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Concrete Roads.

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Synopsis.

This paper deals with a Comparison between Concrete and "Koseki" (Sandless Concrete) based on data from experimentation on these materials in laboratories and in actual use in paving.

The laboratory tests of these materials are compression tests, transverse test, and abraision tests by a brick rattler, a Talbot-Jones rattler testing machine and an Amsler wearing machine at different conditions and ages.

The records of experiment on trial pavements by running vehicles at the Technological laboratory of Osaka and experiments made on pavements actually in use at Kanda, Umejima and Nishinomiya.

The use of automobiles has considerably increased in Japan in recent years, but the majority of vehicles are steel-tired. According to traffic census taken at twenty-five streets in Tokyo, in 1925, two hundred thousand six hundred (200 600) vehicles passed in a day of twelve hours (from 6 a. m. to 6 p. m.) of which only 34 000 (that is 17 per cent.) were rubber-tired, the rest being all steel-tired. Even in urban districts where automobiles are extensively used, such is the present state of affairs; and it is naturally to be expected that on rural highways, vehicles are almost wholly horse drawn steeltired ones. During the seven years between 1918 and 1925, the average daily number of automobiles in the twenty-five roads above referred to, increased from 13 000 to 34 000 showing a rise of more than 250 per cent.

Motor-trucks in Japan are mostly from one to two and a half tons in capacity, and animal-drawn carts and waggons are either two or four wheeled, drawn almost invariably by one animal. There are slight local modifications, but the horse drawn waggons in use in Tokyo and its vicinity have wheels 3 ft. 6 in. in diameter with tires 2.5 in. in width. The total weight of each including load is approximately two-wheeled, 3 800 lbs.; four-wheeled, 4 200 lbs. Their speed is 2.5 miles an hour. Hand-carts usually have tires of about one inch in width and weigh less than 1 500 lbs. (The new regulation requirement for the width of tires of horse-drawn waggons is $3^3/_4$ in. and over, under about the same wheel load as above mentioned, but its enforcement is temporarily withheld.)

The width of roads is not in a very satisfactory condition. National or prefectural roads are usually from 12 to 15 ft. wide, rarely exceeding 18 ft. Besides, as telegraph-poles and other obstacles take up space available for traffic, streets do not have ample width; roadways possessing a double truck electric car line are generally less than 48 ft. wide.

These circumstances cause the rapid wearing of roads, and the ordinary gravel facing has but a short life. The necessity for better roads is felt more keenly than ever before, Financial and other considerations, however, make it difficult to build good, high-class paved roads even in the city and the question of less expensive but economical road-making is receiving the active attention of experts.

Experiments have long been tried with wood block and asphalt paving, and there is considerable road area in this country paved after these types. But concrete pavement is a new thing. Its actual study has only lately been started among our specialists and its application, which is still very limited in extent, is confined to side-walks. It has been apprehended that the prevalence of steel-tired vehicles would prove very detrimental to concrete pavements. This apprehension has been confirmed by actual experiments, though these may not have been properly conducted. Later experiments have shown, however, that concrete proportioned with a smaller percentage of sand and a certain rich percentage of cement, increases wear resisting power. Concrete with no sand in its composition has more wear-resisting power than ordinary concrete. A pavement of this sandless concrete analogous to granolithic pavement is known among our pavers as "koseki" pavement. This paper deals with a comparison between concrete and "koseki" based on data collected from experimentation on these materials in laboratories and in actual use in paving.

The following laboratory tests have been carried out:—

1. Compression test.
2. Transverse test.
3. Abrasion test.
    (a) By a brick rattler. A.S.T.M. Standard (U.S.A.);
    (b) By a Talbot-Jones rattler testing machine (U.S.A.);

(c) By an Amsler wearing machine.

4. Emperiment on trial pavements by running vehicles thereon.

Table I. Tests of Cement.

The test made in accordance with the Standard Methods for Portland Cement by the Japanese Government.

Cement: Asano Portland Cement, manufactured at the Fukagawa factory, Tokyo.

A) Strength Tests.

Normal Consistency %	Tensile Strength (kg. cm²)			Compressive Strength (kg. cm²)
	Neat Cement	Mortar (1:3)		Mortar (1:3)
	7 days	7 days	28 days	28 days
26.4	75.2	30.8	38.0	386

B) Chemical Analysis.

MgO %	SO_3 %	Loss on Ignition %
1.28	1.51	1.05

C) Miscellaneous Tests.

Residue on		Time of Setting			Specific Gravity	Soundness (Boiling)
900 mesh. cm² sieve %	4900 mesh. cm² sieve %	Temp. C	Initial h m	Final h m		
0.0	3.2	19	2 32	5 22	3.15	O.K

Table II. Tests of Aggregates.

Aggregates: The aggregates consisted of sand and crushed granite.

SAND: Arakawa River sand, from Yorii, Chichibu, mainly consisted of quartz, greywacke and crystalline-schists. Before using, the sand was screened through a No. 8 sieve. All materials coarser than this size was rejected. The sand was used without further screening, but care was taken to see that it was uniform throughout the series.

CRUSHED GRANITE: Fresh fine grained Biotite-granite, from Makabe, Ibaraki. The crushed granite was screened to three different sizes (No. 4-3/8, 3/8-3/4, 3/4-1 inches) and recombined in definit proportions for each batch, as shown in the sieve analysis in Table II. Miscellaneous tests of aggregate are given in Table II-B.

A) Sieve Analysis of Aggregates.

Sieve N. or Size in in.	Size of clear opening in mm.	Per cent by Weight, Coaser than Each Sieve					
		Sand	Crushed Granite	Mixed Aggregate			
				1:2.5	1.2:2.5	1.5:3.3	2:4.5
100	0.149	98	100	99.4	99.3	99.3	99.3
50	.297	86	100	95.6	95.1	95.9	95.0
30	.59	68	100	90.0	88.8	89.8	88.5
16	1.19	25	100	76.7	73.8	75.2	73.1
8	2.38	0	100	69.0	65.0	66.7	64.1
4	4.76	—	100	69.0	65.0	66.7	64 1
3/8	9.5	—	90	62.1	58.5	60.0	57 7
3/4	19.0	—	15	10.3	9.7	10.0	9.6
1	25.4	—	0	0	0	0	0
Fineness Modulus		2.77	7.05	5.72	5.55	5.63	5.51

Table II. (*Continued*)

B) Miscellaneous Tests of Aggregates.

Test	Sand	Crushed Granite
Weight of Dry Aggregate (loose measure) kg/m³	1547	1381
Water Absorption of Aggregate, Per cent by Weigt	2.49	1.59
Specific Gravity	2.64	2.64
Abrasion Tests, Loss in Weight-Per cent		
A. S. T. M. Standard Method	—	2.0
Rea's Method	—	24.3
Hardness Test	—	18.5
Toughness Test	—	14
Elutriation, Per cent by weight	2.5	—

In order to conduct these experiments the materials to be used were first tested and the results are given in Tables I and II. In the experiments, equal conditions were secured as far as possible in mixing, tamping, curing etc.; and special care was exercised in the aggregate. The aggregate was screened to several different sizes and recombined in definite proportions. In the table the water-ratio and the results of slump test are both given.

For compression test, a cylindrical test piece, 8 in. high and 4 in. in diameter, was used. The Olsen automatic and autographic universal testing machine, 100-ton capacity, was worked with a pressure increment of about 6 tons per minute. The results are given in Table III. It will be gathered from the table that the compressive strength of rich concrete is stronger than that of a poor one. The strength is about 35 per cent. higher in "koseki", which has no sand ingredient, than in rich concrete with a mixture 1:1.5:3.3.

For transverse test, a beam, 6 in. square and 30 in. in length was used. The clear span was fixed at 24 in. The machine used in this test was the same as that used in the compression test. The results are given in Table IV. A similar result has been obtained in this as in the compression test. "Koseki" with a mixture of 1:1.8 was found about 20 per cent. stronger than rich concrete proportioned 1:1.5:3.3, and about 100 per cent. stronger than 1:3:6 concrete. Although it differs according to time and place, the usual cost of "Koseki" proportioned with 1:1.8 is about double that of 1:3:6 concrete. As the stress of a slab is inversely proportional to the square of its thickness, it would seem, from a purely statical point of view, that the use of poor, thicker concrete is more economical than the use of either richer concrete or "koseki". From this it will be seen that a pavement with two layers, ("koseki" layer placed upon green concrete) is a favorable section

Table III. Compressive Strength of Concrete and "Koseki".

Kind of Specimen	Mix. by Volume	Water-Ratio	Slump in in.	No. of test	Compressive Strength, kg/cm²			
					7 days	14 days	21 days	28 days
"Koseki"	1 : 1.8	0.43	1.00	1	237.2	412.5	408.8	400.8
				2	289.5	410.7	482.2	552.5
				3	277.5	411.9	494 6	496 1
				4	292.3	411.6	461.9	473 6
				5	266.4	428.6	423.0	526.6
				Average	279.8	401.5	454.1	489.9
Concrete	: 1.5 : 3.3	0 63	0.50	1	210.9	249.7	360.3	369.5
				2	206.6	274.7	335.6	298 2
				3	207.2	252.2	347.9	427.6
				4	203 7	253.4	309.4	366.2
				5	210.9	288.6	338 1	411.3
				Average	208.7	263.7	317.3	374.6
Concrete	1 : 2 : 4.5	0.75	0.50	1	178.5	230.3	258.7	334.6
				2	188.1	237.4	270.6	346.5
				3	181.6	242.9	276.9	308.3
				4	170.5	248.5	276.2	346.5
				5	175.3	207.2	286.1	325 6
				Average	178.8	213 3	273,7	332.3
Concrete	1 : 3 : 6	1.10	0.25	1	78 3	109.1	141.2	176.0
				2	75.5	113.1	139.3	182.5
				3	78.0	105.0	137.5	169.2
				4	77.0	110.0	162 8	217.0
				5	73.0	107.3	149.5	168.9
				Average	76.4	108.9	146.1	182.7

Hand-mixed Concrete and "Koseki".
Compression tests of 4 by 8-in. cylinders.
Cement and Aggregates: same as Table I. and II.
Specimens cured in water.
Water-ratio is to volume of cement (1520 kg. per cubic meter).

when tensile strength is required on the surface of a pavement.

In the abrasion test, those made by a brick rattler specified by A. S. T. M., U. S. A., a ball 6 in. in diameter was used as a test-piece. After it was moulded, it was kept in the air for twenty-four hours. It was then removed from the mould and cured in damp sand. As in the case of a brick test, the balls were tested at a speed of 30 revolutions per minute. A record was taken at the completion of 1 800 revolutions. In the tests were used ten 3.75 in. diameter steel balls and from two hundred and fourty five to two hundred and sixty (245 to 260) 1.875 in. diameter steel balls, with an aggregate weight of 300 lbs. The results are shown in Table V. The figures indicate the average results of six test-pieces.

These tests were conducted with a view to ascertain the resistance to abrasion of "koseki" and concrete and also to ascertain in these two substances the effect on the wear of proportion, age at test, amount of water, size of the

Table IV. Modulus of Rupture of Concrete and "Koseki".

Kind of Specimen	Mix. by Volume	Water-Ratio	Slump in in.	No. of Test	Modulus of Rupture. kg. per sq. cm. 7 days	14 days	21 days	28 days
"Koseki"	1:1.8	0.43	1.00	1	51.67	50.65	59.41	68.71
				2	50.10	66.51	59.93	70.26
				3	50.36	63 29	66.39	56.31
				Average	50.71	60.15	61.91	65.09
Concrete	1:1.5:3 3	0.63	0.50	1	33.26	51.01	47.78	57.47
				2	43.81	47.78	54.25	52.30
				3	47.01	46.49	54.89	52 95
				Average	41.36	48.43	52.31	54.24
Concrete	1:2:4 5	0.75	0.50	1	38.22	50.62	53.73	55.53
				2	34.86	36.40	47.01	48.04
				3	37.19	46.49	51.01	50.36
				Average	36.76	44.51	50.58	51.31
Concrete	1:3:6	1.10	0.25	1	20.14	17.56	25.83	31.51
				2	21.95	28 41	31.51	27.63
				3	23.24	—	30.99	30.99
				Average	21.78	22 99	29.44	30.04

Hand-mixed concrete and "Koseki"
Transverse tests of 6×6×30-in. beams, 24-in. span.
Cement and Aggregate: same as in Table I and II.
Specimens cured in water.
Water-ratio is to volume of cement (1520 kg. per cubic meter).

aggregate, and calcium chloride. In Table V, A. "koseki" comes out as possessing a superior resisting power to abrasion compared with concrete. In the case of "koseki" it seems that there is a certain limit beyond which any increase of cement fails to bring about a corresponding increase in any appreciable degree in wear resisting power.

The proper amount of cement differs with aggregate, but at least, for the aggregate used in the experiments, it has been found that the addition of more than 55% to aggregate is unnecessary. In concrete the richer the proportion the greater is the resisting power to abrasion. In both "koseki" and concrete abrasive resistance, increases with their age, attaining a fair degree of strength in about three weeks. As in the case of concrete, the strength weakens with the increase in the amount of water, and a good result is likely to be obtained by reducing water as much as possible and thorough tamping. Experiments show the effectiveness of adding calcium chloride in the composition of "koseki" as a means of quicking its hardening. By the addition of calcium chloride, "koseki" attains, in about ten days, a strength which it would otherwise require twenty days to acquire. The effect of calcium chloride

Table V. Wear tests, by means of Brick Rattler.

Kind of Specimen	Mix. by Volume	Water-Ratio	Slump in in.	Age at Test, in days	Average Weight (kg.) Before Rattling	Average Weight (kg.) After Rattling	Wear Per cent by Weight	Wear Depth in in.
A) Effect of Proportion on the Wear.								
"Koseki"	1 : 1	0.40	1.25	21	4.329	3.676	15.1	0,159
	1 : 1.5	.39	0.50	21	4.419	3.821	13.5	.142
	1 : 1.8	43	1.00	21	4.472	3.874	13.4	.141
	1 : 2	.46	0.20	21	4.475	3.823	14.6	.154
Concrete	1 : 1 : 2.5	.49	1.50	21	4.451	3.479	21.8	.236
	1 : 1.2 : 2.5	.66	1.50	21	4.486	3.401	24.2	.264
	1 : 1.5 : 3.3	.68	0.75	21	4.482	3.212	28.3	.314
	1 : 2 : 4	.75	0.50	21	4.503	2.873	36.2	.417
B) Effect of Amount of Water on the Wear.								
"Koseki"	1 : 1.8	.35	0.00	21	4.483	3.946	12.1	.127
		.40	0.50	21	4.529	3.955	12.7	.133
		.43	1.00	21	4.472	3.874	13.4	.141
		.45	2.00	21	4.468	3.853	13.8	.145
C) Effect of Calcium Chloride on the wear. (Calcium Chloride: 3 % by weight of Cement).								
"Koseki"	1 : 1.8	43	2.00	2	4.183	3.283	21.5	.232
				3	4.203	3.412	18.8	.201
				4	4.211	3.419	18.8	.201
				10	4.203	3.625	13.8	.145

Table V. (*Continued*).

Kind of Specimen	Mix. by Volume	Kind of Cement	Water-Ratio	Slump in in.	Age at Test, in days	Average Weight (kg.) Before Rattling	Average Weight (kg.) After Rattling	Wear Per cent by Weight	Wear Depth in in.
D) Effect of Age on the Wear.									
"Koseki"	1 : 1.8	Asano	0.43	1.00	10	4.429	3.731	15.8	0.167
					15	4.410	3.739	15.2	.160
					21	4.472	3.874	13.4	.141
		Ciment Fondu	42	1.00	2	4.377	3.929	10.2	.106
Concrete	1 : 1.5 : 3.3	Asano	.68	0.75	10	4.538	3.224	29.0	.324
					15	4.546	3.363	26.0	.286
					21	4.482	3.212	28.3	.314
		Ciment Fondu	.66	0.75	2	4.491	3.722	17.1	.182

E) Effect of Size of Aggregate on the Wear.

Kind of Specimen	Mix. by Volume	Size of Aggregate in in.	Water-Ratio	Splum in in.	Age at Test, in days	Average Weight (kg) Before Rattling	Average Weight (kg) After Rattling	Wear Per cent by Weight	Wear Depth in in.
"Koseki"	1 : 1.8	1 - 1/4	0.40	0.50	21	4.448	3.834	13.8	0.145
		3/4 - 1/4	0.44	0.50	21	4.461	3.789	15.1	.159
		3/8 - 1/4	0.50	1.25	21	4.382	3.315	24.3	.265
Mortar	1 : 1.8	No. 8 – 0	0.50	0.00	21	4.225	2.993	29.2	.326

Hand-mixed concrete and "Koseki".—Wear tests of 6-in. dia. spherical balls placed in the brick rattler, with 300 lbs. cast iron balls, 1800 revolutions at the rate of 3) r. p. m. Results: mean value of six balls.—Cement and aggregate: same as Table I and II.—Specimens cured in damp sand.—Water-ratio is to volume of Cement (1520 kg. per cubic mater).

is remarkable in the early stage of hardening. In "koseki" the smaller the size of aggregate, the weaker seems its strength. From the results shown in the table, it will be found that the strength of mortar has been proved to be the weakest, next followed by "koseki" made of the aggregates $^1/_2$ in. and $^3/_4$ in. etc. in size. The strength is considerably weak when the size is smaller than $^1/_4$ in. Undue largeness in the size of aggregate, however makes the road surface non-homogeneous, which results in quickening abrasion. The size, therefore, should be adjusted according to the traffic conditions and other requirements.

Judging from these tests, actual roads, and present traffic conditions, the aggregate retained on $^1/_2$ in. screen and passed through $1^1/_2$ in. screen, seems to be most satisfactory in the majority of cases in this country.

In this tests made with a Talbot-Jones rattler, the shape and size of the test-piece, the speed of revolution, the weight and number of cast iron balls used, were as given in Table VI.

A slight modification was made only in the Talbot-Jones testing machine, that is a 2-in. square shaft was set across the center of the drum. In Series E, however, a Talbot-Jones rattler in its original form was used.

Similarly as in the wear tests, already mentioned, these tests were made to compare abrasion resistance of "koseki" and concrete and to ascertain the effect of proportion, amount of water, calcium chloride, size of aggregate, and silicate soda.

Table VI. Wear Tests by means of Talbot-Jones Rattler.

Kind of Specimen	Mix, by Volume	Water-Ratio	Slump in In.	Age at Test, in days	Average Weigt (kg) Before Rattling	After Rattling 1,800 rev	After Rattling 5,400 rev.	Wear Per cent by Weight 1,800 rev.	Per cent by Weight 5,400 rev.	Depth in in. 1,800 rev.	Depth in in. 5,400 rev.
A) Effect of Proportion on the Wear.											
"Koseki"	1:1	0.53	0.75	21	12.73	11.97	11.07	5.97	13.04	0.299	0.652
	1:1.5	0.59	1.00	21	12.63	11.91	10.97	5.70	13.14	.285	.657
	1:1.8	0.43	1.00	21	12.85	12.28	11.60	4.44	9.73	.222	.487
	1:2	0.46	0.50	21	12.88	12.54	11.70	3.39	9.90	.170	.495
Concrete	1:1 :2.5	0.47	1.00	21	12.98	12.47	11.71	3.93	9.78	.197	.489
	1:1.2:2.5	0.54	1.00	21	12.99	12.50	11.75	3.77	9.55	.189	.478
	1:1.5:3.3	0.68	0.75	21	12.98	12.54	11.66	3.39	10.17	.170	.509
	1:2 :4.5	0.75	0.50	21	12.96	12.51	11.42	3.47	11.88	.174	.594
B) Effect of Amount of Water on the Wear.											
"Koseki"	1:1.8	0.40	0.15	21	12.80	12.20		4.69		.235	
		0.41	0.50	21	12.81	12.11		5.46		.273	
		0.42	1.00	21	12.82	12.21		4.76		.238	
		0.45	1.50	21	12.71	11.99		5.66		.283	
C) Effect of Calcium Chloride on the Wear. (Calcium Chloride: 3% by Weight of Cement).											
"Koseki"	1:1.8	0.43	1.50	3	12.70	11.95		5.91		.296	

D) Effect of Size of Aggregate on the Wear.

Kind of Specimen	Mix by Volume	Size of Aggregate	Water-Ratio	Slump in in.	Age at Test, in days	Average Weight (kg) Before Rattling	Average Weight (kg) After Rattling	Wear Per cent by Weight	Wear Depth in in.
"Koseki"	1:1.8	1 – 1/4	0.45	1.00	21	12.88	12.35	4.11	0.206
		3/4 – 1/4	0.45	1.00	21	12.98	12.33	5.01	0.251

Table VI. *(Continued).*

Kind of Specimen	Mix by Volume	Surface	Water-Ratio	Slump in in.	Age at Test, in days	Average Weight (kg)			Wear			
						Before Rattling	After Rattling		Per cent. by Weight		Depht in in.	
							1,800 rev.	5,400 rev.	1,800 rev.	5,400 rev.	1,800 rev.	5,400 rev.
E) Effect of Silicate of Soda on the Wear.												
"Koseki"	1 : 1.8	Treated	0.45	1.00	21	12.75	12.00	10.79	5. 8	15.36	0 294	0.768
		Non-treated	0.45	1.00	21	12.69	11.87	10.66	6.46	15.96	.323	.798
Concrete	1 : 1.5 : 3.3	Treated	0.68	0.75	21	12.82	12.16	10.89	5 15	15.04	.258	.752
		Non-treated	0.68	0.75	21	12.92	12.27	10.90	5.03	15.64	.256	.782

Specimens cured 14 days in damp sand, and 7 days in air.
Surface treated with Silicate of Soda (4%) such as follows:
1st. treatment . . . . 14 days after placing
2nd. treatment . . . . 15 days " "
3rd. treatment . . . . 16 days " "
Tests made at Technological Laboratory of Osaka Municipality.

Hand-mixed concrete and "Koseki".
Wear tests of 8×8×5-in. blocks of concrete and "Koseki", placed in Talbot-Jones Rattler with 200 lbs. cast iron balls.
Speed: 30 revolutions per minute.
Specimens cured in damp sand.
Water-ratio is to volume of cement (1520 kg. per cubic meter).

A glance at the results of the tests, will show that they are substantially the same in results as those of the brick rattler tests with the exception of the relative wearing strength of "koseki" and concrete. Series A relates to a comparison in abrasion between "koseki" and concrete. The tests were made at two different numbers of revolution—1 800 and 5 400. In either case, concrete had a better showing. In "koseki" the larger the percentage of cement the greater the abrasion.

In concrete, the richer the proportion the greater the abrasion up to 1 800 revolutions. The case was reversed when the number of revolution was increased to 5 400; that is, the poorer the proportion, the greater the abrasion.

As already mentioned, "koseki" is superior to concrete in compressive strength and modulus of rupture. In abrasion also, "koseki" stood higher than concrete in ball tests with a brick rattler and with an Amsler wear testing machine. In the abrasion tests conducted with a Talbot-Jones rattler, however, the position was reversed. Examining the nature of abrasion in the tests with this machine, it has been ascertained that the abrasion in the test-pieces, both "koseki" and concrete is conspicous on the outside, that is, on the edge and at the corners, and that the central part suffers but slight abrasion. The size of broken pieces on the outside due to impact is larger in the case of "koseki".

It will be observed that the abrasion in the tests made with this machine largely consists of splitting of the borders, differing remarkably in the effect of abrasion on balls in the tests with a brick rattler. A close examination of abrasion both during its progress and at its final state revealed the fact that abrasion is effected in larger pieces in "koseki" than in concrete, presumably because the latter is harder and has a greater modulus of rupture. In Series A "koseki" is represented as having a higher rate of abrasion at an earlier stage of revolution, the rate lowering with the increase in the number of revolution, while in concrete the rate of abrasion is, generally speaking, proportional to the number of revolutions. The results of abrasion tests on rich and poor concretes are reversed when the number of revolution is raised from 1 800 to 5 400. These facts seems to indicate the difference in property between "koseki" and concrete. Generally speaking, the result of tests does not indicate the actual wear which takes place under traffic.

In the tests with an Amsler wearing machine, a cubic testpiece of 7.07 centimeter was used. It was subjected to a weight of 30 kg., and measure-

Table VII.

Wear Tests by means of Wear-testing Machine, Amsler & Co.

Kind of Specimen	Mix. by Volume	Water - Ratio	Slump in in.	Age at Test, in days	Condition	Wear Test				
						Distance revolved in meter	Weight (g)		Wear	
							Initial	Final	Per cent by Weight	Depth in in.
"Koseki"	1 : 1 8	0.43	1.00	14	Dry Dry Wet	500 1.000 500	863 863 822	840 821 780	2.66 4.87 5.11	.19 .34 .36
Concrete	1 : 1.5 : 3.3	0.68	0.75	14	Dry Dry Wet	500 1 000 500	875 875 824	848 823 773	3.09 5.94 6 19	.22 .42 .44
Concrete	1 : 2 : 4.5	0.75	0.50	14	Dry Dry Wet	500 1.000 500	878 878 832	855 831 785	2.62 5.35 5.65	.19 .38 .40

Hand-mixed concrete and "Koseki".

Wear tests of 7.07 cm. cubes, the figures in the column wear indicate the average value of two tests.

Load laid on specimens was 30 kg.

As abrasive charge quartz sand in used (No. 30 -No. 40).

Cement and aggregate: same as Table I and II.

Specimens cured in damp sand.

Table. VIII.

Section	Kinds of Pavement	Area ft²	Proportion by Volume	Aggregate		Water Cement Ratio by Volume	Remarks
				Sand	Broken Stone		
1	Concrete	51.5	1 : 1.75 : 3	Yodo River Sand	Granite Pass. 7/8" Retain. 1/8"	0.39	Fine and coarse grained granite mixed Cement (a)
2	"Koseki"	58 7	1 : 1.5	—	"	0.37	Fine grained granite, cement (a)
3	"	41.8	1. : 1.5	—	Andesite Pass. 7/8" Retain. 1/8"	0.37	Cement (a)
4	"	36.0	1 : 1.5	—	Granite Pass. 7/8" Retain. 1/8"	0.33	Fine and coarse grained granite mixed, Cement (a)
5	"	15.8	1 ; 1.5	—	Slag	0.33	Cement (a)

ments were taken at the end of every 500-meter travel, operating the machine at the speed of one meter per second. The results are shown in Table VII. The results of these tests may differ according to the property, size, and state of interlocking of the aggregate, but, generally speaking from the results obtained in these tests, "koseki" suffers less from abrasion than concrete, and that in both cases abrasion is greater when these are moist than when dry.

Elaborate tests more closely corresponding to actual conditions were made at the Technological Laboratory of the Osaka Municipality. In these the rate of abrasion was measured on circular test slabs with an average diameter of 26 feet 3 inches. On these slabs, steel wheels weighing 1 225 lbs., with tires 3 in. in width were rotated at a speed of 5.5 miles per hour. The test slabs were of five kinds as shown in Table. VIII.

The pavement was prepared as follows. A sandy subgrade was covered with gravel to a thickeness of one foot followed by careful tamping. The second layer consisted of concrete (6-in. thickness) with a 1:3:6 mixture. On this concrete layer was constructed a wearing course to be tested. These concrete and "koseki" with proportions and consistencies as given in Table VIII were spreaded over a specified site. The material was first rammed down with a pneumatic tamper and then rolled with an iron roller, 210 lbs. in weight, being finally finished with trowels. After finishing, the surface was covered with straw matting for 24 hours, and cured under water for 30 days.

Table IX.

Section	Kind of pavement	Proportion by Volume	Wear in inches			No. of Pot Holes
			Max.	Min.	Avera.	
1	Concrete	1 : 1.75 : 3	5/8	1/8	1/4	8
2	"Koseki"	1 : 1.5	5/16	1/16	1/8	-
3	"	1 : 1.5	7/8	1/8	1/4	4
4	"	1 : 1.5	1/8	1/16	1/8	-
5	"	1 : 1.5	3/8	1/8	1/4	4

During the process of testing, sand was strewn on the pavement, while the wheels were in motion.

The wear was measured by taking the longitudinal and transverse sections with the use of an automatic recorder. The results given in Table IX are those obtained after the test pavement was subjected to 18 000 revolutions for 50 hours, equivalent to wheel loads of 43 800 tons per foot width.

The notes taken during the progress of the tests are given in Table X.

Table X.

Condition of pavement when tested	No. of Revolution	Time of Operation in Minutes	Loads Passed per Liniar Ft. of Width in Tons	Results
Wet	1,800	300	4,380	Wear conspicuous in Section I.
Wet	3,600	600	8,760	Relative abrasion on each section more distinct; best results shown in Section II and IV.
Wet	5,400	900	13,140	Damage in seve- places in Section I; damage in Section III gradually enlarged.
Dry	7,200	1,200	17,520	Pot holes in Section I enlarged: greater jerking of wheels.
Dry	9,000	1,500	21,000	Greater damage in Section I, III, and V
Dry	10,800	1,800	26,280	Enlarged pot holes in Section I, III, and V filled with sand or gravel.
Dry	12,600	2,100	30,600	Same condition as above.
Dry	14,400	2,400	35,420	Wear in all Sections conspicuous.
Dry	16,200	2,700	39,420	Same condition as above
Dry	18 200	3,000	43,800	Damage in Section I so serious that the test had to be stopped.

In Section I abrasion was found to be more considerable than in any other section at the end of five hours after the commencement of the test, when the traffic density was 4 380 tons per foot of effective width. The destruction was so considerable with the progress of the test that in a little over ten hours pot holes were produced in several places. As, in this section, great damages were done in the earlier stage of the test, repairs were made with sand or crushed stone so as to prepare for the continuation of the test in the later stage and also to minimize the affection of other sections due to the dumping of the wheels in this Section.

In Section II, better results were obtained compared with Section I, III and V. Pot holes were not visible.

In Section III, andesite was used as aggregate. In the course of the test, the stone particles projected on the surface and the cement was worn off, but no pot holes were produced making a far better showing than that of Section I.

In Section V, slag was used as aggregate, and as it lacked uniformity, abrasion varied in places.

In Section IV, the best results of these test were obtained. The surface wear was uniform and smooth with no pot holes.

In these tests, it has been ascertained that "koseki" resist wear more effectively than concrete. In Sections II and IV "koseki" successfully bore the traffic of 43 800 tons per foot of width, that is 18 000 rotations at a speed of 5.5 miles an hour.

The foregoing reffers to laboratory experiments on concrete and "koseki". Below are given instances of experiments made on pavements actually in use:—

Experiment at Nishiki-cho, Kanda, Tokyo.

This experimental pavement was constructed in the spring of 1922. A "koseki" pavement was laid on a concrete base (proportion 1:3:6) already in existence at the time of the experimental work. The "koseki" layer was $3^1/_4$ in. thick and covered an area of about 400 square yards.

For aggregate, crushed granite passed through a 7/8 in. sieve and retained on a $^1/_2$ in. sieve, was used. The mixture was a rich one, being one part of cement to one part of granite. The amount of water was such that it exuded on the surfaces when tamped. This mixture was first rammed down with a pneumatic tamper and then rolled with a hand roller of about 400 lbs.. in weight. Expansion and contraction joints 5/8 inch wide, were provided with a spacing of about 18 ft. for half the entire length of the pavement.

This experimental road has a width of 88 ft. The roadway has a total width of 53 ft. with a double track street car line. The roadway and the side-walk are separated by a side ditch, 1 ft. wide and 1 ft. 6 in. deep.

Under these circumstances, traffic is naturally heaviest on the middle part of the pavement. According to traffic census taken in June, 1925, during one day (from 6 a.m. to 6 p.m.; slight rain in the forenoon), the traffic at the site of the experimental pavement included 1 360 mechanically driven and 2 460 animal and hand-drawn vehicles. The entire traffic reaches 10 200 vehicles when bicycles and jinrikishas are taken into account.

About one year after construction, a crack was found across the road at a construction joint. Two or three similar cracks several feet long were subsequently found acros the road, but these cracks were not further enlarged by vehiclar traffic. Only at the edge and corners, the "koseki" layer was crushed under heavy traffic, and these damages were spreading. The surface is little worn and remained smooth. It looks in excellent condition bearing a resemblance to mosaic work. The pavement has preserved its original condition without a single repair.

Experiment on National Road No. 4 (in Umeshima-mura Tokyo Fu).

This pavement was constructed for purpose of experiment in 1925. It is 1 800 feet long and 21 feet wide. It was laid over an earth coated gravel road and consisted of "koseki" made of various kinds of materials.

The original gravel road was raked evenly and rolled to specified form with a roller. The surface was then covered with conrete (1:3:6 proportion) made of river gravel and sand.

Before setting, the concrete was topped with "koseki" of gravel, crushed granite or andesite. The concrete foundation is $4^1/_2$ in. thick at the middle part and at the corner and the edge, the thickness is increased by about 30 per cent. For joints special shapes or dowels were used, so that the adjacent slabs, may work as a whole. Transverse joints (expansion or contraction) were provided at intervals of from 40 ft. to 80 ft. Longitudinal joints were provided in the center of pavement in some sections, but in others they were not provided. The aggregate retained on a $^1/_2$ in. and passed through $1^1/_4$ in. screen (fineness modulus 7.00) was used and the proportion was one part cement to two parts aggregate. The amount of water used for mixing "koseki" was about 40 per cent. of the volume of cement. This dry-mixed material (slump test 0 and flow test nearly 100) was rammed down with a hand and pneumatic tamper and then finished off with striking boards and floats. As the concrete mixer then in use was not fit for the preparation of concrete of the required consistency, mixing had to be done by hand.

The cost of this pavement was roughly 14 yen per tsubo (unit tubo is equal to 4 square yards). The pavements now under construction in Tokyo range in cost from 32 to 70 yen per tsubo, detailed figures being as follows:— Stone block, 70 yen; wood block, 48 yen; brick, 44 yen; durax, (conrete base, 6 in. thick), 36 yen; sheet asphalt, 32 yen. The estimated cost of a "koseki" pavement with a foundation of the same thickness as in the pavements above mentioned is about 22 yen per tsubo, which is half the cost of a wood pavement and two-thirds the cost of a sheet asphalt pavement.

The volume of traffic on the site of this pavement, according to the investigation made in May, 1925, was 155 mechanically driven vehicles (mostly motortrucks and a few passenger cars) and 1 080 animal or hand-drawn vehicles, making a total of 1 235. These are figures for a twelve hour day from 6 a.m. to 6 p.m.

It is yet too early to speak definitely about the durability of this type of pavement, but so far no cracks or other damages are discernible, and the condition of surface is satisfactory. Only at places where river gravel was used the cement coating on the gravel seems liable to fall off under the strain of vehicular traffic.

Experiment at Nishinomiya, Hyogo prefecture.

This pavement was constructed in 1923. The original earthcoated gravel road was scarifired and rolled to specified form preparatory to laying 1:2:4 concrete 4 in. thick. Before the concrete set, it was topped with "koseki" 2.5 in. thick. The surface was consolidated with a tamper, rolled with a hand roller, and finally finished with a trowel. The proportion was one part cement to 1.7 parts crushed stone. The amount of water used was very small and as the mixing of "koseki" could not effectively be done with an ordinary mixer, it had to be executed by hand. The crushed stone was of two sizes— $^1/_4''$ to $^1/_2''$ and $^3/_8''$ to $^3/_4''$. The method of construction and curing were substantially the same as those adopted in other experimental pavements, and the road was opened to traffic two weeks after its construction. The volume of traffic over this pavement for one day is roughly—70 mechanically driven and 400 horse-drawn vehicles. The results as shown after a lapse of three years after constraction are fairly good. No serious damages are to be detected with the exception of some wear at the edges and corners of joints. The condition of surface wear is uniform and smooth.

"Koseki" pavement has been experimented upon in Ibaraki prefecture, Osaka-fu, and Tokyo-fu etc. and it is now being used in the construction of a street railway track in Osaka. In all these cases the method of construction is substantially the same as the already described, and the results too are generally in accordance with those of the experimental pavements dealt with in the foregoing pages.

Summing up the results obtained from laboratory tests and experiments on pavements in actual use, we notice various features in favour of "koseki" pavements. As long as the present traffic condition continues, a "koseki" pavement resists the wear of steel-tired vehicles more successfully than an ordinary concrete pavement. In a "koseki" pavemet the surface wear is uniform and smooth, and it is likely to cause less wear on rubber tires than in the case of a concrete pavement. The materials are easily obtainable in all parts of the country, and the methods of construction are comparatively simple; "koseki" pavement can be adopted wherever required. The cost of "koseki" pavement is far lower than wood or asphalt pavement, when it is used as wearing course only. Maintenance cost of such roads is very small.

A "koseki" pavement, however, has nearly the same disadvantages as those of a concrte pavement. It requires much time in repairing; and unless some special device be invented, it can not be opened to traffic immediately after construction as in the case of asphalt. It is not elastic as wood or asphalt pavements, consequently passing vehicles make much noise. The surface tends to become somewhat slipperly with the progress of time.

The best results are obtainable with the use of as little water as possible and with adequate tamping. The aggregate should be neither too hard nor too soft, keeping the golden mean. Its size should be decided according to the condition of traffic. As the cost is higher than that of concrte, in many cases it would be found to be more economical to use concrete as a basis, and "koseki" of a certain thickness for wearing course. In order to attain a high standard of excellence in laying "koseki" pavements, mixers and tampers better adopted to its special requirements have to be designed.

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