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# A Study on the Optimum Mix Proportion of the Mass Concrete Designed as Massive and Deep Structure

Yeong-Ho Kwon[1)]* and Hwa-Jin Lee[1)]

[1)] *Dept. of Architectural Engineering, Dong-Yang University, 750-711, Korea*

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## Abstract

This study describes data from determination of the optimum mix proportion and site application of the mass concrete placed in bottom slab and side wall having a large depth and section as main structures of LNG in-ground tank. This concrete requires low heat hydration, excellent balance between workability and consistency because concreting work of LNG in-ground tank is usually classified by under-pumping, adaptation of longer vertical and horizontal pumping line than ordinary pumping condition. For this purpose, low heat Portland cement and lime stone powder as cementitious materials are selected and design factors including unit cement and water content, water-binder ratio, fine aggregate ratio and adiabatic temperature rising are tested in the laboratory and batch plant.

As experimental results, the optimum unit cement and water content are selected under 270kg/m$^3$ and155~160 kg/m$^3$ separately to control adiabatic temperature rising below 30℃ and to improve properties of the fresh and hardened concrete. Also, considering test results of the confined water ratio($\beta p$) and deformable coefficient(Ep), 30% of lime stone powder by cement weight is selected as the optimum replacement ratio.

After mix proportions of 5cases are tested and compared the adiabatic temperature rising($Q\infty$, r), tensile and compressive strength, modulus of elasticity, 2cases satisfied with the required performances are chosen as the optimum mix design proportions of the side wall and bottom slab concrete. $Q\infty$ and r are proved smaller than those of another project. Before application in the site, properties of the fresh concrete and actual mixing time by its ampere load are checked in the batch plant. Based on the results of this study, the optimum mix proportions of the massive concrete are applied successfully to the bottom slab and side wall in LNG in-ground tank.

***Keywords :*** ***high belite cement, lime stone powder, adiabatic temperature, confined water ratio, mixing time***

## 1. Introduction

Korea gas corporation has a plan to build liquefied natural gas(LNG) in-ground tank in order to supply stably in near Seoul and another large city. Inchon is proved to have the best situation for storage and supply of LNG. Now, Inchon receiving terminal was already constructed and operated 10tanks of above type and 6tanks of in-ground type having the largest storage capacity about 200,000*kl* in the world have been constructing in regular sequence.

In-ground tank is composed entirely of many structures including slurry wall, pile cap slab, bottom slab, side wall and roof. Also all of structures are designed as a massive concrete having a large depth and section because of safety, soil pressure and buoyancy.

Especially it should be considered with countermeasure to decrease the hydration heat of these concrete placed in the bottom slab(thickness 9.0m) and side wall(width 3.0m).

Therefore, procedures of concrete mix design are very important in a view point of preventing thermal crack from hydration heat. The purpose of this study is to confirm all materials adapted in the concrete mix design for the bottom slab and side wall and to determine the optimum mix design having a good workability and low hydration heat.

For this purpose, the concrete mix design condition of two types including low heat portland cement plus fly ash and low heat portland cement plus lime stone powder as a binder are investigated. After comparing with the properties of fresh and hardened concrete and hydration heat, finally

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* *Corresponding author*
*E-mail address: kyh00127@phenix.dyu.ac.kr*

one type using low heat portland cement plus lime stone powder is chosen and also the optimum mix proportion of two cases adapted to the bottom slab and side wall concrete having a good performance is selected. All procedures are carried out under the laboratory and site condition.

## 2. Summary of structures and requirements

### 2.1 Structural summary

Table 1 shows the structural summary of bottom slab, side wall and roof as main structures of LNG in-ground tank. Bottom slab has a thickness of 9.0 m and inside diameter of 72.6m. It will be placed the massive concrete separated by 2 lots. Also, side wall contacted with slurry wall by shear key which has a width of 3.0 m and total height of 50m, and it will be placed by 10 lots. These structures will be constructed in-ground by under-pumping. Therefore, the fresh concrete condition including workability, consistency, pumpability, flowability and control of hydration heat are very important factors.

### 2.2 Required performances

Table 2 gives the required performances of the massive concrete placed in the bottom slab and side wall.

2.2.1 Calculation of the required compressive strength

Increment factor($\alpha$) for coefficient of variation(V) which may be introduced by practices used in proportioning, mixing, transporting, placing, curing and testing is applied 1.2.

When V is 10%, $\alpha = 1/(1 - 1.64 \times 10/100) \cong 1.2$

Therefore, the required compressive strength(fcr) at 91 days is calculated as following equation.

- Bottom slab (fcr) = fck $\times \alpha = 24.0 \times 1.2 = 28.8$ MPa
- Side wall (fcr) = fck $\times \alpha = 30.0 \times 1.2 = 36.0$ MPa

2.2.2 Slump

In general, most of concrete placing method in normal site is adopted the upper-pumping method by concrete pump. But concrete placing method of LNG in-ground tank will be used the under–pumping method on the contrary.

Therefore, these concrete placed in site condition must have excellent consistency including workability, pumpability and flow-ability without segregation in the fresh concrete.

At the same time, another item which has effect on the real construction process of the site including the hydration heat, cold joint, bleeding and flowing pressure in the form and form design should be considered.

**Table 1** Structural summary of the main structures

| Classifications | Bottom slab | Side wall | Roof |
|---|---|---|---|
| Size (m) | Diameter: 72.6 | Width : 3.0 | Thickness : |
| Place method | 2 Lifts(6m, 3m) | 10 Lots (5m) | 6 Blocks |
| Total concrete | 35,500m$^3$/tank | 55,50m$^3$/tank | 5,000m$^3$/tank |

**Table 2** Required performances of the main concrete

| Measurement items | Target value | | Remarks |
|---|---|---|---|
| | Bottom slab | Side wall | |
| Specified strength | 24.0 MPa | 30.0 MPa | KS F 2405<br>(91days) |
| Proportioningstrength | 28.8 MPa | 36.0 MPa | |
| Slump | 210±30 mm | | KS F 4009 |
| Air content | 5 ±1 % | | |
| Chloride content | Max. 0.3 kg/m$^3$ | | |
| Mix condition | Water-binder ratio : 55% max. | | |

Considering on the above items and actual data of another project, slump range(180±25 mm) of bottom slab concrete is not enough to be satisfied with the required pumpability because pile cap concrete having a slump range 180~190 mm in another project is difficult to pump in under-pumping method. Therefore, the slump range had better increase from 180 mm to 210 mm without segregation. Also, smaller size (20 mm) of coarse aggregate than that of ordinary concrete is selected in order to improve pumpability and vibrating effects. Although batch plant used in concrete production is located in the construction site (it may be required 5minutes for transportation), it should be consider-ed the concreting work including pumping, flowing in the vertical pipe and placing in the form. Therefore, the above slump value (210±30 mm) should be controlled and kept until 90 minutes considering elapsed time

2.2.3 Air content

Though these concrete are classified into the ordinary concrete by KS F 4009, air content is determined in the range of 5±1% considering site condition which these structures are constructed by the sea.

## 3. Materials and mix design process

### 3.1 materials

All materials make it a rule to use domestic products including low heat portland cement(high belite cement), fine and coarse aggregates, high-range water reducing agent and lime stone powder. Table 3 shows all materials used in this study. After comparing with test results of all materials according to maker or sources, properties of the selected materials are arranged and proposed as followings.

**Table 3** Classification according to materials

| Materials | Selection standards | Remarks |
|---|---|---|
| Low heat portland cement | - Reducing effects for hydration heat | KS L 5201(Type Ⅳ) |
| Lime stone powder | - Quality, stable supply | JIS A 5008 |
| Fine aggregate | - Quality & quantity<br>- Stable supply | KS F 2526<br>(River sand) |
| Coarse aggregate | - Quality & quantity<br>- Stable supply | KS F 2526<br>(Crushed) |
| High range water reducing agent | - Quality & quantity<br>- Ability for Q/C<br>- Site applications | ASTM C 494(F type)<br>KS F 2560 |

**Table 4** Chemical and physical properties of cement(Type Ⅳ)

| Specific gravity | Specific surface ($cm^2/g$) | $SO_3$ (%) | $Fe_2O_3$ (%) | MgO (%) | $C_3S$ (%) | $C_2S$ (%) | $C_3A$ (%) | Loss on Ig. (%) |
|---|---|---|---|---|---|---|---|---|
| 3.22 | 3,492 | 2.0 | 4.1 | 1.9 | 28.6 | 51.4 | 1.1 | 0.7 |

| Autoclave Expansion (%) | Setting time (hr:min) | | Strength (MPa) | | Hydration heat (cal/g) | |
|---|---|---|---|---|---|---|
| | Initial | Final | 7days | 28days | 7days | 28days |
| 0.03 | 340 | 9:15 | 18.6 | 34.5 | 58 | 68 |

**Table 5** Physical properties of aggregates

| Type | F.M | Specific gravity | Water Absorption (%) | Sound-ness(%) | Passing 0.08mm (%) | Unit weight ($kg/m^3$) |
|---|---|---|---|---|---|---|
| Fine | 2.75 | 2.60 | 1.16 | 4.2 | 1.1 | 1,658 |
| Coarse | 6.68 | 2.63 | 0.65 | 3.9 | 0.1 | 1,568 |

**Table 6** Test results of high range water reducing agent

| Water content (%) | Setting time (hr:min) | | Comp. strength ratio (%) | | | Flex. strength ratio (%) | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | Final | 3days | 7days | 28days | 3days | 7days | 28days |
| 81.0 | +25 | +20 | 130 | 122 | 119 | 119 | 110 | 108 |

3.1.1 Cement

Considering the hydration heat and required performances of the bottom slab and side wall concrete, some kinds of cementitious materials are investigated. Two types of cement conditions which one type is composed of low heat portland cement plus fly ash and another type as low heat portland cement plus lime stone powder. If the bottom slab and side wall concrete were used these cementitious materials, it is able to expect the effects such as the enhancement of the long-term strength, the increase of water-tightness, chemical resistibility and the decrease of the hydration heat.

Especially, usage of low heat portland cement is proved to have good qualities including the low hydration heat, the fresh and hardened concrete considering an actual data in another project. Table 4 gives test results for the chemical and physical properties of low heat portland cement(Type Ⅳ) performed by the independent laboratory. Test results for all items are satisfied with KS L 5201 as a specification of the portland cement (Type 4). Therefore, the low heat portland cement in order to reduce the hydra-tion heat of cement is selected.

3.1.2 Fine and coarse aggregate

Pumpability, flowability, balance between workability and viscosity in the site construction are influenced by the properties of the fine and coarse aggregate. To be satisfied with these performances, the fineness modulus, specific gravity, results of sieve analysis test of the fine aggregate are very important factors.

Also, considering quality and productivity system of fine aggregate, permission time, stable supply and distance from site to aggregate sources, fine aggregate manufactured from mun-san in the boundary of im-jin-kang(river sand) and coarse aggregate produced from the source of kwang-myeong(crushed aggregate :19mm).

Table 5 gives test results of fine and coarse aggregates performed by the independent laboratory.

Test results for all items are satisfied with KS F 2526 as a specification of the fine and coarse aggregates. Also, the potential alkali-aggregate reactivity for these aggregate to check chemical stability with low heat portland cement is tested. Test results of the potential alkali reactivity are proved as a no harmful aggregate.[2)]

3.1.3 High-range water reducing agent

High-range water reducing agent(H.R.W.R) used in this project is based on the poly-carbonate which has the advantage of the compatibility with maintainable time and dispersal function of the required slump until 90minutes.[2)]

It is generally more effective, but more expensive, than regular water reducing admixtures used in normal concrete. Also, it helps reduce slump loss during elapsed time.

Table 6 shows test results of the high range water reducing agent performed by the independent laboratory. Test results are satisfied with ASTM C494 (F class) as a specification of the high-range water reducing agent.

3.1.4 Lime stone powder

The principal mineral of lime stone powder(L.S.P) is calcite ($CaCO_3$) as a form of calcium carbonate. Apart from the physical uses of lime stone powder for activities such as construction, it is also used as a chemical where its functions are largely indirect and are primarily predicated on its being the prime source of lime. Lime stone powder is used as flux and filler in chemical process industries such as metallurgical plants, portland cement plants, glass plants and so on. At times lime stone powder may also be used for effluent treatment.

In the concrete part, lime stone powder is used for the mass concrete as a powder type in order to enhance the workability and reduce the hydration heat of the concrete. Considering site conditions including massive structures, the vertical and horizontal pipe line by under-pumping method, the required high workability and consistency of concrete, lime stone powder having a high blaine about 600 $m^3$/kf is selected as a cementitious material.

Table 7 shows test results for properties of the lime stone powder performed by the independent laboratory.

## 3.2. Mix design process

### 3.2.1 General considerations

The mass concrete placed in the bottom slab and side wall as a main structure must have a excellent workability and consistency. Also these concrete have to be satisfied with properties of concrete according to KS F 4009.

Table 8 shows the general mix conditions for the bottom slab and side wall concrete. B means total binder material's content as cement plus lime stone powder.

### 3.2.2 Basic mix condition

Considered test results of the fresh and hardened concrete including compressive strength of actual data executed by another project, the basic mix design condition for the bottom slab and side wall concrete is as following Table 9.

### 3.2.3 Mixing method and mixing time

In the laboratory test, concrete mixer of tyranny pan type having maximum capacity of 60 liters and 44 rpm is used. Trial mixing test will be performed by mixing method and mixing time as following Table 10.

### 3.2.4 Factors and range of mix design

On the base of mix condition in Table 9, trial mix test is executed by changing mix design factors including water-binder ratio, fine aggregate ratio and dosage of high range water reducing agent in the laboratory.

Table 11 shows factors and range of mix design condition. After tested trial mixing by design factors of Table 11, the optimum mix proportion which satisfied with the required performances specifying in Table 1 is selected. Also, in this trial mixing, test items including the fresh and hardened concrete, hydration heat will be checked.

# 4. Test results and discussion

## 4.1 General considerations

Before selecting the optimum mix proportion of bottom slab and side wall concrete, design factors including unit water content, replacement ratio of lime stone powder, fine aggregate ratio, water-binder ratio and compressive strength are checked and analyzed. Also, test of adiabatic temperature for the optimum mix design is checked. Test results are described in the following sentence.

## 4.2 Test results for unit cement content

Unit cement content has an effect on not only compressive strength but also hydration heat in the bottom slab and side wall which is classified into the super massive structure. Therefore, in order to choose the optimum unit cement content, adiabatic temperature test by unit cement content in the range of 260~300 kf/$m^3$ is performed.

**Table 7** Chemical and physical properties of L.S.P

| Specific gravity | Specific surface ($cm^2$/g) | $SiO_2$ (%) | $Fe_2O_3$ (%) | MgO (%) | CaO (%) | $Al_2O_3$ (%) | Moisture Content (%) | Loss on Ig. (%) |
|---|---|---|---|---|---|---|---|---|
| 2.61 | 6,320 | 1.2 | 0.2 | 1.2 | 53.5 | 1.1 | 0.1 | 42.1 |

**Table 8** Mixing condition for the bottom slab and side wall

| Classification | Mixing condition | Remarks |
|---|---|---|
| Max. size of coarse aggregate | 20 mm | KS F 4009 |
| Water-binder ratio (W/B) | 55 % max | |
| Unit water contents (W) | 175 kg/$m^3$ max | |
| Unit binder contents (B) | 270 kg/$m^3$ min | |
| Fine aggregate ratio (S/a) | 55 % max | |
| Dosage of H.R.W.R | B x 3.5 % max | |

**Table 9** Basic mix condition for massive concrete

| W/B (%) | S/a (%) | Unit weight (kg/$m^3$) | | | | | Ad (B*%) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Water | Cement | L.S.P | Sand | Gravel | | |
| 50.9 | 42.0 | 168 | 231 | 99 | 710 | 979 | 0.8 | F24 |
| 45.9 | 41.0 | 168 | 256 | 110 | 696 | 925 | 0.8 | F30 |

**Table 10** Mixing method and time in the laboratory test

| Sequence | Mixing method | Mixing time |
|---|---|---|
| (1) | Fine aggregate + Coarse aggregate | 30sec |
| (2) | Cement + Lime stone powder | 30sec |
| (3) | Water + H.R.W.R | 120sec |
| (4) | Total mixing time | 3min |

**Table 11** Test range of the trial mixing for design factors

| Design factor | Test range | Remark |
|---|---|---|
| Water-binder ratio(W/B) | 42 ~ 55 % | Strength |
| Fine aggregate ratio(S/a) | 38 ~ 45 % | Workability<br>Consistency |
| Dosage of H.R.W.R | 0.6~1.8% (B×%) | |

Fig. 1 gives test results of adiabatic temperature rising for unit cement content.

Compared with test results of adiabatic temperature rising for the unit cement content, the more unit cement increase, the higher adiabatic temperature became. Therefore, the optimum unit cement content is selected under 270 kf/$m^3$ to control adiabatic temperature rising below 30℃.

### 4.3 Test results for unit water content

Unit water content used in the fresh concrete has an effect on the properties of concrete including bleeding, plastic shrinkage and segregation. Therefore, unit water content had better decreased in the range of satisfying with the required specification. The properties of fresh concrete in the range of 150~170kg/$m^3$ to choose the optimum unit water content are tested.

Fig. 2 shows test results of the slump according to range of unit water content. When water-binder ratio(45%), dosage of high range water reducing agent(0.6%), fine aggregate ratio(41.5%), and replacement ratio of lime stone powder (30%) are same, the fresh condition in case of 150 kf/$m^3$ shows as coarse and slump value is not satisfied. Also, slump loss during elapsed time is high.

In case of 165 and 170 kf/$m^3$, the fresh condition is smooth but bleeding and segregation shows in the some point. In the range of 155~160 kf/$m^3$, the fresh concrete conditions are very smooth and no bleeding and slump loss are satisfied with the required specification.

Then, 155~160 kf/$m^3$ as the optimum unit water content of the bottom slab and side wall concrete is selected.

### 4.4 Test results for replacement ratio of L.S.P

In general, lime stone powder is used in concrete as a binder in order to decrease the hydration heat and to increase the consistency of the fresh concrete. Test for the condition of paste to choose the optimum replacement ratio of lime stone powder is performed.

Fig. 3 shows the test results of the confined water ratio (βp) and deformable coefficient(Ep) by replacement ratio of lime stone powder in the paste condition.

In case of low heat portland cement only used (L.S.P =0%), the confined water ratio is 1.045 and the deformable coefficient is 0.079. But in case of the replaced lime stone powder by cement weight(L.S.P=10, 20 and 30%), the confined water ratio became to increase in the range of 1.074~1.079 but the deformable coefficient is same in the range of 0.077~0.079 regardless of L.S.P replacement ratio.

Also, the properties of fresh and hardened concrete for the replacement ratio of lime stone powder from 10% to 30% are tested.

Based on test results by changing of L.S.P replacement ratio, conditions of the fresh concrete having a same mix condition(W/B and S/a) shows as same range including slump, air content within the required specification. Also, in a view point of compressive strength, all of strength test results are satisfied with the required strength.

Therefore, about 30% as a replacement ratio of lime stone powder considering the hydration heat and consistency of the fresh concrete is selected as the optimum replacement range of L.S.P.

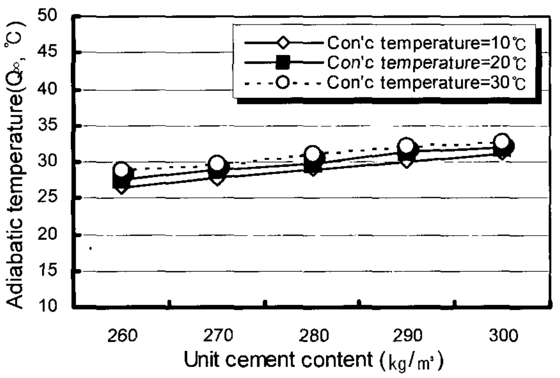

**Fig. 1** Test results of adiabatic temperature for unit cement

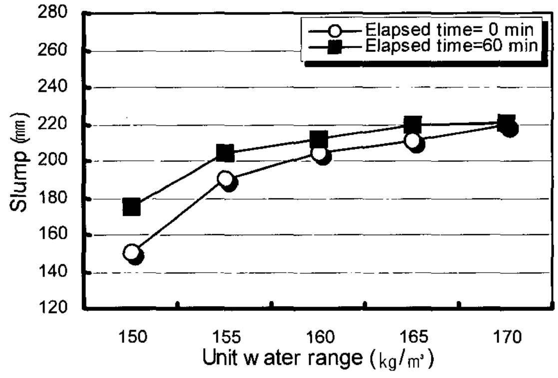

**Fig. 2** Slump results for unit water in the elapsed time

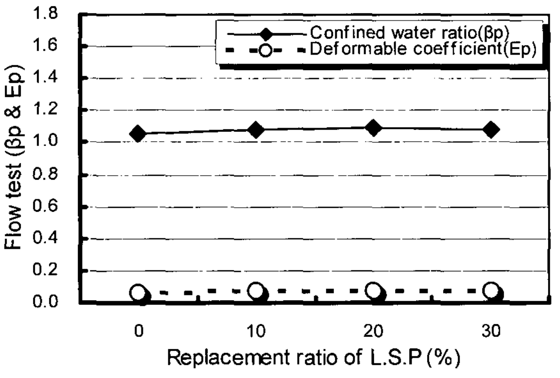

**Fig. 3** Test results of the paste according to L.S.P ratio

### 4.5 Test results for fine aggregate ratio

In general, the higher fine aggregate ratio increase, the higher total surface of aggregate became and the more paste needed to make a workable concrete. Then, fine aggregate ratio has an effect on not only the workability but also the consistency of the fresh concrete.

To select the optimum fine aggregate ratio, test for the fresh concrete according to fine aggregate ratio, which another design factors including water-binder ratio(45%), unit water content(155 kf/m$^3$), replacement ratio of lime stone powder(30%) and dosage of high range water redu-cing agent(0.6%) are same condition is tested and analyzed. Fig. 4 shows test results of slump for the elapsed time.

Though all of slump results according to fine aggregate ratio are satisfied with the required specification (210± 30 mm), balance between workability and consistency of the fresh concrete is different. Also slump loss during elapsed time is different. In the range 42~43% of fine aggregate ratio, workability of the fresh concrete indicates very good but consistency and slump loss does no good. In the range 40~41% of fine aggregate ratio, balance between workability and consis-tency of the fresh concrete is very good. Also, slump loss is very small. In the range of 39%, balance between work-ability and consistency of the fresh concrete is no good. Also, bleeding of the fresh concrete during elapsed time increases. Therefore, 40~41% is selected as the optimum range of fine aggregate.

### 4.6 Test results for dosage of H.R.W.R

Test for the properties of the fresh concrete until 90 minutes to confirm the pumpability in the long pipe-line and flow-ability in the form after pumping is tested and analyzed to select the optimum dosage of high range water reducing agent. Fig. 5 shows test results of slump trend for dosage of high range water reducing agent during elapsed time until 90 minutes.

When design factors including water-binder ratio(45%), fine aggregate ratio(41.0%), unit water content(155 kf/m$^3$) and replacement ratio of lime stone powder(30%) are same, the fresh concrete condition in the dosage range of 0.7~0.75% shows some segregation between aggregate and paste and high slump loss in a 90minutes. Also, in the dosage range of 0.55~0.6%, segregation is not checked but slump loss during 60~90minutes gives very high.

But slump trend by adding a dosage of 0.65% shows the good balance between dispersal and maintainable function, it is revealed small slump loss and no segregation.

Therefore, about 0.65% is selected as the optimum dosage of high range water reducing agent.

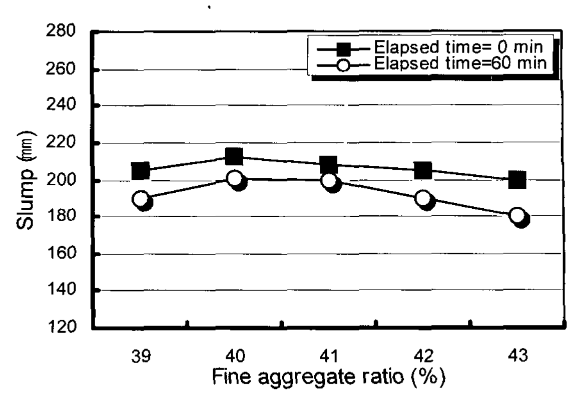

**Fig. 4** Test results of slump trend for fine aggregate ratio

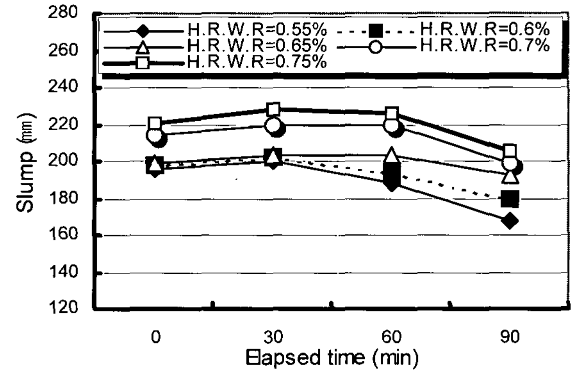

**Fig. 5** Test results of slump trend for a dosage of H.R.W.R

### 4.7 Test results for water-binder ratio

Based on the above test results, the properties of the fresh and hardened concrete by water-binder ratio are checked and analyzed. And suitable mix proportions of 5cases for the bottom slab and side wall concrete are selected.

Table 12 shows mix proportions for water-binder ratio. Also, Fig. 6 gives test results of the fresh concrete for the elapsed time. Test results are satisfied with the required specification without segregation and bleeding. To improve balances between consistency and workability of the bottom slab concrete in the high slump range, the replacement ratio of lime stone powder is increased from 30% to 32% as a binder portion(may be over 320 kf/m$^3$) and retested for the properties of fresh and hardened concrete.

**Table 12** Mix design proportions for water-binder ratio

| W/B (%) | S/a (%) | Unit weight (kg/m$^3$) | | | | | Ad (B*%) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Water | Cement | L.S.P | Sand | Gravel | | |
| 50.1 | 40.0 | 158 | 221 | 95 | 717 | 1,117 | 0.65 | F24 |
| 48.5 | 40.0 | 158 | 228 | 98 | 714 | 1,149 | 0.65 | |
| 44.5 | 40.5 | 155 | 244 | 105 | 718 | 1,131 | 0.65 | F30 |
| 43.4 | 41.0 | 155 | 250 | 107 | 724 | 1,117 | 0.65 | |
| 41.6 | 41.0 | 155 | 261 | 112 | 718 | 1,109 | 0.65 | |

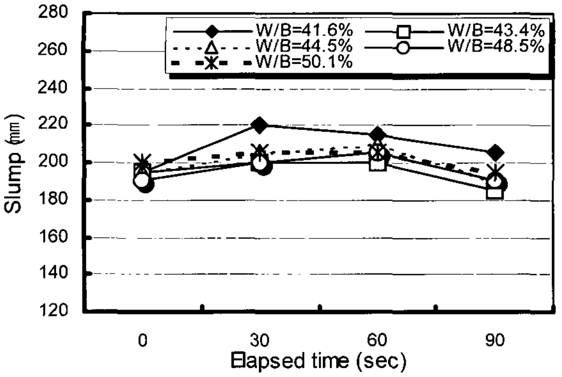

**Fig. 6** (a) Test results of slump trend for water-binder ratio

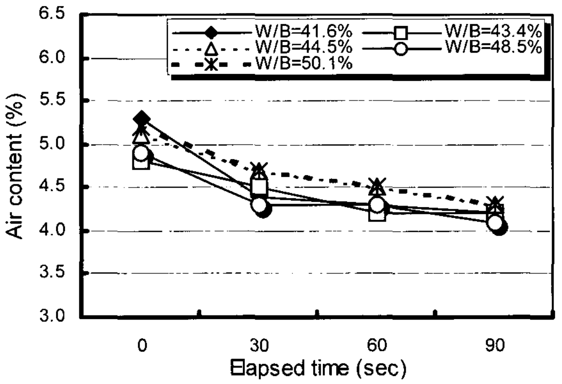

**Fig. 6** (b) Test results of air content for water-binder ratio

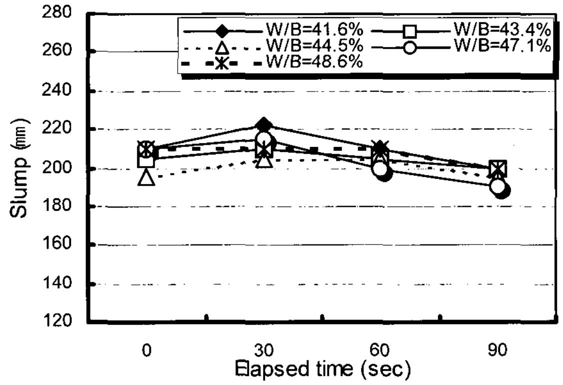

**Fig. 7** (a) Retest results of slump trend for water-binder ratio

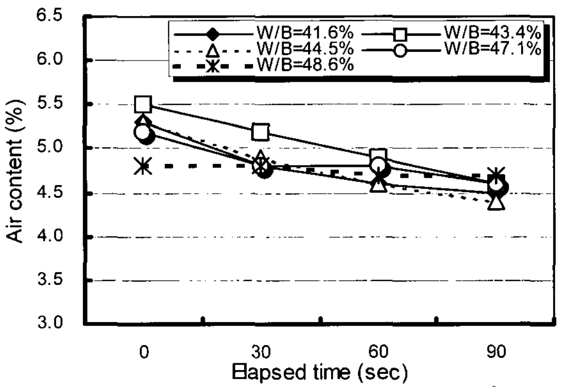

**Fig. 7** (b) Retest results of air content for water-binder ratio

**Table 13** Adjusted mix design proportions for water-binder ratio

| W/B (%) | S/a (%) | Unit weight (kg/m$^3$) | | | | | Ad (B*%) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Water | Cement | L.S.P | Sand | Gravel | | |
| 48.6 | 40.0 | 158 | 221 | 104 | 714 | 1,148 | 0.65 | F24 (Bottom) |
| 47.1 | 40.0 | 158 | 228 | 107 | 710 | 1,143 | 0.65 | |
| 44.5 | 40.5 | 155 | 244 | 105 | 718 | 1,131 | 0.65 | F30 (Wall) |
| 43.4 | 41.0 | 155 | 250 | 107 | 724 | 1,117 | 0.65 | |
| 41.6 | 41.0 | 155 | 261 | 112 | 718 | 1,109 | 0.65 | |

Table 13, Figs. 7, and 8 show the adjusted mix design proportions and test results for these mix conditions.

All of test results for the slump and air content until 90minutes are satisfied with the required specification. Also, it shows very small bleeding and good balances between workability and consistency without segregation. In case of mix conditions(W/B=41.6%, 43.4% and 44.5%) for side wall, two cases including W/B=41.6%, 43.4% are satisfied with the required compressive strength (36MPa) at 56days and one case(W/B=44.5%) is satisfied with the required strength at 91days. Also mix conditions(W/B=47.1% and 48.6%) for bottom slab are satisfied with the required compressive strength (28.8MPa) at 91days. Therefore, after comparing with test results for the adiabatic temperature rising, the optimum mix design conditions will be selected.

### 4.8 Test results for adiabatic temperature rising

Test of the adiabatic temperature rising for the proposed mix proportions is performed to analyze the thermal stress in the massive structure. Table 14 and Fig. 9 show test results of the adiabatic temperature rising($Q_\infty$, r), tensile and compressive strength, static modulus of elasticity tested by KS F 2423 and KS F 2438.

All of test results including $Q_\infty$ and r are proved smaller than those of another project in Japan.[3] Therefore, 2cases as a following Table 15 are selected as the optimum mix design proportion of the side wall and bottom slab concrete.

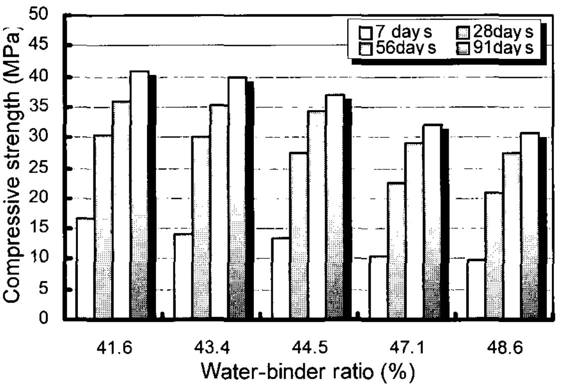

**Fig. 8** Test results of compressive strength for W/B

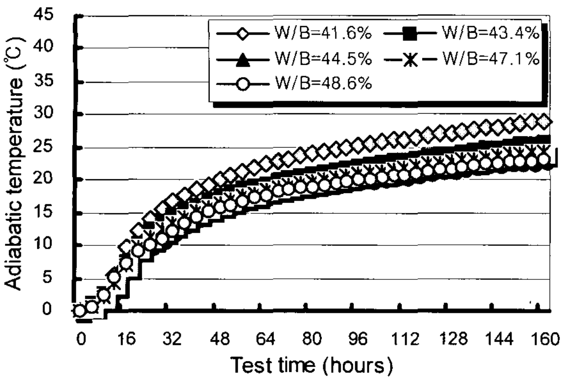

**Fig. 9** (a) Test results of the adiabatic temperature rising

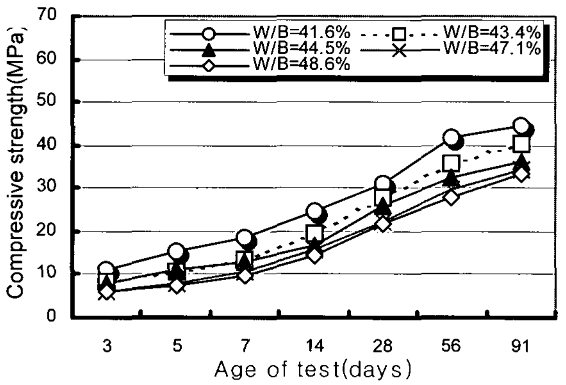

**Fig. 9** (b) Test results for compressive strength at test ages

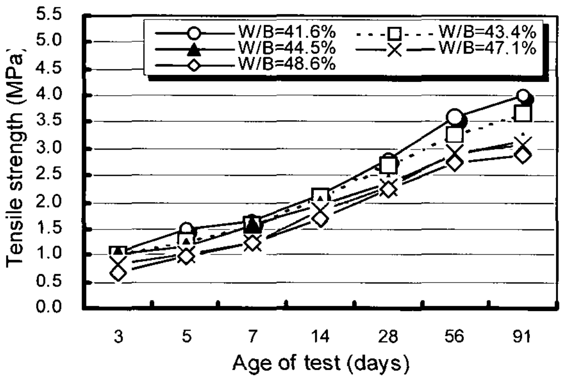

**Fig. 9** (c) Test results for tensile strength at test ages

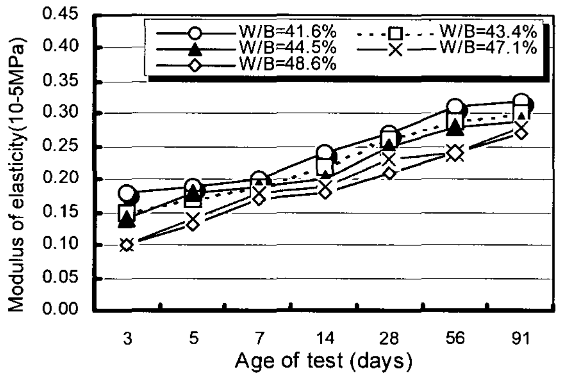

**Fig. 9** (d) Test results for modulus of elasticity at test ages

**Table 14** Test results of the adiabatic temperature rising

| | Water-binder ratio (%) | | | | | Remark |
|---|---|---|---|---|---|---|
| | 41.6 | 43.4 | 44.5 | 47.1 | 48.6 | |
| $Q_{\infty}$(℃) | 28.4 | 25.3 | 24.9 | 24.0 | 22.0 | - |
| r | 0.596 | 0.577 | 0.563 | 0.558 | 0.556 | |

**Table 15** The optimum mix design conditions

| W/B (%) | S/a (%) | Unit weight (kg/m³) | | | | | Ad (B*%) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Water | Cement | L.S.P | Sand | Gravel | | |
| 47.1 | 40.0 | 158 | 228 | 107 | 710 | 1,143 | 0.65 | Bottom |
| 43.4 | 41.0 | 155 | 250 | 107 | 724 | 1,117 | 0.65 | Wall |

**Table 16** Classification and facilities of the batch plant

| Classification | Facilities | Remark (total) |
|---|---|---|
| Mixer type | Twin shaft(210 m³/hr) | 2 mixers |
| Cement/L.S.P silo | 500 ton/silo×4silos | 2 silos (1,000ton) |
| Water tank | 200 ton/mixer | 2 tanks (400ton) |
| H.R.W.A tank | 25 ton/tank | 2 tanks (50ton) |
| Chiller system | 150 RT/mixer | 2 chillers (300RT) |
| Boiler system | 400,000 kℓ/hr | 400,000 kℓ/hr |
| Electric generator | 500 kW | - |

## 4.9 Trial mixing test in the batch plant

### 4.9.1 General considerations

For the optimum mix proportions of the bottom slab and side wall concrete derived from test results in the laboratory test process, trial mixing test in the batch plant is performed for the properties of the fresh concrete using materials and mix proportion same as laboratory test.

All of tests are executed to consider actual site condition as the management of batch plant and agitator, materials used in the bottom slab and side wall concrete, temperature condition, manufacture capacity and transportation. Test procedures in the batch plant are arranged as follows.

### 4.9.2 Classification and facilities of the batch plant

Classification and facilities of the batch plant shows as following Table 16.

### 4.9.3 Selection of mixing time in the batch plant

Mixing time in the batch plant is very important factor because it had effect on the properties of the fresh concrete and manufacturing capacity to supply the bottom slab and side wall concrete.

Longer mixing time in the laboratory test is selected comparatively considering capacity, rpm and energy of the laboratory mixer. But, trial mix test to select a suitable mixing time of the bottom slab and side wall concrete having a

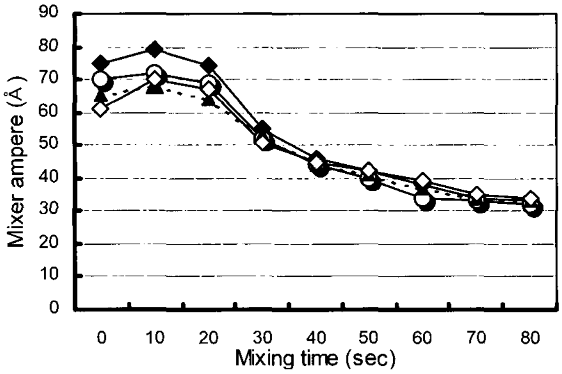

**Fig. 10** Test results for selecting mixing time in the batch plant

Start batching
↓
Measuring time ⇒ Mixing time ⇒ Discharging time ($3m^3$)
(20sec) (55sec) (30sec)
↘
Measuring time ⇒ Mixing time ⇒ Discharging time ($6\ m^3$)
(20sec) (55sec) (30sec)
↓
Depart 1 agitator
Critical path = 20+55+55+30sec (Total time:**2min 40sec** per $6\ m^3$)

**Fig. 11** Required time for manufacturing $6\ m^3$ concrete

good workability and consistency should be checked and conformed in the batch plant Fig. 10 shows test results for relation between mixing time and mixer ampere.

After considering this actual data in the batch plant, about 50~60seconds is suitable as the optimum mixing time with a constant ampere(under 40Å). Therefore, 55seconds a batch is selected as a mixing time for bottom slab and side wall concrete considering the properties of fresh concrete after mixing in the batch plant.

4.9.4 Production capacity in the batch plant

In the above test, an actual mixing time in the batch plant by its ampere load and fresh concrete is fixed as 55seconds a batch. Also, production capacity of concrete per hour by the mix process shows as following Fig.11.

Because the production time required for manufacturing concrete $6m^3$ needs 2minutes 40seconds, the production capacity will be calculated and expected about 95~110 $m^3$/hr when manufacturing efficiency of mixer is 70~80%. Therefore, production capacity is enough to supply concrete quantity required in construction site.

4.9.5 Test results of trial mixing in the batch plant

Based on the proposed mix design conditions of laboratory test and the fixed mixing time, trial mixing in the batch plant is executed for the fresh concrete.

**Table 17** Test results of the fresh concrete in the batch plant

| Mix No. | W/B (%) | Slump(mm) for elapsed time(minutes) | | | | Air content(%)) for elapsed time(minutes) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 30 | 60 | 90 | 0 | 30 | 60 | 90 |
| F30 | 43.4 | 205 | 215 | 215 | 210 | 5.4 | 5.1 | 5.3 | 4.9 |
| F24 | 47.1 | 200 | 210 | 220 | 220 | 5.1 | 4.7 | 4.5 | 4.5 |

Table 17 shows test results of the fresh concrete in the batch plant. Test results are satisfied with the required specification until 90minutes. Also, chloride content shows in the range of 0.012~0.024kg/$m^3$ and unit weight of the concrete gives in the range of 2.33~2.39 t/$m^3$. Based on the results of this study, the optimum mix proportions of the massive concrete are applied successfully to the bottom slab and side wall in LNG in-ground tank.[4)]

## 5. Conclusions

Based on the results obtained in this study, the following conclusions can be made.

1) Low heat portland cement and lime stone powder as a binder are chosen cementitious materials in order to prevent the thermal crack from hydration heat.
2) The optimum unit cement content is selected under 270kg/$m^3$ in order to control adiabatic temperature rising below,30℃. And considering test results of the confined water ratio and deformable coefficient, 30% of lime stone powder by cement weight is selected as the optimum replacement ratio.
3) Compared with test results including balance with workability and consistency, bleeding, segregation and slump loss during elapsed time, the optimum range of design factors in the laboratory is selected as following; unit water content (155~160kg/$m^3$), fine aggregate ratio (40~41%) and dosage of high range water reducing agent (0.65%).
4) Considering test results of the adiabatic temperature rising($Q_\infty$, r), tensile and compressive strength, modulus of elasticity for test ages, 2cases are selected as the optimum mix design conditions of the side wall and bottom slab concrete and $Q_\infty$ and r are proved smaller than those of another project in Japan.

| W/B (%) | S/a (%) | Unit weight (kg/$m^3$) | | | | | Ad (B*%) | $Q_\infty$ (℃) |
|---|---|---|---|---|---|---|---|---|
| | | Water | Cement | L.S.P | Sand | Gravel | | |
| 47.1 | 40.0 | 158 | 228 | 107 | 710 | 1,143 | 0.65 | 24 |
| 43.4 | 41.0 | 155 | 250 | 107 | 724 | 1,117 | 0.65 | 25.3 |

5) An actual mixing time by its ampere load is fixed as 55seconds a batch. And the production capacity are about 95~11$m^3$/hr which is enough to supply the required concrete in construction site.

## References

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