	v (%)	n	supplied (2) $\bar{x}$ (kgf/100c)	v (%)	n	Difference $\frac{\|(1)-(2)\|}{(1)+(2)} \times 100$ (%)
1	Pit sand		82.8	0.98	20	83.4	2.01	28	0.39
2	Blended 7-P-A		140.1	0.79	7	136.7	1.15	19	1.23
2	Blended 9-P-B		172.7	1.06	14	174.2	0.76	8	0.43
2	River 25,28-P-B		168.5	1.34	10	171.1	0.77	10	0.77
2	Crushed 2005	9-G-A	130.6	0.63	5	129.7	0.82	5	0.35
2		10-G-A	139.2	0.32	5	138.8	0.54	5	0.14
2	Crushed 4005	13-G-A	208.1	0.62	5	207.4	0.36	4	0.17
2		14-G-A	220.1	0.57	5	224.3	0.51	7	0.95

Except the cases in which the residual content of aggregate is extremely large or small, namely in case the residual content varies from 90% to 10% of the capacity of the container, it may be concluded that the residual content of aggregate does scarcely influence the measurement and feed of the aggregate.

Fig. 4 shows the sequences of batched quantities of aggregates when the residual content varies from 40% to 50% of the volume capacity of the container which is supplied continuously by a shovel or a belt conveyor. The sequence of batched quantities for a full to empty state of the container are also plotted in Fig.4 in order to compare the results of each cases. It is shown in Fig. 4 that the variation in the quantity is almost the same for two cases. Differences of the batched quantities between the two cases are summarized in Table 6, from which it is clear that the differences of the quantities do not show the same tendency depending on the supplying method into the aggregate storage container, and the differences are within 1% for most cases. It may be also concluded from these results that the residual content of the aggregate in the container does scarcely influence the batched quantity of aggregate.

5. EFFECT OF THE OPERATION OF THE CUT GATE

The quantity of aggregate may change after operating the cut gate up or down to vary the mix proportion of concrete. The following experimental sequences were performed to determine the effect of this operation on the quantity of supply. At first, measurements and feedings of the aggregates were carried out for the specified period at a determined position of the setting dial, after which, the aggregates dispensed by the former opening of the cut gate were discharged from the belt feeder by operating the dial for 40 counts. Then, the operation was performed again after resetting at another specified value. This sequence was to be repeated until needed. Examples of the obtained test results are illustrated in Fig. 5. A comparison between these experimental results and those obtained with a constant cut gate opening are shown in Table 7.

It can not be recognized what differences in the magnitude of variation of the aggregate supply between the two sequences exist. It is clear that a larger

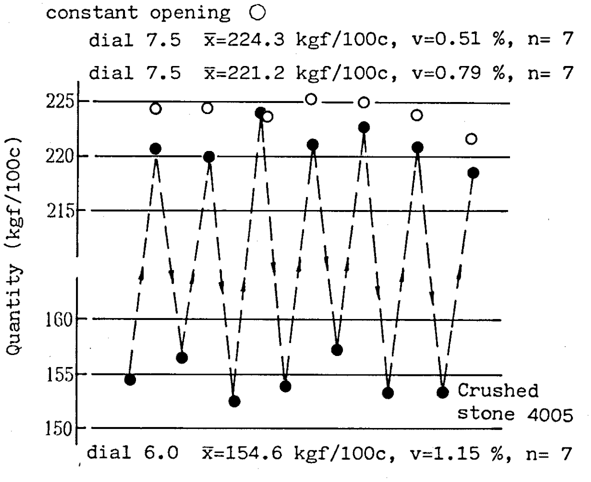


Fig. 5 Feeding quantities in case of changing cut gate

Table 7 Effect of the operation of cut gate on feeding quantities

Specimen	Setting dial	up-down (1) $\bar{x}$ (kgf/100c)	up-down v (%)	up-down n	constant (2) $\bar{x}$ (kgf/100c)	constant v (%)	constant n	Difference $\frac{\|(1)-(2)\|}{(1)+(2)}\times 100$ (%)
Sea sand 3-P-A 18-P-A	5.7 (7.0)	139.4	0.96	5	134.0	1.00	10	1.98
Sea Sand 4-P-B 19-P-B	6.3 (5.5)	156.7	0.76	5	154.6	0.70	8	0.67
Sea sand 5-P-B 24-P-B	6.3 (5.5)	162.2	1.21	5	160.0	1.36	11	0.68
Crushed 22-G-A 4005	7.5 (6.0)	221.2	0.79	7	224.3	0.51	7	0.70

quantity of fine aggregate is obtained by changing the cut gate compared to the case of constant opening of the cut gate. However, this difference is very small, and a reverse phenomenon is observed for the case of crushed stone. In all cases, the difference between the two sequences was 2% at the largest, and was within 1% for most cases. Therefore, it may be said that the effect of the up and down operation of the cut gate is negligible.

6. MEASURING AND FEEDING OF COARSE AGGREGATES WITH A MAXIMUM SIZE OF 40mm BY A TWO LINE SYSTEM

When measuring and feeding of coarse aggregates with a maximum size of 40 mm were performed, both a two line system with aggregate sizes of 40-20 mm and of 20-5 mm, and another one line system with an aggregate size of 40-5 mm were employed. Test results are summarized in Table 8. A supplementary measuring and dispensing equipment was adopted for the line of 40-20 mm (see Table 1). In this equipment, the number of counts of the meter per minute was 245. Therefore, the quantity of aggregate supplied by this equipment was multiplied by a factor of 245/167=1.467 times in order to obtain the quantity of the continuous mixer with 167 counts per minute.

Table 8 Feeding quantities of crushed stone by one line system and two line one

Specimen	One line Dial	One line (1) $\bar{x}$ (kgf/100c)	One line v (%)	One line n	Two line Dial	Two line (2) $\bar{x}$ (kgf/100c)	Two line v (%)	Two line n	Difference $\frac{\|(1)-(2)\|}{(1)+(2)}\times 100$ (%)
Crushed stone 13-G-A 14-G-A	7.50	220.1	0.57	5	4.11 4.94	208.1	0.62	5	2.80
Crushed stone 15-G-B 17-G-B	7.84	237.0	0.60	4	5.16 4.95	229.8	0.41	6	1.54

It is shown in Table 8 that even coarse aggregates with a maximum size of 40 mm can be measured and dispensed by the one line system within a required tolerance, without adopting the two line system. It is most important to consider that segregation of aggregates must be avoided until supplying them into the storage container.

7. QUANTITY OF SIMULTANEOUSLY FED FINE AND COARSE AGGREGATES

In practice, concrete is manufactured by measuring and dispensing fine and coarse aggregates simultaneously. However, calibrations are conducted individually for each of these kinds of materials, therefore, it is important to determine the relation between the quantity of simultaneously batched aggregates and that of individually batched ones.

Fig. 6 shows the sequences of the total quantity of fine and coarse aggregates measured every 100 counts for the two cases of simultaneous and individual feeding. In both cases, experiments were carried out until one of the two kinds of aggregates, pit sand and river gravel was completely fed, after they had been fully stored in their separate containers. The value of setting dial was 5 for each kind of aggregate. The quantity of fine aggregate was adjusted in the individual feeding because the quantity of aggregates included a fine aggregates surface moisture content of 3.1% in the simultaneous feeding. These figures are illustrated in Table 9.

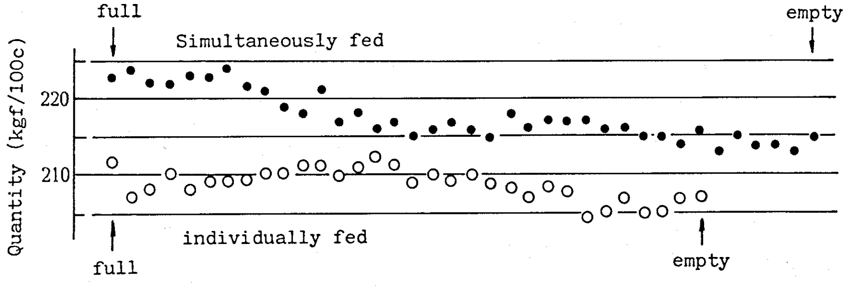


Fig. 6 Quantities of simultaneously fed fine and coarse aggregates

Table 9 Quantities of fine and coarse aggregates simultaneously and individually fed

Series	Kind	Individually			Simultaneously			Difference
		(1) $\bar{x}$ (kgf/100c)	v (%)	n	(2) $\bar{x}$ (kgf/100c)	v (%)	n	$\frac{\|(1)-(2)\|}{(1)+(2)} \times 100$ (%)
1	Pit sand	85.3	1.08	40	217.6	1.50	38	2.14
	River gravel	123.2	1.47	31				
		208.5						
2	Crushed 4020	81.1	0.43	4	208.1	0.62	5	0.86
	Crushed 2005	130.6	0.63	5				
		211.7						

It is clear from Fig. 6 and Table 9 that the simultaneously fed quantity is larger than the individually fed one by about 2%. The vibrator attached at the outer surface of the fine aggregate container was connected with the belt conveyor of the continuous mixer. From the study of only one data, it can not be concluded but it may be thought that comparing the cases of simultaneous and individual feeding of the fine and coarse aggregates, the batched quantities varied because they were slightly affected by mechanical vibration.

Another experiments in which simultaneous and individual feeding with the continuous mixer were adopted in order to measure and dispense crushed stone with a particle size of 20 mm to 40 mm, by means of the supplementary measuring and feeding equipment. It is clear from Table 9 that the differences of the measured quantities between the two cases may be negligible because they are within 1%.

8. DIFFERENCES BETWEEN SAME TYPE OF MIXERS

Fig. 7 and Table 10 show the batched quantities of sea sand measured and dispensed by two mixers of the same type, but having a slightly different decreasing motor ratio. Differences of the quantities measured every 100 counts between the two mixers were about 2%, when the usual measuring, feeding and cut gate operations were employed.

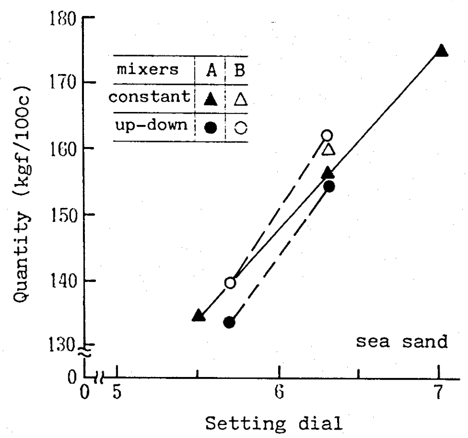


Fig. 7 Feeding quantities by two mixers of the same type

Table 10 Differences between same type of mixers

Specimen	Setting dial	Mixer A			Mixer B			Difference $\frac{\|(1)-(2)\|}{(1)+(2)}\times 100$ (%)
		(1) $\bar{x}$ (kgf/100c)	v (%)	n	(2) $\bar{x}$ (kgf/100c)	v (%)	n	
Sea sand full→empty	6.30	154.6	0.70	8	160.0	1.36	11	2.51
Sea sand up-down	5.50	134.6	0.80	5	139.4	0.94	5	1.75
	6.30	156.7	0.76	5	162.2	1.21	5	1.72

9. EFFECT OF THE SURFACE MOISTURE CONTENT OF FINE AGGREGATES

Since of materials are measured by volume in continuous mixers, it can be thought that the bulking of fine aggregates affects the batched quantities. Fig.8 shows the relationship between the surface moisture contents of river sand and the fed quantities. The quantities per 100 counts are plotted as weights of saturated surface-dry aggregate.

When the moisture of the river sand is near the saturated surface-dry state, the corresponding batched quantity is smaller as the surface moisture content is larger. However, it is noted that the effect of surface moisture content on the batched quantity decreases, when the surface moisture content ranges from 3% to 6% as it does in reality. In this range, for a moisture content variation of 1%, the batched quantity varies only from 1.5% to 2%. Fig. 9 shows test results plotted from other paper[1]. It has been reported that for a 1% variation of surface moisture content the batched quantity is changed by about 1% when the surface moisture content of sand varies from 4% to 11%, as shown in the figure. Therefore, it may be said that the effect of the surface moisture content is unexpectedly small, in moisture conditions of the fine aggregates commonly used. This may be because vibrations in the feeding of fine aggregates from the container may reduce the effect of bulking of fine aggregate.

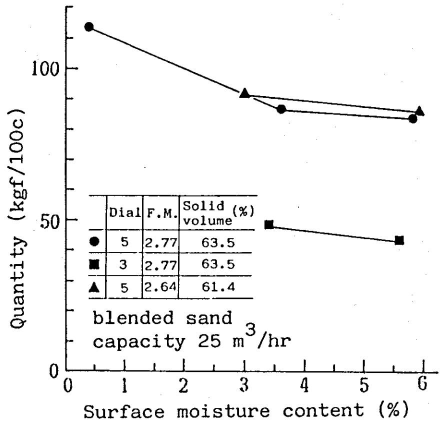


Fig. 8 Effect of surface moisture content of fine aggregate on feeding quantities

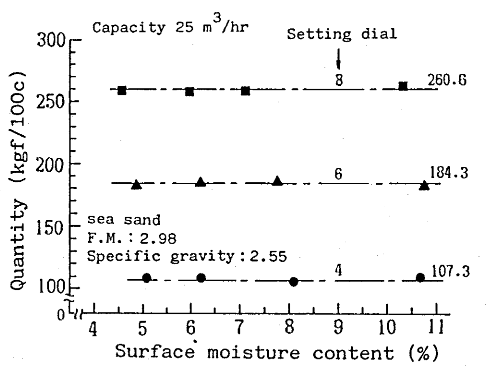


Fig. 9 Surface moisture content of fine aggregate versus feeding quantities

10. EFFECT OF AGGREGATES GRADING

The batched quantities will change if the gradings of the aggregates change. The grading of aggregates was selected as the best parameter for being the most relevant to the fed quantity among the others, i.e, the fineness modulus, weight of unit volume and solid volume percentage.

The relationship between the batched quantity and the grading of coarse aggregate is shown in Fig. 10. The gradings were changed by adopting different combination ratios between crushed stones with particle size of 20-10 mm and 10-5 mm. Parameters such as weight of unit volume and solid volume percentage are also illustrated in Fig. 10. However, it is clear that the effect of these parameters on the batched quantity is very small, and that a good correlation exists between the fineness modulus and the batched quantity. When the fineness modulus is larger, the smaller the quantity is. This trend is also shown in Fig. 11 which shows previously reported test results[1].

Fig. 12 shows the same relationship in case of fine aggregates. It is shown that the batched quantity of river sand decreases as the fineness modulus increases. The same trend occurs in the case of crushed stones. However, a reverse relationship has been reported. This is, the batched quantity increases slightly as the fineness modulus of sea sand increases.

It may be correct that the relationship between the fineness modulus of the aggregate and the batched quantity depends on the type, maximum size, grading

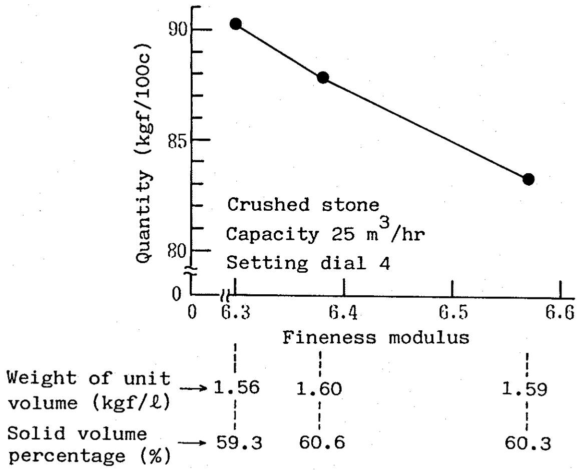


Fig. 10 Effect of fineness modulus of coarse aggregate on feeding quantities

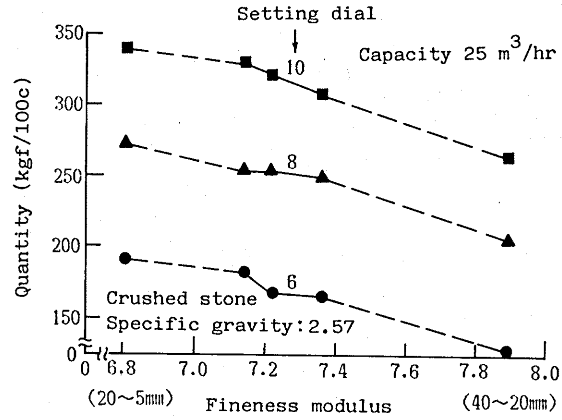


Fig. 11 Effect of fineness modulus of crushed stone on feeding quantities

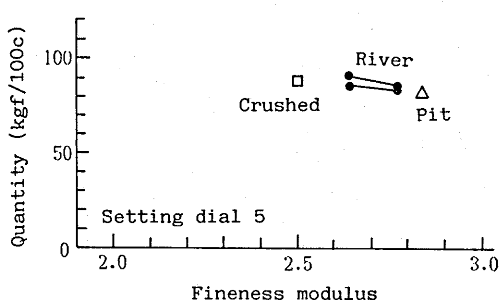


Fig. 12 Effect of fineness modulus of fine aggregate on feeding quantities

and surface moisture content of the aggregates. Further researches will be needed to clarify these dependencies.

11. CONCLUSIONS

In this paper, experimental results, concerning the accuracy of measuring and feeding of aggregates in continuous mixers, were discussed. Such parameters as the type, grading and surface moisture content of aggregates as well as operating methods of the continuous mixer were taken into consideration. As the result of a series of tests, the following conclusions were obtained:

(1)The measurement accuracy of aggregate worsens when the opening of the cut gate is small compared to the particle size of the aggregate and when the weight of the batch is extremely small.

(2)The residual content of aggregate in the storage container scarcely influences the batched quantity when this residual content ranges from 90% to 10% of the volume capacity of the container.

(3)The effect of the up-down operation of the cut gate on the batched quantity of aggregate is relatively small.

(4)Even coarse aggregates with maximum size of 40 mm can be measured and dispensed within a required tolerance by a one line system, making it not necessary to adopt a two line one.

(5)The quantity obtained by simultaneous feeding of fine and coarse aggregates is slightly larger than the one obtained by individual feeding.

(6)The effect of the surface moisture content of fine aggregates on the batched quantity is unexpectedly small when the surface moisture content ranges from 3% to 6%.

(7)It is seen that a batched quantity of aggregate decreases as the fineness modulus of the aggregate increases.

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