SIGNIFICANCE OF VISUAL TEST AND HAMMERING TEST TO MANAGE CONCRETE STRUCTURE DURABILTY

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***ABSTRACT*:** Inspection of reinforced concrete is important to ensure durability, and visual test and hammering test are widely applied to the inspection. In this study, reliability on the result of the visual test for cold joint and sand streak and the hammering test for checking concrete strength distribution was investigated, and it was clarified that error among those test results obtained by more than 100 students is fairly small. Then method to estimate durability of reinforced concrete based on visual test results is proposed and general concepts for applying the hammering test to evaluation of concrete strength distribution is described.

The following (1) and (2) are main conclusions.

(1). Relation between visual test result for cold joint and diffusion coefficient of chloride ion in hardened concrete is very close, so that the durability of reinforced concrete structure can be predicted based on visual test results according to Japan Society of Civil Engineers standard specification.

(2). Hammering test results accord with dynamic elastic modulus, thus the hammering test play a important role to evaluate the distribution of concrete strength. Defects in concrete are also inspected, but as soon as the defects are observed, the defects must be broken or repaired because this hammering test is small distractive test.

KEYWORDS: concrete, visual test, hammering test, inspection

1. INTRODUCTION

Many infrastructures in Japan have to be maintained for sustainable progress, because Japanese economy has been already matured. Thus Japan Society of Civil Engineers published standard specification for maintenance of concrete structures. Visual test and hammering test are playing an important role in inspection section on the standard. The Japanese Society for Non-Destructive Inspection also published “Method of visual test for concrete structures” as the standard of the Japanese Society for Non-Destructive inspection. However many experts have confidence in their visual and hammering inspections, some engineers feel a suspicion against ability of inspectors and error of judgment among inspectors.

On the other hand, methods to predict durability of concrete structures based on the visual test and the hammering test are not authorized, but many concrete structures serving for more than 100 years have been maintained based on the visual and

Table 1 Raw materials of concrete for visual test

Cement	Ordinary Portland cement (Density: 3.16g/cm^3, specific surface area: 3320cm^2/g)
Fine aggregate	River sand (Density under saturated surface-dry condition: 2.58g/cm^3, Water absorption: 2.72%, Fineness modules: 2.50)
Coarse aggregate	Crushed stone (Maximum size: 20mm, Density under saturated surface-dry condition: 2.71g/cm^3, Water absorption: 0.77%, Fineness modules: 6.84)
Chemical admixture	Air-entraining and water-reducing admixture, Air-entraining agent

Table 2 Specified mix of concrete for visual test

W/C (%)	Slump (cm)	Air content (%)	s/a (%)	Unit content (kg/m^3)				Ad1 (ml/m^3)	Ad2 (ml/m^3)
				W	C	S	G		
55	12.0	4.5	44	180	327	762	1027	491	8.2

Ad1: Air-entraining and water-reducing admixture

Ad2: Air-entraining admixture

hammering test by experts.

In this study, errors of results of the visual test and the hammering test among inspectors are researched at first. Then diffusion coefficient of chloride ion in hardened concrete at cold joint recognized by the visual test is evaluated, and the close relation between the coefficient and the visual test results for cold joint is proposed to predict the durability against chloride attack. By the way, the relation between visual test result for sand streak and durability against freezing and thawing is also examined, and the effective relation to estimate frost damage is described. And also Reliability of hammering test for prediction of compressive strength and defect in concrete is discussed.

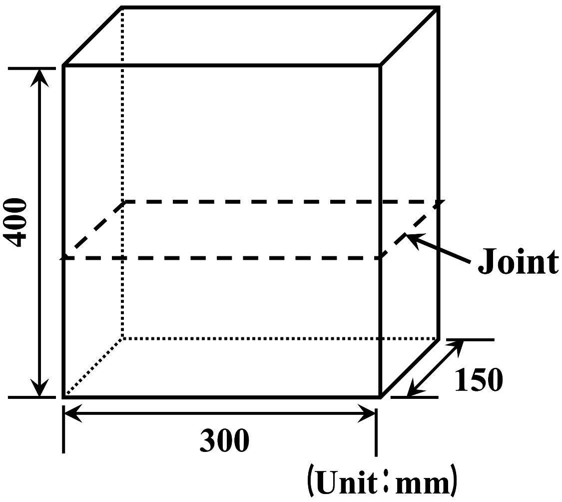


Fig.1 Specimen size for inspecting Cold joint

Fig.2 Photograph of student survey on Cold joint

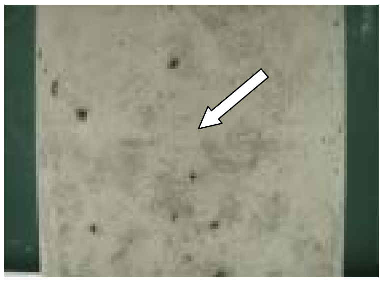
2. Test

2.1 Visual test for cold joint

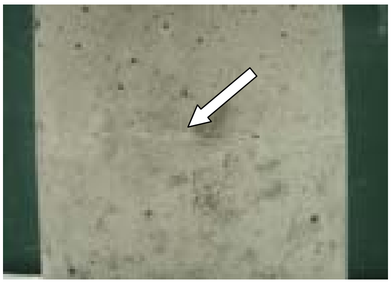
2.1.1 Specimens

Properties of materials prepared for this

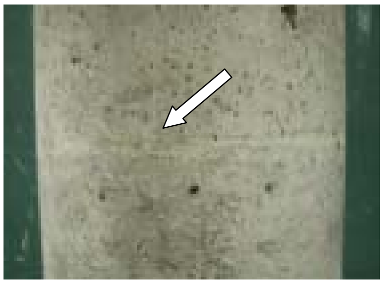
Level 1: no joints



Level 2: recognized partially and slightly



Level 3: recognized linearly



Level 4: recognized obviously as band

SPECIMEN No.	1	2	3	4	5	6	7	8	9	10	11	12
Level												

Fig.3 Questionnaire for Cold joint

experiment and Specified mixes are respectively shown in Table 1 and Table 2.

Specimens for 116 students to inspect cold joint are rectangular specimen (H400×W300×D150) as shown in Fig.1. Concrete was placed by 2 layers to make cold joint at half of height of the specimen. After compaction of the lower layer concrete, the upper layer concrete was placed over bleeding water remaining on the lower concrete, and was compacted. Time interval between the lower concrete compaction and the upper layer concrete placement is changed from 10 min to 180 min.

2.1.2 Visual test for cold joint by 116 students

Student survey was carried out as shown in Fig.2, after distribution of the questionnaire as shown in Fig.3 to each student. The photograph on the questionnaire was taken on cylindrical specimens (150 by 300 mm), however the concrete faces for visual test were flat faces of rectangular specimen. The survey was practiced twice i.e. before and after soaking specimens into NaCl solution.

2.1.3 Soaking test into NaCl solution

After first visual test by 116 students, the specimens were soaked into 10% NaCl solution for 1 month. Then visual test was practiced again. As soon as the last visual test, the specimens were split and part containing chloride were measured with silver nitrate ($AgNo_3$) solution.

The students are 2nd grade in our university at 2007, and have no experiences in inspection.

2.2 Visual test for sand streak

2.2.1 Specimens

Materials and specified mix proportions are respectively shown in Table 1 and Table 2. Specimen is cylindrical (88 by 200mm), and concrete is cast in clear PET plastic mold by 2 layers. The thickness of each layer is 100mm. Each layer was jogged with steel rod (diameter of 6mm) by 60 times for compaction. Interval between the lower layer concrete compaction and the upper layer concrete placement was changed from 60min to 180min. Two sequences for the upper layer placement were examined. One sequence was that the upper layer concrete was directly placed over remaining bleeding water on lower the layer concrete. The other sequence was that after recompacting the lower layer concrete with steel rod for softening the jointing surface, that is upper surface of the lower layer, the upper layer concrete was placed over the adjusted bleeding water on the lower layer concrete. The adjustment of bleeding water was controlled for amount of bleeding water to be almost same as that of bleeding water measured just before recompaction. After taking off mold at the age of 24 hours, the specimens were cured in atmospheric conditions.

2.2.2 Visual test for sand streak by 116 students

For student answer, questionnaire is designed for students to answer that “defect is observed” or “defect is not observed”. After visual test, the width of the observed defects was also measured with scale and the defects were distinguished by the width. In case of the width under 10mm and over 10mm, the defect is evaluated as level 2, and level 3 respectively.

The students were 2nd grade in our university in 2007, and have no experiences in inspection.

2.2.3 Freezing and thawing test

After the visual test for sand streak, freezing and thawing test was carried out. At the 36 cycle freezing and thawing test, loss of mass was measured.

2.3 Hammering test

2.3.1 Specimens

The properties of materials prepared for this experiment and the specified mixes for examining concrete strength are respectively shown in Table 3 and Table 4~7. Table 4 was designed to evaluate the minimum difference of concrete strength which can be distinguished between two specimens. In this test, only normal aggregate concrete was examined. Table 5, 6 and 7 were designed for students to rank the order of concrete strength among 5 specimens consisting of each aggregate. On the other hand, survey was also conducted for students to rank the order of concrete strength among specimens of N-50, L-50, R-35 and R-50 mix. This survey is to confirm the effect of aggregate and dynamic elastic modulus of concrete. Specimens for 100 students to inspect compressive strength were rectangular specimens (H530×W150×D150) as shown in Fig.4.

Specimens for 100 students to inspect defect in hardened concrete were rectangular specimens (L300×W150×D150) as shown in Fig.5 and Fig.6. The concrete consisted of river sand and crushed stone. The void defect was performed by dissolving styrene foam in acetone, i.e. after concrete hardened, preplaced styrene foam at defect position was dissolved in acetone injected through straw set behind of specimens, and the solution was taken out.

2.3.2 Hammering test by 100 students

After explanation that “The higher the compressive strength, the better the rebound, the higher the tone,” and “On defect, tone differs from other parts,” student survey on strength comparison and on defect inspection was carried out as shown in Fig.7 or Fig.8 respectively.

The students are not experienced in inspecting.

Table 3 Raw materials for hammering test

Cement	Ordinary Portland cement (Density: 3.16g/cm^3, specific surface area: 3320cm^2/g)
Fine aggregate	River sand (Density under saturated surface-dry condition: 2.59g/cm^3, Water absorption: 2.59%, Fineness modules: 2.60) Lightweight aggregate(Density under saturated surface-dry condition: 1.84g/cm^3, Water absorption: 12.31%, Fineness modules: 3.05) Recycled aggregate(Density under saturated surface-dry condition: 2.24g/cm^3, Water absorption: 11.64%, Fineness modules: 3.71)
Coarse aggregate	Crushed stone (Maximum size: 20mm, Density under saturated surface-dry condition: 2.69g/cm^3, Water absorption: 0.82%, Fineness modules: 6.35) Lightweight aggregate (Maximum size: 20mm, Density under saturated surface-dry condition: 1.64g/cm^3, Water absorption: 28.32%, Fineness modules: 6.23) Recycled aggregate (Maximum size: 20mm, Density under saturated surface-dry condition: 2.32g/cm^3, Water absorption: 8.42%, Fineness modules: 6.72)
Chemical admixture	Air-entraining agent and air-entraining and high-range water-reducing admixture
Admixture mineral	Silica fume (Density:2.20 g/cm^3)

Table 4 Specified mix of concrete for hammering test

Conbination	W/C	Unit content (kg/m^3)				Compressive strength (N/mm^2)	Difference of Compressive strength (N/mm^2)
		W	C	S	G		
A-1	57	183	322	785	1012	44.8	3.2
A-2	47	197	418	725	981	48.0	
B-1	43	182	421	680	1000	32.3	9.5
B-2	56	190	349	757	989	41.8	
C-1	56	190	342	767	996	37.2	12.8
C-2	40	180	446	664	1012	53.0	
D-1	48	182	382	699	1013	44.2	5.0
D-2	42	185	440	678	1004	49.2	
E-1	40	185	459	655	987	45.3	3.9
E-2	51	173	342	717	1028	41.4	
F-1	44	183	420	705	1010	43.9	9.1
F-2	56	191	344	748	995	34.8	

Table 5 Specified mix of concrete consisting of river sand and crushed stone for hammering test

Mix No.	W/C (%)	s/a (%)	Unit content(kg/m^3)					Compressive strength (N/mm^2)
			W	C	SF	S	G	
N-20	20	37	165	660	165	485	858	108.3
N-35	35	40	165	377	94	651	1014	90.5
N-50	50	43	183	366	-	731	1006	36.3
N-65	65	46	183	282	-	814	992	28.2
N-80	80	49	183	229	-	888	960	13.5

Table 6 Specified mix of concrete consisting of lightweight aggregate for hammering test

Mix No.	W/C (%)	s/a (%)	Unit content(kg/m^3)					Compressive strength (N/mm^2)
			W	C	SF	S	G	
L-20	20	37	165	660	165	349	529	67.5
L-35	35	40	165	377	94	465	621	62.8
L-50	50	43	183	366	-	519	613	35.1
L-65	65	46	183	282	-	578	605	19.4
L-80	80	49	183	229	-	631	585	13.0

Table 7 Specified mix of concrete consisting of recycled aggregate for hammering test

Mix No.	W/C (%)	s/a (%)	Unit content(kg/m^3)					Compressive strength (N/mm^2)
			W	C	SF	S	G	
R-20	20	37	165	660	165	425	749	61.8
R-35	35	40	165	377	94	566	879	50.4
R-50	50	43	183	366	-	632	868	23.5
R-65	65	46	183	282	-	704	856	9.6
R-80	80	49	183	229	-	768	828	5.5

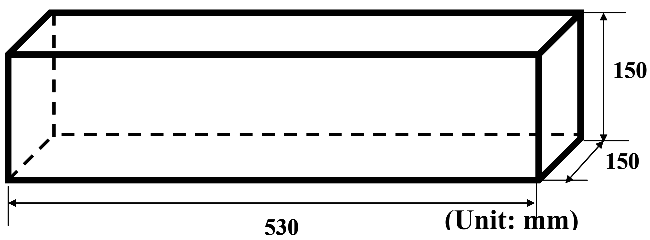


Fig.4 Specimen size for inspecting compressive strength

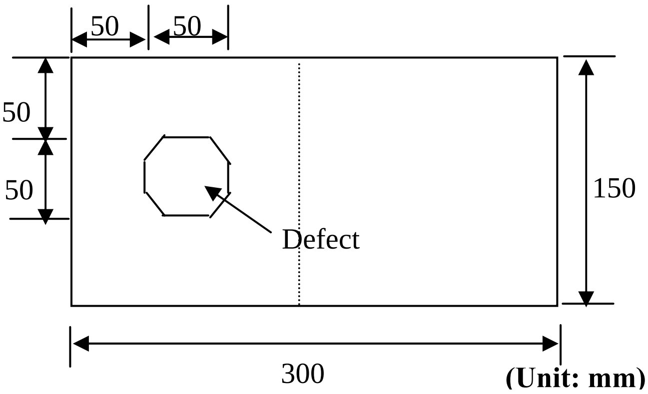


Fig.5 Specimen size for inspecting internal defect

Fig.6 Defect on photograph of cut section

Fig.7 Photograph of student inspecting compressive strength

Fig.8 Photograph of student inspecting internal defect

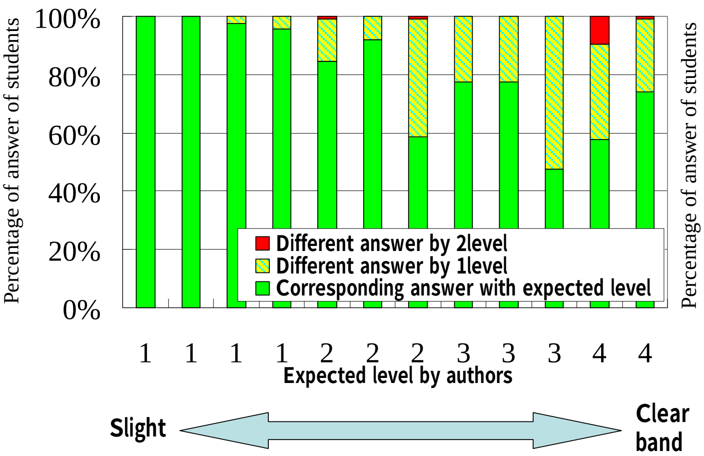


Fig.9 Result of visual test for Cold joint by 116 students (Before soaking NaCl solution)

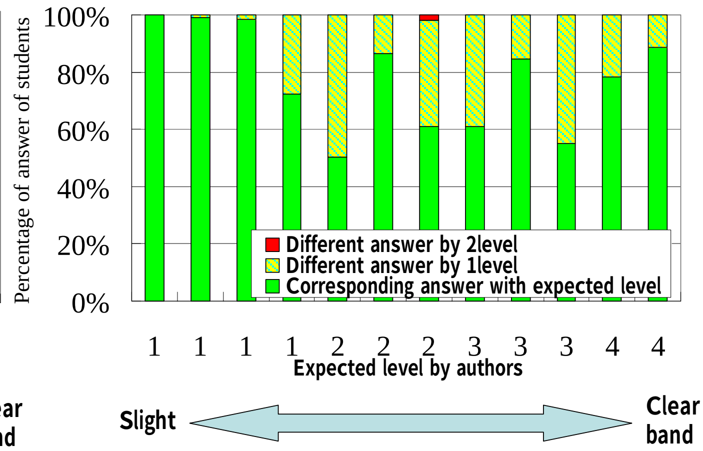


Fig.10 Result of visual test for Cold joint by 116 students (After soaking NaCl solution)

Those students are 2nd grade in our university in 2002, so that they are different from the students for visual test.

3. Test Result and Discussion

3.1 Visual test for cold joint

3.1.1 Visual test for cold joint by 116 students

The answers of students are almost corresponding with the expected answer by authors, as shown in Fig.9 and Fig.10, even when the specimens after soaking into NaCl solution were inspected. The percentage of corresponding answer in Fig.10 is more than that in Fig.9, because the inspection before soaking is a first experience for student and the inspection after soaking is a second experience. Difference of level between the student's answers and the expected answers is almost under 1 level. But around boundary between two levels i.e. 1&2, 2&3, 3&4, percentage of perfectly corresponding answer is smaller a little.

Fig.11 is a rewrite of Fig.10 based on the answers of 97 students except 19 students who gave up taking course unit of concrete experiment. All the difference is under 1 level.

3.1.2 Soaking test into NaCl solution

Relation between penetration of chloride and visual test result at cold joint is very close as shown in Fig.12. It is recognized that the larger the level of

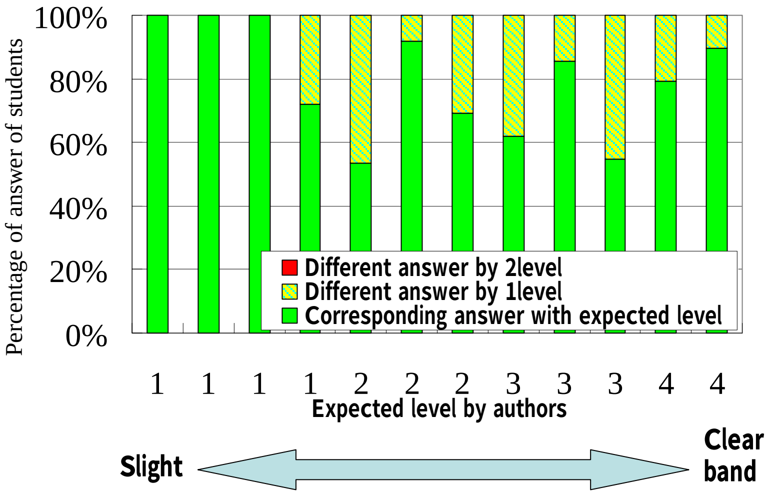


Fig.11 Result of visual test for Cold joint by 97 earnest students (After soaking NaCl solution)

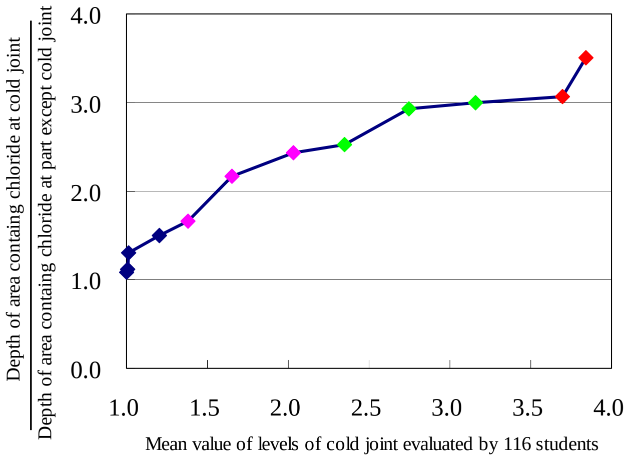


Fig.12 Relation between result of visual test for Cold joint and depth of area containing chloride

cold joint observed by visual test, the deeper the chloride penetration. This tendency will be useful to estimate the diffusion coefficient of chloride ion at cold joint based on the visual test result, so that the depth of chloride penetration can be predicted with the estimated diffusion coefficient of chloride ion according to Japan Society of Civil Engineers standard specification. As the worst level of evaluation was limited, near of level 4 the plotted line is inclined sharply.

3.2 Visual test for sand streak

3.2.1 Visual test for sand streak by 116 students

The answers of students are almost corresponding with the expected answer by authors, as shown in Fig.13. When the upper surface of lower concrete is significantly soft just before upper concrete placement because of short interval from upper layer placement to lower layer placement or adjusting bleeding water after recompaction, there are a few different answers.

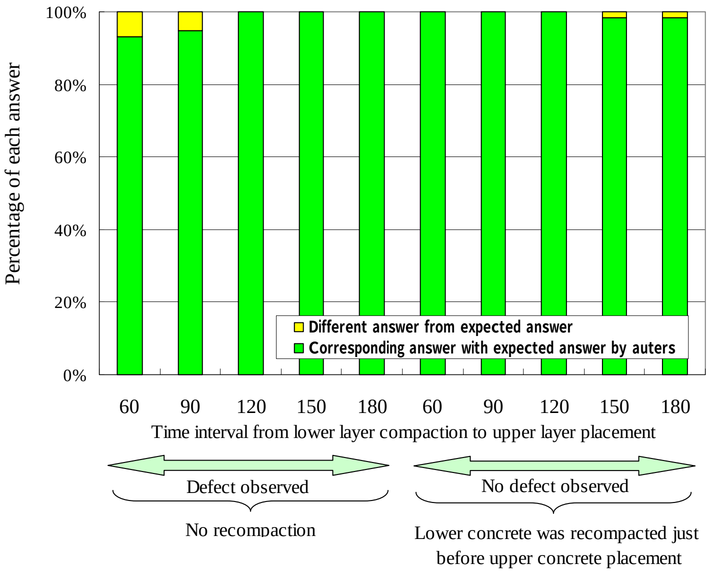
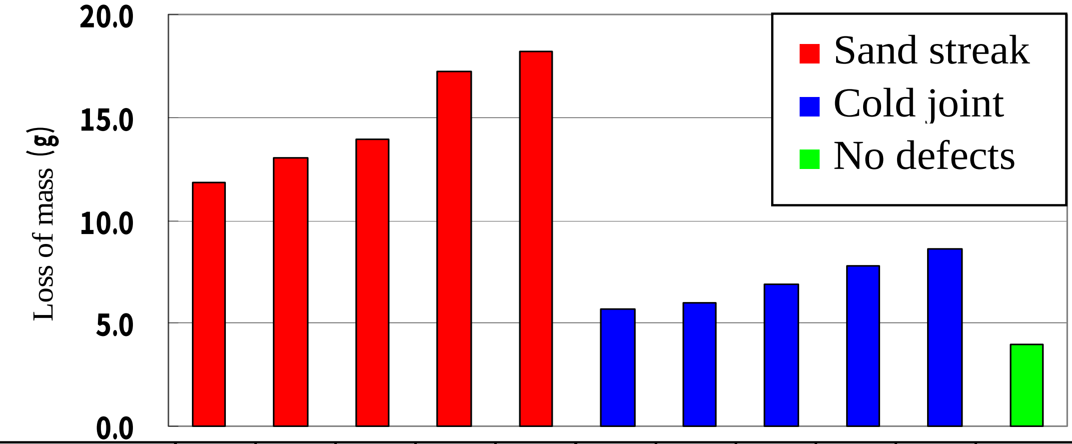


Fig.13 Result of visual test for Sand Streak

3.2.2 Freezing and thawing test

When sand streak was observed, cold joint was always observed. Even when cold joint was observed, sometimes sand streak could not be observed. Fig.14 shows the relation between visual test result and loss of mass after freezing and thawing test. The tendency i.e. “the higher the level of defect, the larger the loss of mass” is an effective observation on prediction of durability against frost damage based on visual test result.



Level of cold joint (No sand streak)						2	3	3	4	4	No defects
Level of sand streak	2	2	2	3	3						

Fig.14 Relation between visual test result and loss of mass at 36 cycle freezing and thawing

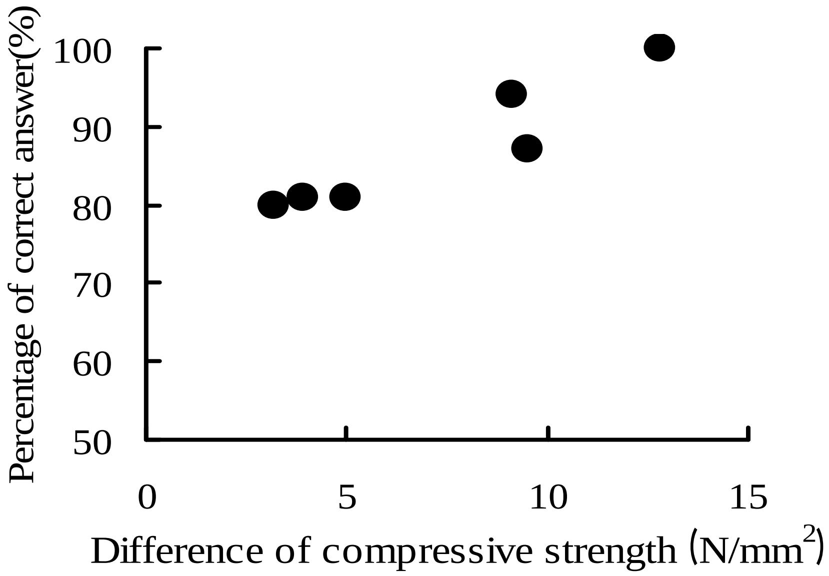


Fig.15 Relation between percentage of answer distinguishing correctly and difference of actual compressive strength of concrete (Specified mix is shown in Table 4)

3.3 Hammering test

3.3.1 Hammering test for strength distribution

When two specimens consisting of normal aggregate were compared, percentage of correct answer is shown in Fig.15. When the difference of compressive strength between two specimens is about 5N/mm^2 and 10N/mm^2, percentage of correct answer is respectively about 80% and 90%. When the difference is about 13N/mm^2, all students could distinguish the strength.

Fig.16 shows percentage of absolutely correct answer among concrete specimens of 5 strengths consisting of each aggregate (mix is shown Table5, 6

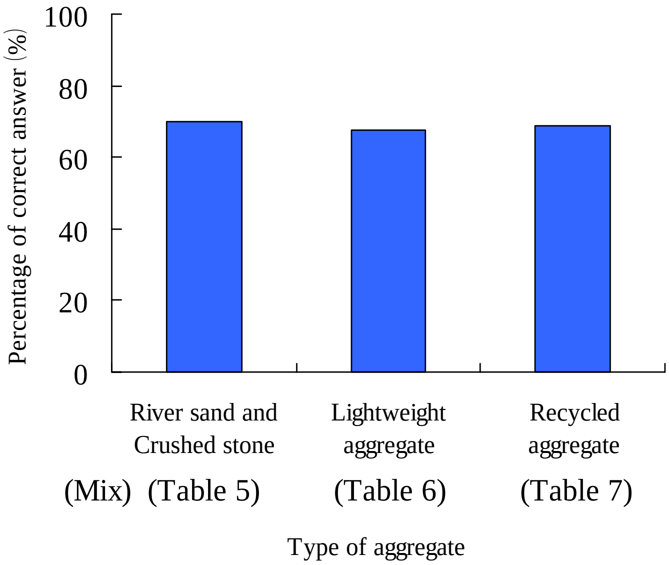


Fig.16 Effect of each aggregate on percentage of answer perfectly predicting the order of concrete strength between 5 concrete specimens

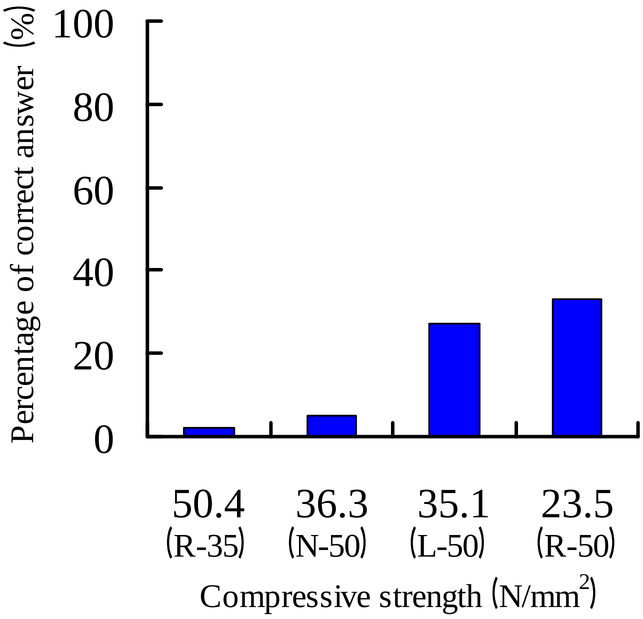


Fig.17 Relation between correct answer and compressive strength of concrete consisting of different aggregate

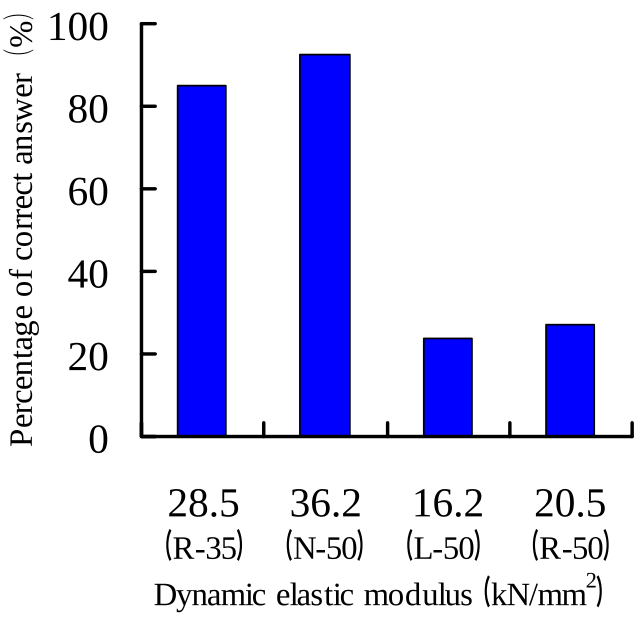


Fig.18 Rewritten result assuming hammering test inspects dynamic elastic modulus

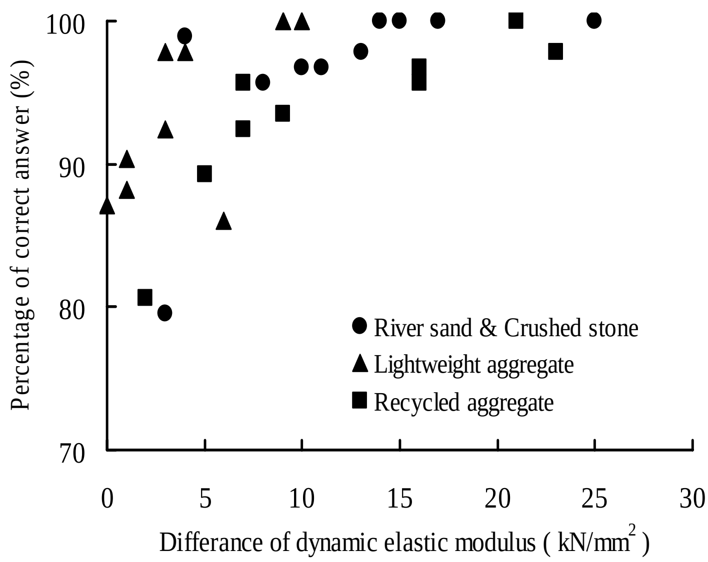


Fig.19 Relation between correct answer and difference of dynamic elastic modulus

and 7). However when different aggregate concrete (mix N-50, L-50, R-35, R-50 shown in Table 3, 5, 6 and 7) is inspected, percentage of correct answer is significantly small, as shown in Fig.17. In this case, student predicted for the strength of lightweight aggregate concrete to be smaller so that the correct answer for L-50 and R-50 is small. Assuming that the higher strength specimen predicted by student is the higher dynamic elastic modulus concrete, Fig.18 was drawn. Even if different aggregate concrete is inspected, the lager the dynamic elastic modulus, the lager the percentage of correct answer.

Table 8 Percentage of student who could find out the void defect

Compressive strength of concrete (N/mm²)	57.7		39.0			6.9
Depth of void defect from concrete surface (mm)	10	20	30	50	70	20
Percentage of student who could find out void defect (%)	58	42	59	67	56	100

Fig.19 shows relation between percentage of correct answer and difference of dynamic elastic modulus. Students more than 95% can correctly distinguish when the difference of dynamic elastic modulus is over 10kN/mm^2. The tendency that is "The larger the difference of dynamic elastic modulus, the larger the percentage of correct answer" can be considered to express that hammering test is for dynamic elastic modulus.

3.3.2 Hammering test for void defect in concrete

Table 8 shows the percentage of student who could find out the position where void defect was remained in concrete as shown in Fig.4 and 5. The percentage is getting to be lager when the depth of defect from concrete surface is smaller and the compressive strength of concrete is lower. Mass of hammer head used in this test was 280g and length of hammer shaft was 390mm. Then in case of high strength concrete and deep defect, students who have no experiences can not find out defect so easily.

During this test, the defect part were fractured finally. However use of heavier human make inspection to be precisely and easily, the damage of concrete must be heavier.

Any way, when defect is noticed, the defect has to be taken off or repaired to prevent skin concrete from peeling off or falling down after inspection.

4. Conclusion

Based on the results obtained from the experimental investigation, the following conclusions can be drawn.

(1) The error in visual test among inspectors is significantly small enough to inspect cold joint and sand streak, even when the inspectors are students who have no experiences.

(2) Relation between the visual test result for cold joint and the diffusion coefficient of chloride ion in hardened concrete is very close, so that the durability of reinforced concrete structure against chloride attack can be predicted based on visual test results according to Japan Society of Civil Engineers standard specification.

(3) Relation between the loss of mass under freezing and thawing test and the result of visual test for cold joint and sand streak is close, so that the visual test can be an effective method to predict durability against freezing and thawing.

(4) When the difference of strength is 5N/mm^2 and 15N/mm^2, the students more than 80% and all the students could distinguish concrete strength by hammering test respectively. Thus hammering test can play an important role to inspect the distribution of concrete strength. However hammering test is hardly applied to estimating the strength of concrete consisting of different aggregate, because hammering test results accord with dynamic elastic modulus of concrete.

(5) Void defect near concrete surface can be inspected by hammering test, but this test damages concrete around defect, so that when defect is noticed, the defect has to be taken off or repaired to prevent skin concrete from peeling off or falling down after inspection.