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Quality Management for Arctic Offshore Concrete Structures

Gestion de la qualité des structures en béton armé, en mer arctique

Qualitäts-Management bei Offshore-Tragwerken aus Beton

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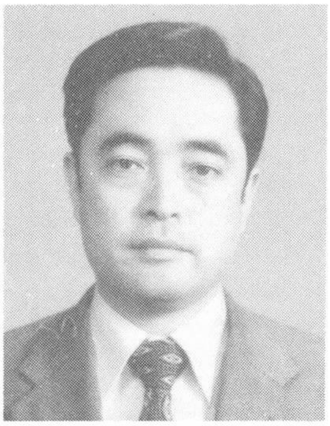
Mizuhito Iguro, born 1933, received his civil eng. degree at Waseda Univ., Tokyo. 8 years of site experience. Involved in the design of LNG in-ground tanks and marine structures, and in the detailed design and QC for the CIDS concrete structure.

Tomoo Suzuki, born 1950, received his M.S. degree at Kyoto Univ. He has since been involved in a number of designs and supervised projects dealing with bridges, offshore structures, and plant construction.



Motokazu Niwa, born 1939, received his civil engineering degree at the Univ. of Tokyo. He was involved in the construction of Super CIDS as a deputy manager in charge of the quality assurance of the concrete structure.

SUMMARY

This paper presents a systematic and practical approach to the internal quality management activities for constructions using high strength lightweight concrete with high freeze-thaw durability as well as water-tight caracteristics. The approach was applied to the construction of a steel-concrete hybrid mobile drilling structure, now in operation in the Beaufort Sea.

RÉSUMÉ

L'article présente une approche systématique et pratique des activités internes de gestion de la qualité pour des constructions en béton léger étanche, à résistance élevée et présentant une grande durabilité vis-à-vis du gel et du dégel. Cette méthode a été appliquée lors de la construction d'une plateforme de forage mobile, en construction hybride acier-béton. Cette plateforme est actuellement opérative en mer de Beaufort.
recherches pétrolières.

ZUSAMMENFASSUNG

Der vorliegende Beitrag stellt einen systematischen und auf die Praxis zugeschnittenen Ansatz eines firmen-internen Qualitäts-Managements für Leichtbeton-Bauwerke mit hohen Anforderungen an Festigkeit, Frostbeständigkeit und Wasserdichtigkeit vor. Der Ansatz wurde beim Bau einer mobilen, hybriden, aus den Baustoffen Stahl und Stahlbeton bestehenden Bohrinsel angewandt, welche heute unter arktischen Verhältnissen im Einsatz ist.

1. INTRODUCTION

The systematical and practical approach for the site work entails the definition of the quality for the required functional performances and structural integrities, and the developments of quality assurance program and of quality control manual accordingly. The system includes a quality control organization characterized by an internal quality control and inspection team, which stands independent of a construction execution team.

Quality items of the primary importance are cited in this paper and the practical approach to suffice these requirements along with the necessary countermeasures are described.

Particular interests lie in the control of the initial moisture content of the artificial lightweight aggregates to achieve the required durability as well as the control of thermal crackings during the construction, and the control of the dimensions and the weight of the final structure. Topics of further interests include quality control activities related to the use of silica fume as a concrete mineral admixture, the prestressing work, and fabrication of precast concrete elements. However, these topics are not covered in this paper.

2.SUPER CIDS AND ITS REQUIREMENTS

Super CIDS, the world's first Arctic mobile drilling unit, is composed of three modular units, namely the top Deck Storage Barges mounted with drilling facilities and living accomodation, the middle Concrete Basic Brick of 44 ft in height (BB44) constructed primarily of high strength lightweight concrete, and the bottom Steel Mud Base which rests directly on the seabed foundation. Super CIDS configuration and its dimensions are given in Fig.1(Ref.(1)).

The concrete basic brick consists of the bottom slab, external wall, shear walls, internal wall, silos, and the top slab. The interior is characterized by a honeycomb structure. Precast segment construction was employed to the silos. The rest was constructed by cast-in-place concrete to which prestressings were applied. Normal weight high strength concrete(NWC) was used for the internal wall and shear walls, while the rest was constructed using four different mixes of high strength lightweight concrete(LWC).

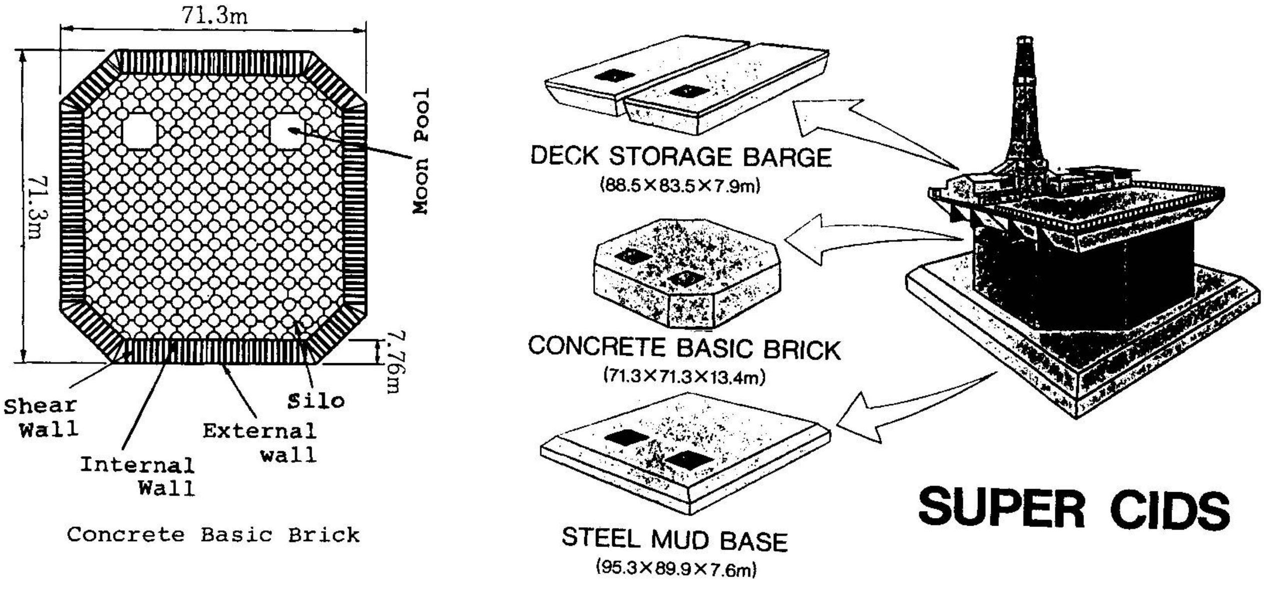


Fig.1 Super CIDS configuration

The concrete basic brick placed at the splash zone is designed to resist the most unlikely loads exerted on the structure. High strength characteristics as well as adequate durability and water-tightness are of the importance for the concrete basic brick to resist the severe temperature conditions as low as -50°c and highly intense ice pressure accompanied by the repeated freeze-thaw actions exerted on its members.

Furthermore, Super CIDS is a mobile drilling unit which is capable of submerging and refloating using its ballasting-deballasting system. Such exploratory drilling structure requires its mobility even with a greater payload to assess an all-year-round operation in the ice infested waters, which in turn implies the benefits attained by the utilization of lightweight concrete and a strict weight control.

3. QUALITY MANAGEMENT AND ITS ORGANIZATION

3.1 Specifications

Quality requirements on the finished structure were stated implicitly in the contract document as ;
-strength and serviciability
-durability
-weight/draft control
-water-tightness
-appearance and grade controls
Furthermore, the specifications for concrete material of primary importance are summarized in Table 1.

Fresh unit weight	LWC : 1.84 t/c.m
56-day design strength	LWC : 457 kg/s.cm
Concrete Cl' content	max.0.06%cement wt.
Air content	7 ± 2%
Air-void spacing factor	max. 250 μm
Air-void surface area	min. 24 s.mm/c.mm
Freeze-thaw durability index (ASTM. C666 A)	min. 80% after 300 cycles

Table 1 Concrete specifications

3.2 Quality management

In order to achieve the specified quality requirements for the intended purpose of the structure, these implicit statements of the quality requirements were redefined explicitly in a working format in accordance with the proposed materials and the construction procedures throughout the procurement, construction, and delivery phases. Extensive in-house research work and field mock-up tests were carried out to assess a set of criteria for the quality control activities. These preparatory work encompases all the phases of the construction activities of primary importance.

Site quality management system was developed to carry out the following tasks;
- development of Quality Control Manual
- quality control activities for fresh and hardened states of concrete
- inspections of rebar and tendon placements, formwork assemblage, and the construction joints
- quality control activities for prestressing operations
- quality control activities for precast fabrications and assemblage
- inspections and water-tightness tests of the finished structure

3.2.1 Quality Control Manual

Quality Control Manual consists of three distinct parts; Quality Assurance Program, Quality Control Chart, and Manufacturer's Standards.

Quality Assurance Program simply defines the quality requirements in an explicit manner, which forms a basis for developing the working format of Quality Control Chart. All the items of quality to be controlled during the construction are clarified in their relations to the intended performance of the structure. Furthermore, the intended properities and possible deviations are cited along with the factors which rank the importance of their consequences. A portion of Quality Assurance Program is shown in Table 2.

Requirement Specified by the Owner	Intended Properties	Quqlity Evolution System	Items for Quality Control
Draft of the structure conforms to the specified value.	Maximum fresh unit weight; 155 pcf for NWC 115 pcf for LWC Torelace of member thickness ; Wall thickness 3/8 in. Slab thickness 1/4 in.	Weight of concrete conforms to the specified value. -Unit weight of concrete conforms to the specified value. -Concrete volume	Test results of unit weight Dimensions of finished members

Table 2 Quality Assurance Program (extracted)

An extensive Quality Control Chart, a working format for the site quality control activities, was developed in accordance with Quality Assurance Program which explicitly defines the quality requirements. Criteria for inspections and countermeasures for the critical construction items were established after extensive laboratory tests and field tests. Table 3 shows a portion of the chart extracted for formworks.

Work		Items of Quality Control	Survey and Inspection				Countermeasure		STANDARD /SPEC	Record of Inspection
Category	Event		Criteria	When	Method	Frequency	Prompt Action	Recurrence Prevention		
Form work	Placement of forms	Deviation from base lines	Tolerance ±1/4 in.	Upon erection of first lift	Visual observation, scale measurement if necessary	8 points	Make necessary correction	Review of work standard	ACI 347-78	Check sheet
		Differential between adjacent units	Tolerance ±1/4 in.	After form assembly	-ditto-	8 points per each lift	-ditto-	-ditto-	-ditto-	-ditto-
		Form assembled form	Tolerance ±1/4 in. per 10 ft	After form assembly	Plumb and scale measurement	-ditto-	-ditto-	-ditto-	ACI 347-78 3. 3. 1. 1	Data sheet

Table 3 Quality Control Chart(extracted)

3.2.2 Laboratory and field tests

The following laboratory and field tests are a part of the tests carried out to confirm the applicability of the proposed materials and procedures for the construction. The results were reflected in the quality management activities.

- developments of high strength lightweight and normal weight concrete mixes with high freeze-thaw durability
- field pumpability, bucket-tremie placeability, and compactability tests for the plant mixed concrete
- air-void distribution and volume change upon compaction
- field mock-up test of external wall for the evaluations of concrete constructibility, air-void system, heat of hydration, and thermal crack control measures
- adequacy of adhesives and sealing materials for precast silo connections and prestressing anchor pockets

3.3 Internal quality control organization and its responsibilities

Verifications by the authorities and certifications for the owner are illustrated in Fig.2, in which the detailed description of Quality Control Organization is shown. Quality control activities at the concrete plant and the precast fabrication plant were under the direct supervisions of the contractior's Quality Control Team.

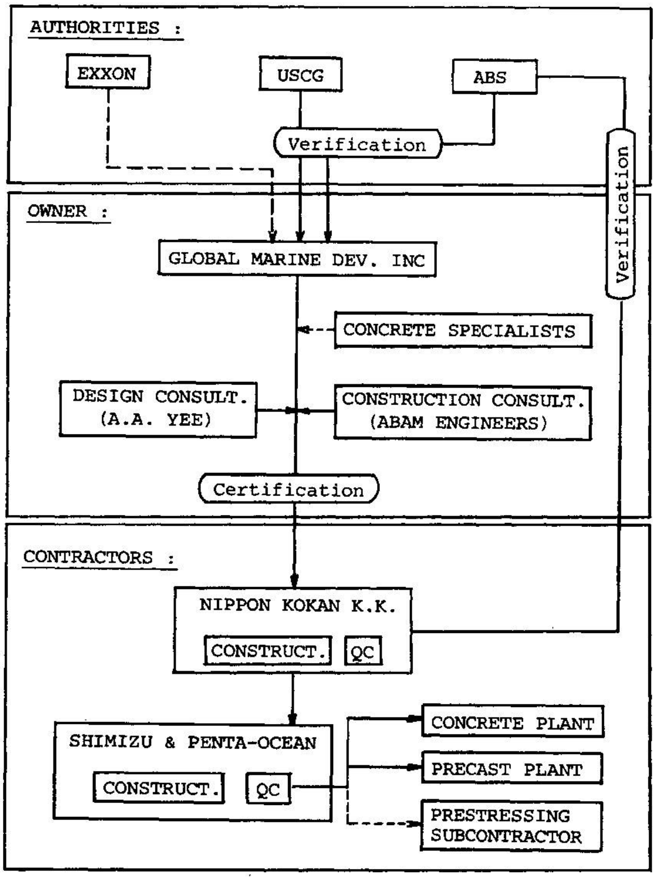


Fig.2 Quality Control Organization

The internal Quality Control Team was organized totally independent of the construction team. The team performed the following tasks;

- development of Quality Control Manual
- evaluation and acceptance of the owner's Inspection Manual in which the items and frequencies of the inspections conducted by the owner are described.
- in-house inspection work. All items subjected to inspections were covered comprehensively in accordance with and to comply with Quality Control Chart. The results of inspections were reported immediately to the construction team in charge of the specific work category. Prompt countermeasures were taken at this time and the procedures to avoid the recurrences were set forth.

4. QUALITY CONTROL FOR ATTAINMENT OF FREEZE-THAW DURABILITY

Use of lightweight concrete for the purpose of achieving the minimal draft poses a challenge to the construction technology in regards to the water absorbing nature of expanded-shale aggregate, which in turn causes the deterioration of concrete upon repeated freeze-thaw attacks. A solution to this problem as well as its quality control to assure the sufficient durability are the highlights of the construction of the concrete basic brick.

Among the various factors that contribute to the freeze-thaw durability of concrete, the amount of the free-water in the paste as well as in the aggregate is the most significant. Quality assurance activities were initiated with an extensive laboratory tests for the selections of concrete mixes and the concreting procedures to produce minimum free-water. The criteria for quality control were developed accordingly. The second step to the assurance activity was a large scale concrete placement test for the confirmation of the mix with site practices. The final step was to implement the planned quality control activities at the site.

4.1 Laboratory Tests

More than 200 batches of concrete were tested in order to finalize five different concrete mixes with optimal proportions. The result of the test is best represented by Fig.3 which clearly indicates the critical aggregate moisture content. The target value for the as-mixed aggregate quality was set at the maximum moisture content of 4%.

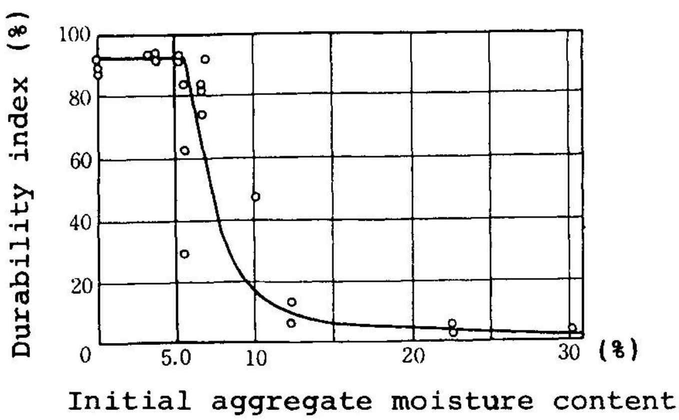


Fig.3 Freeze-thaw durability

4.2 Control of the aggregate moisture content

A proposed construction procedure for achieving the least moisture content of the as-mixed aggregate was to employ an absolute-dry aggregate upon batching. Moisture absorption was allowed during wet-mixing. The amount of mixing water was adjusted to compensate for this free water absorption.

Special cares and controls were taken during production, transportation, and stockpiling of the aggregate. Concrete was placed using a bucket-tremie system to minimize the pressure induced during the placement. The aggregate moisture content was monitored upon the delivery at the site using the mil-certificates and once a day during the concreting phase using an accelerated oven-drying procedure. This procedure, which had been calibrated to the maximum deviation of 0.2% from the standard procedure that takes 12 hours, employs an accelerated 40 minutes oven-drying procedure.

4.3 Site control work

A staff of the internal quality control team was dispatched to the concrete plant in order to enforce the quality control measures over the raw materials, especially the amount of admixtures, and to control the production rate to cope with the site work. Upon receiving concrete at the site, the quality controls were extended over the plasticization of base concrete, concrete placement and compaction procedures. Details on the concrete quality controls are given in Ref.(2).

5. CONTROL OF THERMAL CRACKING

Concrete that suffices all the quality requirements as depicted previously is inherently rich in its cement content. It is a well-known fact that such rich mix could pose a serious problem of thermal cracking due to heat of cement hydration and subsequent cooling effect during the construction. For this reason, thermal crack control measures were incorporated in the quality management.

In order to assess the most cost efficient procedure, a comprehensive analytical tool for the predictions of crack occurrence as well as the estimations of crack width and spacing had been developed. Detail description of the tool had been presented at the ACI 1984 fall convention. The information is available from the authors. (Ref.(3))

An imporvement of the proposed mix, scheduling of concreting lifts and blocks, and the selection of curing procedure were finalized in accordance with the result of the analysis for the given member configurations and reinforcing details. The applicability of the procedure was confirmed through the field large-scale test. During the construction, quality control measures were extended to the control of fresh concrete temperature and monitoring of concrete temperature rise as placed in the forms. The result of the monitoring was fed back to the construction to take the countermeasures with respect to the curing procedure. The duration of the specified curing method was also chosen to be the item for quality control. The construction was carried out commencing in September 1983 and completed in March 1984. As a result, the bottom slab and the main deck suffered no thermal cracks. Thermal cracks observed in the exterior ice wall was 0.04 mm in their maximum width. This maximum crack width corresponds to the value predicted using the proposed thermal crack evaluation system during the planning phase of the project. The result suffices with sufficient margin the specified level of the quality.

6. WEIGHT CONTROL

The total weight, and hence the draft of the final structure can be estimated from the designed quantity or from the results of the inspections on the final structure. However, either method could result in a significant error. Hence the total weight of the final structure was estimated on the basis of the delivered volumes of the materials which had been corrected for the returned or rejected volume and the losses during the construction. The volume was multiplied by the recorded unit weights of the materials, which resulted in the weight of the final structure.

The volume loss due to the concrete remained in the agitator truck was determined from the results of the measured weights of sample trucks. Furthermore, the volumetric change in the placed concrete due to compaction was measured on the sample concrete of unit volume. Three percent reduction in the concrete volume was observed. The figure 4 shows the flow for the concrete weight control. The histograms for the unit weight of fresh concrete are shown in Fig.5. The figure shows a stable result indicated by the coefficient of variation of approximately 1%. Furthermore, the actual draft upon float-out of the concrete basic brick deviated from the predicted value by a favorable margin of 1%.

7. CONCLUSIONS

Upon final inspection and hydrostatic tests, the concrete basic brick was completed, which was certified by the U.S.Coast Guard and ABS as well as the owner's representatives. The structural integrity and the seaworthiness of SUPER CIDS has been proven and acknowledged through a satisfactory performance in a severe arctic climate.

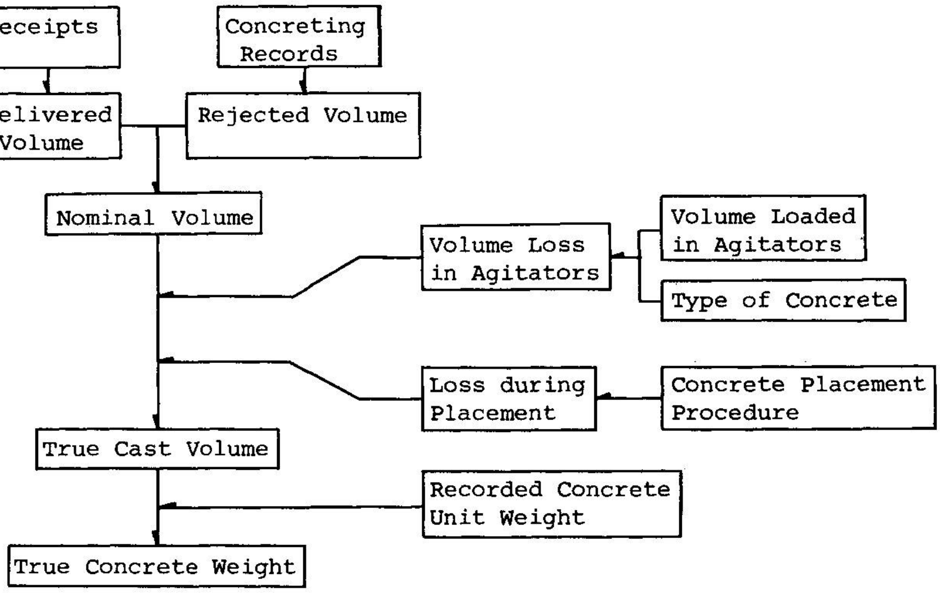


Fig.4 Concrete weight monitoring procedure

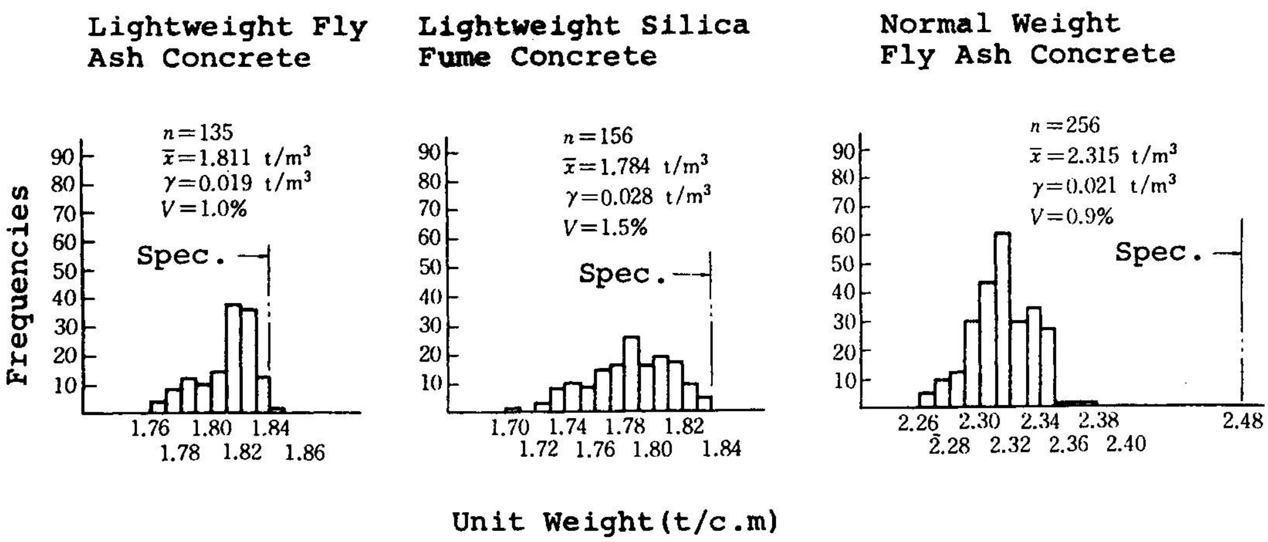


Fig.5 Concrete unit weight histograms

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