CURRENT STATE AND ACTION FOR EXTENSION OF CONCRETE LIFESPAN OF INFRASTRUCTURES IN JAPAN

－ POPULARIZATION OF SUPER QUALITY CONCRETE －

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***ABSTRACT*:**

The importance of asset management for infrastructures has recently been pointed out as part of total maintenance systems for infrastructures in Japan. In response to this requirement, new technologies for long-term utilization of infrastructures with low cost have been in the spotlight.

To ensure a long lifespan span of concrete infrastructures, “super quality concrete” (S.Q.C.) was developed by “The Association for the Development and Popularization of Super Quality Concrete Structures”, leading to the publication of “Recommendations for Design and Construction of Structures Using Self-compacting Concrete with High Strength and High Durability” by Japan Society of Civil Engineers (JSCE) in July 2001. After the publication of these recommendations, S.Q.C. has been employed in three projects by 2006. This paper presents the current state and action to be taken for the development and popularization of S.Q.C. in Japan, and remarks the problems on the popularization of S.Q.C. from a constructor’s viewpoint.

1. INTRODUCTION

Over 40 years have passed since the rapid economic growth period in Japan. Enormous amounts of infrastructures have now been facing their aging and necessity for maintenance. Regarding this problem, the importance of asset management for infrastructures is pointed out as part of total maintenance systems for infrastructures in Japan. According to this requirement, new technologies for long-term utilization of infrastructures with reasonable cost have bee attracting attention.

In 1989, Prof. Okamura of the University of Tokyo developed self-compacting high performance concrete. This new technology has now spread over the world. In Japan, various kinds of standards, specifications, and recommendations for self compacting concrete have been published by a number of public organizations and civil associations.

However, the advantages of self compacting concrete such as high strength and high durability had not been utilized effectively in the structural design.

“The Association for the Development and Popularization of Super Quality Concrete Structures” (S.Q.C. Association) was established in 1995 for development and popularization of S. Q. C. structure. “S.Q.C.” is a name for self-compacting concrete with high strength and high durability, and “S.Q.C. structure” is a structure which uses S.Q.C. and high strength reinforcement and/or fibers to ensure the long lifespan of concrete structures. The S.Q.C. association has established the design and construction method of S.Q.C. structure to utilize the advantages of S.Q.C. effectively and decrease the

life-cycle-cost of infrastructures.

This paper presents the current state and measures to be taken for the development and popularization of S.Q.C. in Japan, and remarks the problems hampering the popularization of S.Q.C. from a constructor's viewpoint.

2. ACTIVITIES OF S.Q.C. ASSOCIATION

The S.Q.C. Association was established in 1995 for development and popularization of S. Q. C. organizing 14 construction companies and 27 material suppliers, consultants, etc. Since 1995, a variety of experiments have been carried out for clarifying the durability and structural characteristics of S.Q.C. structures. As a result, it was clarified that the lifespan of S.Q.C. structures exceeds 100 years without any maintenance, and ranges from 300 to 500 years with easier maintenance than for conventional concrete structures. These structures were also proven highly resistant to earthquakes. The association confided the establishment of a subcommittee on self-compacting high performance concrete to JSCE. This subcommittee established in 2000 (Chairman; Koichi MAEKAWA, University of Tokyo) conducted researches to prepare recommendations and manuals for design and execution, eventually publishing a book titled "Recommendations for Design and Construction of Structures Using Self-Compacting Concrete with High Strength and High Durability" [1], as volume No. 105 of the Concrete Library of JSCE in July 2001. Self-compacting concrete with high strength and high durability is also referred to as "Super Quality Concrete" (S.Q.C.) in this book, and is defined as the "concrete with a water-binder ratio less than 40% that is expected to possess high strength exceeding a design strength of 60 MPa, (50MPa is allowed in the case that durability requirement allowed) and ensures sufficient self-compaction to prevent any construction defect". This recommendation includes not only design method and construction method, but also includes the maintenance method to ensure the long lifespan of structures.

After publishing these recommendations, the S.Q.C. Association started the activities for promotion of S.Q.C. structures. Super quality concrete was employed in 3 civil projects from 2001 to 2006, which are introduced in the following sections.

3. APPLICATION OF S.Q.C.

3.1 Ritto Bridge Substructure Project [2]

The Ritto Bridge, located in Siga Prefecture, is a prestressed concrete extradosed bridge with corrugated steel webs on the New Meishin

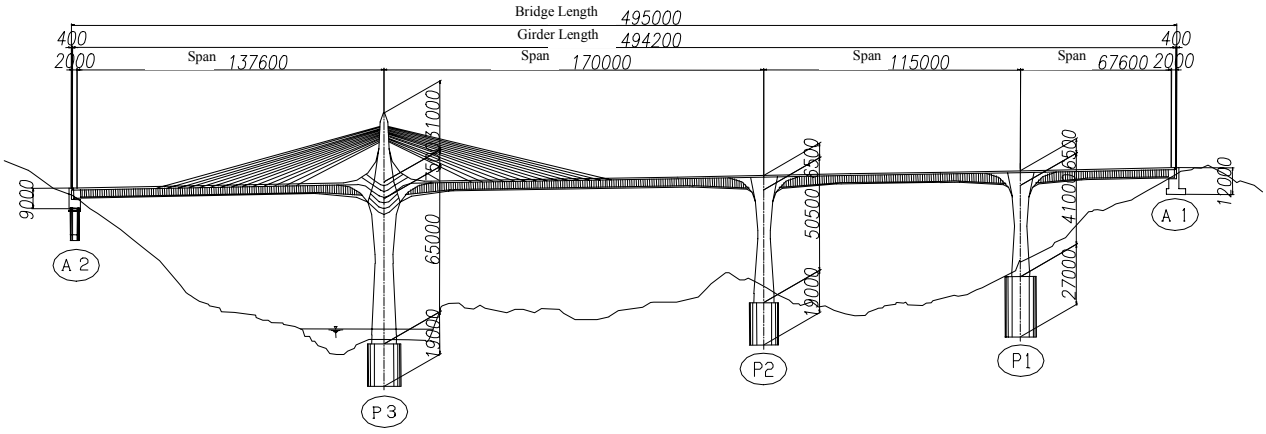

Figure-1 Cross Section of Ritto Bridge (A-Line bound for Tokyo)

Expressway in Japan. Figure-1 shows the shape of Ritto Bridge, with the highest pier reaching 65 meter in height. High strength concrete and reinforcements with the specification of compressive strength 50 MPa and yield strength 685 MPa, respectively, were applied to the construction of the piers to meet the requirements for earthquake resistance. Due to the dense arrangement of reinforcement, S.Q.C. was chosen to obtain good workability.

The requirements for S.Q.C. are shown in table-1 according to the recommendations of JSCE and Japan Highway Public Corporation (JH).

Super quality concrete was proportioned based on in-house trial mixes, plant trial mixes and mock-up tests. The final mix proportions and test results of fresh and hardened concrete are shown in table-2.

Photo-1 shows the panoramic view of this project, and photo-2 shows the state of concrete placing of A-P3 pier. Super quality concrete was once pumped up to the distributor hopper which was set at the top of pier, then flew down into the formwork and fulfilled in the formwork without any vibrating work.

The quality of S.Q.C was carefully checked by skilled engineers, and over 12,000 m3 of S.Q.C was placed successfully in the piers of this bridge.

Table-1 Requirements for S.Q.C

Testing Items	Unit	Spec.
Fresh concrete		
Slump Flow	(mm)	600 or 650
Flow time until 500mm	(sec.)	3 to 15
U type filling capacity	(mm)	min.300
V type Funnel flow time	(sec.)	8 to 15
Air content	(%)	4.5
Chloride ion content	(kg/m^3)	max.0.3
Hardened concrete		
Compressive strength	MPa	50

Photo-1 Ritto Bridge

Photo-2 Concrete Placing

Table-2 Mix proportion and test results

Mix proportion (In-house trial mix)											
Design Compressive Strength (MPa)	Water Cement Ratio (%)	Maximum Aggregate size (mm)	Slump Flow (mm)	Air Content (%)	Unit weight(kg/m^3)						
					Cement	Water	Fine Aggregate	Coarse Aggregate		HRWR	Pigment
								20mm	13mm		
50	33.0	20	600 650*	4.5	470	155	868	505	336	6.11	14.1

Test result										note
Testing Time from Mixing Complete	Slump Flow (mm)	Flow Time 500mm (sec.)	Flow Time Stop (sec.)	U Type Filling (mm)	V Type Funnel (sec.)	Air Content (%)	Concrete Temp (degree Centigrade)	Compressive Strength (MPa)		* Target slump flow was revised when push up height of pump rose.
								7days	28days	
5	630	6.1	34.0	338	11.8	4.3	19.0	41.1	74.0	

3.1 Viaducts in the Kurobe Maintenance Base for the Hokuriku Shinkansen Railway

The Hokuriku Shinkansen Railway is now under construction from Nagano to Kanazawa. The Kurobe maintenance base is located near Shin-Kurobe station in Toyama Prefecture. Two viaducts in the sidetrack to this base were constructed using S.Q.C. The sections of the piers and beams were narrowed down from the original design by applying S.Q.C. and high strength reinforcement.

Figure-2 shows the design of the viaduct. Main changes in the design are shown in table-3 and figure-3.

Though the construction cost of this project increased by nearly 8% due to the higher

Table-3 Main changes in design

item	Original design	New design with S.Q.C
Section size of pier	800×800(mm)	650×650(mm)
Section area of pier	0.64m2	0.42m3 (34% reduced)
Main reinforcement	D29 18nos. (SD390)	D32 16nos. (SD490)
Hoop reinforcement	D13 @100 (SD390)	D10.7 @100 (SBPD1275)
Weight of reinforcement (per 1m height of pier)	150kg/m	145kg/m (4% reduced)
Concrete	27-8-25-N	50-60-25-L(SQC)

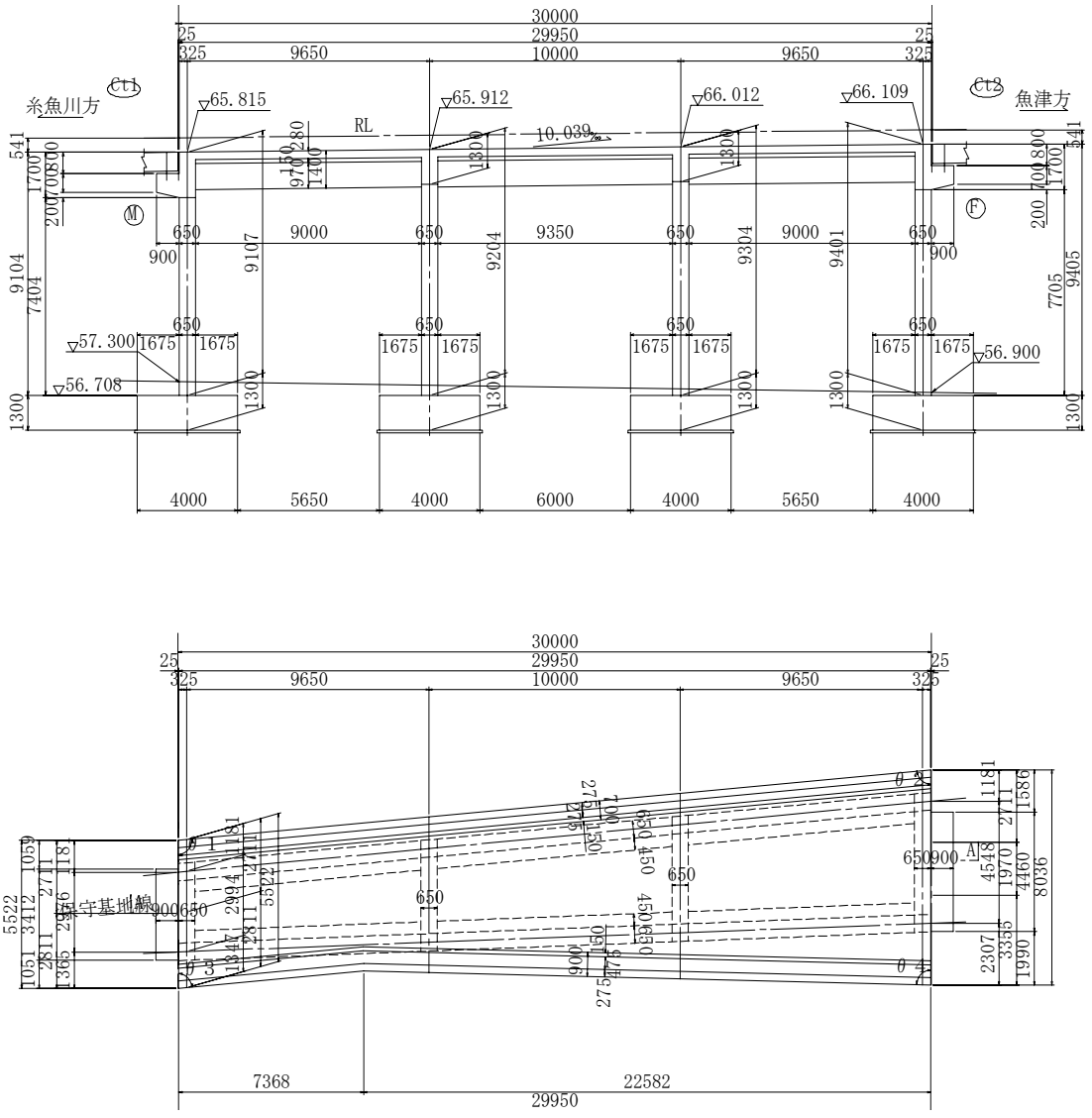

Fig.-2 Design of the viaduct in Kurobe maintenance base

material cost, the maintenance cost will be drastically reduced due to the high durability of S.Q.C. Photos-3 and 4 show the construction of these viaducts. Though the reinforcement at the cross section of pier and beams was very dense, S.Q.C. was successfully placed without any vibrating work.

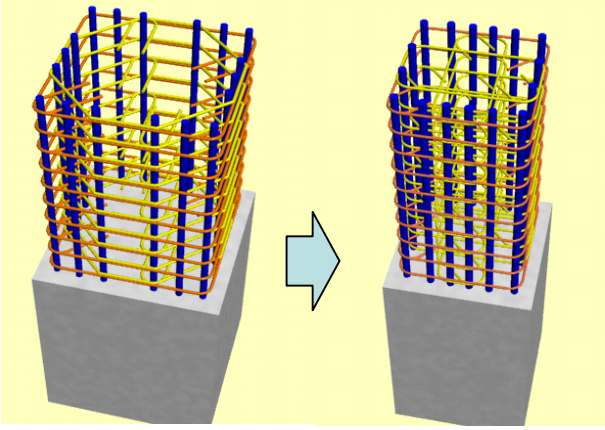

Figure-3 Changes of pier design

Photo-3 Viaduct of Kurobe maintenance base

Photo-4 Reinforcement (cross section of pier and beams)

3.3 Surface repairing project of Odagiri Dam

Odagiri Dam, located in Nagano City, is an old gravity-type dam for a hydro-power station which was constructed in 1954. The surfaces of waterways worn away by the water required surface repair.

Super quality concrete, possesses both of high bond strength to existing concrete and high resistance against abrasion, was applied as trial for this project. Photo-5 shows a view of Odagiri Dam.

After old concrete surfaces were chipped off to a depth of 250mm, S.Q.C. was placed. Usually steel bar is used for crack prevention, but polypropylene fibers were employed in this project to simplify the construction and shorten construction period.

Photo-6 shows the placing of S.Q.C.

Photo-5 Odagiri dam

Photo-6 Placing of S.Q.C.

4. EVALUATION OF THE SOCIAL VALUE OF S.Q.C. STRUCTURE

4.1 Evaluation of initial construction cost

The main materials used for S.Q.C. structures are high-strength steel (USD685 or other types) and S.Q.C. At present, the unit cost of high-strength steel is slightly more than double that of ordinary electric furnace steel. The unit cost of S.Q.C. is 1.5 to 2.5 times that of ordinary concrete. Material costs are thus generally high.

The S.Q.C. Association has been designing S.Q.C. structures and estimating costs under various conditions. The estimates show that S.Q.C. structures require lower construction cost because smaller volumes of concrete are placed and smaller quantities of excavated materials are produced if the cross section of the structure can be reduced. Figure 4 shows design comparison of bridge and box culverts, and Table 4 shows their cost comparisons.

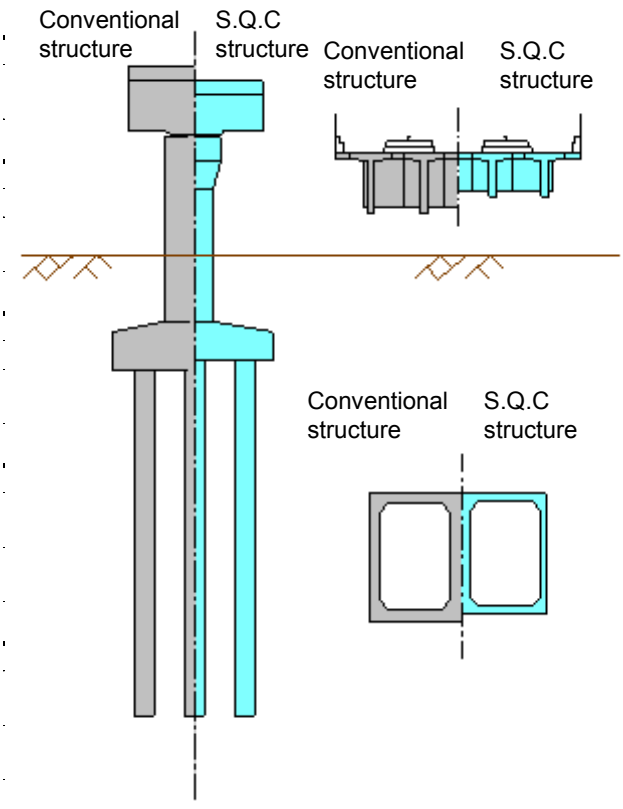

Figure-4 Design comparison

Table-4 Cost comparison

Total Cost of Bridge Construction

	Conventional Structure	SQC Structure
Construction Cost Comparison	1.00	0.97

Superstructure

	Conventional Structure	SQC Structure
Weight Comparison	1.00	0.90
Construction Cost Comparison	1.00	0.99

Bridge Pier

	Conventional Structure	SQC Structure
Weight Comparison	1.00	0.78
Construction Cost Comparison	1.00	1.03

Foundation Pile

	Conventional Structure	SQC Structure
Concrete Volume Comparison	1.00	0.63
Construction Cost Comparison	1.00	0.81

Box Culvert

	Conventional Structure	SQC Structure
Concrete Volume Comparison	1.00	0.65
Construction Cost Comparison	1.00	0.81

4.2 Evaluation of seismic resistance

Kondoh et al. reported the results of reverse cyclic loading to quantify the ductility of S.Q.C. column members [3]. Figure-5 shows an external view of the specimen with the cross section dimensions and loading points. Figure-6 shows the bending moment displacement curves for typical specimens as examples of experimental results. Specimen No. 1 had a longitudinal steel ratio equivalent to that of No. 0, and was made of the high-strength materials. The experimental results show that the yield strength of specimen No. 1 became larger than that of No. 0 in proportion to the increase in the yield strength of longitudinal steel but that their ultimate displacements were almost the same. It was thus found that increasing the strength of S.Q.C. column members was possible while maintaining their ductility, and that S.Q.C. column members could absorb energy and resist seismic forces better than ordinary reinforced concrete members. Specimen No. 9, which was designed to have a reduced cross

sectional area so as to provide a flexural strength equivalent to that of No. 0, had a ductility equivalent to or higher than that of No. 0. Thus, S.Q.C. members could retain their strength and ductility even after their cross sectional areas were reduced to 60 to 70% of those of ordinary reinforced concrete members. Therefore it was proved that reduction of the weight of structure and increasing of seismic resistance could be achieved at the same time.

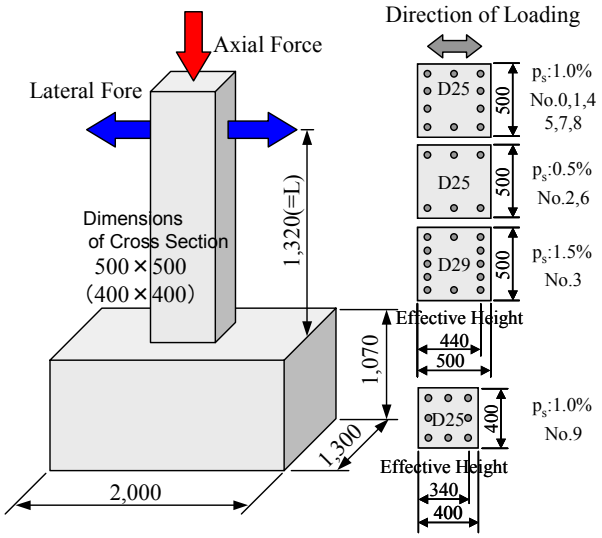

Figure-5 Detail of Specimens

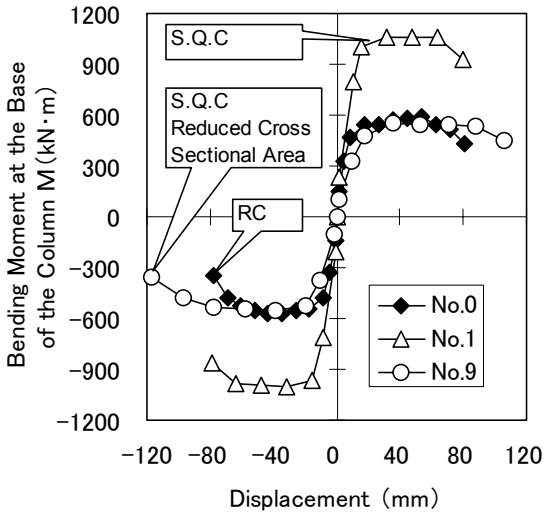

Figure-6 Bending Moment-Displacement Relationships

4.3 Evaluation of maintenance cost

The S.Q.C. Association has been estimating costs for maintenance of a reinforced concrete bridge pier located at the seashore. Figure-7 shows the simulation results of salt penetration depth into the concrete structure. These results show that a conventional concrete structure needs maintenance four times in 100 years against salt damage, but a S.Q.C. structure requires only twice due to its high durability against salt penetration.

Figure-8 shows the estimation results of life cycle cost including the initial construction cost and maintenance cost against salt damage. It was found that more than 40% of the life cycle cost can be reduced by employing S.Q.C.

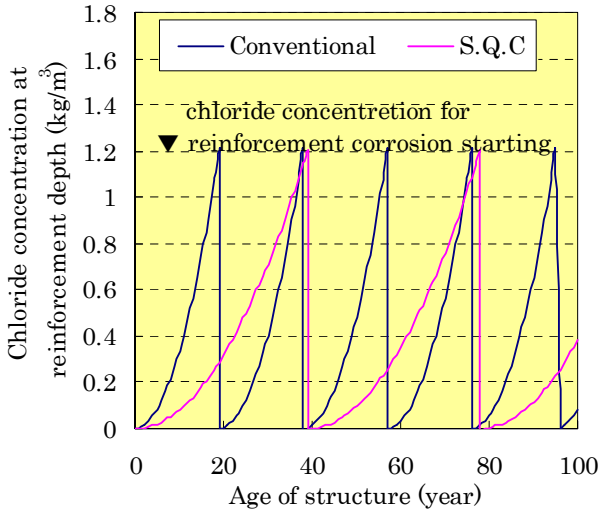

Figure-7 Simulation of salt penetration depth

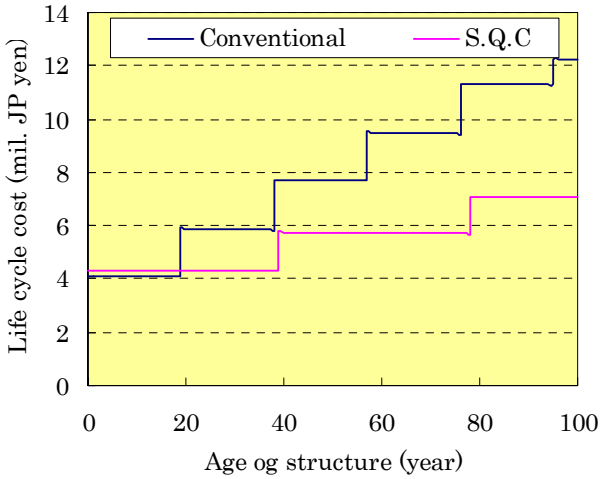

Figure-8 Evaluation of life cycle cost

5. PROBLEMS HAMPERING THE POPULARIZATION OF S.Q.C.

Through the three S.Q.C. projects introduced above, the authors noticed some obstacle factors which cause difficulties in popularizing S.Q.C.

Conservatism of owners refuses the challenge to employ new technology which has few practical applications like S.Q.C. Insufficiency in the number of engineers in the public institutions is accelerating this tendency. It is expected that introduction of a construction management system into public projects will solve this problem.

Lack of knowledge among concrete manufacturers causes their avoidance of S.Q.C. employment or inflation of the cost of S.Q.C. Besides, lack of knowledge on the S.Q.C. design method among structural design engineers causes their avoidance of employing S.Q.C. in the project design, or causes mistakes such as using S.Q.C. in the design without fulfilling its advantage. Though the S.Q.C. Association has carried out various kinds of education programs such as site tours to S.Q.C. projects and conferences, broader educational chances for manufacturers and design engineers provided by public institutes and associations are strongly expected.

Finally, contractors who use S.Q.C. should have enough knowledge on the manufacture, quality control, and construction methods of S.Q.C. A qualification system for S.Q.C. engineer is going to start in 2007 by the S.Q.C. Association. It will significantly improve the reliance on the quality of S.Q.C. structures, and promote the popularization of S.Q.C.

6. CONCLUSIONS

The Association for the Development and Popularization of Super Quality Concrete Structures has carried out the development of S.Q.C., design methods using S.Q.C., an evaluation method for the durability of S.Q.C., construction methods using S.Q.C. and so on. These were organized as the "Recommendations for Design and Construction of Structures Using Self-Compacting Concrete with High Strength and High Durability" published by JSCE.

Super quality concrete has been employed for three projects with its effective advantages such as high workability, durability, seismic resistance with small cross-sectional areas, and durability against abrasion.

Although the advantages of S.Q.C. had been clarified by the association's activities and three actual projects, there still exist some obstacles. The S.Q.C. Association will continue steady activities for popularizing S.Q.C.

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