Establishment of Systematic Maintenance Procedure for Concrete Structures in LNG Terminal

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ABSTRACT: This paper describes the establishment of reasonable maintenance procedure of ageing concrete structures in LNG terminals of Osaka Gas through the systematic survey of the terminals and the study of repair criteria. As the accomplishment of the series of these examinations, we made up our own "Maintenance Manual" of concrete structures in our LNG Terminals. Our original "Maintenance System" composing of database, deterioration prediction system, and life-cycle cost (LCC) optimization system was also established. We can obtain the most reasonable maintenance program and cost of each concrete structure by calculating all the maintenance pattern and cost using this system.

KEYWORDS: Liquefied Natural Gas (LNG), concrete structure, systematic maintenance, repair criteria, deterioration progress, life-cycle cost (LCC)

1. BACKGROUND

Osaka Gas is supplying city gas for 6.75 million customers mainly in Kansai area including Osaka, Kyoto, Kobe etc. (Figure 1). The source of city gas is Liquefied Natural Gas called LNG which is imported from Australia and Indonesia etc. Osaka Gas has been receiving LNG at the three terminals: Senboku 1, 2 and Himeji Terminal (Figure 2).

These terminals have been operated for approximately 30 years. It is required to deal with the ageing of the terminal facilities appropriately because LNG terminals should be operated safely and stably for the long time from the social infrastructure point of view.

Meanwhile, the maximum cost-benefit performance of maintenance is required by carrying out the adequate and reasonable maintenance from asset management point of view.

In order to keep stable and safe operations while reducing maintenance cost, we have been examining for efficient maintenance procedure of LNG terminal facilities since 2000.

This paper describes the general outline of the examination we performed and of systematic

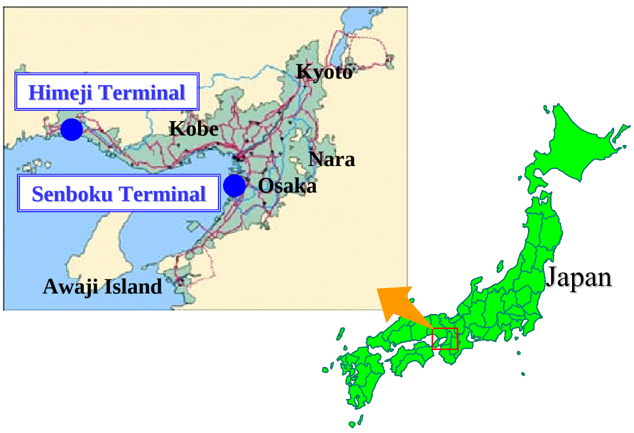

Figure 1 City Gas Service Area of Osaka Gas

Figure 2 View of Senboku Terminal 2

maintenance procedure of structures such as the LNG tank foundation slabs, dikes, jetty facilities, buildings etc.

2. THE EXAMINATION PROCESS OF AGEING CONCRETE STRUCTURES

Figure 3 shows the process of our study to establish the systematic maintenance method for concrete structures of our terminals. In general terms, it consists of the following two stages.

1) Precise analysis of the current status

2) The deterioration prediction and the examination of repair criteria.

2.1 Analysis of the current status

Up to now, taking quick visual surveys has been conducted along the way of routine mechanical equipment checks, but an overall systematic inspection of the ageing structures has not been performed.

At first we assembled the previous inspection results and repair history in order to understand the status of the structures systematically. After that we performed visual survey and detailed inspection such as the testing of chloride ion penetration and carbonation depth etc. all over the LNG terminals.

Visual survey was performed systematically for all concrete structures; its surface area is approximately 300,000m^2 in terminals.

As they have been located on seashore area and been operated for long time, chloride attack and carbonation were expected to be major deterioration factors. Attention was particularly given to appearance of concrete surface such as longitudinal cracks along rebar, delamination, spalling, peeling, rust exudation and rebar exposure which is the characteristics of these deterioration factors.

On the other hand, detailed inspections such as testing of chloride ion penetration and carbonation depth and chipping test were conducted in order to comprehend the deterioration factors and predict the deterioration progress and configure repair criteria. In general deterioration progress depends on the concrete mix proportion, environmental condition and the length of in-service etc. Therefore in the inspection all structures were grouped according to distance from the shoreline and in-service condition. And the chloride ion content and carbonation depth of the representative structures picked up on each group were analyzed. Chipping test was carried out to check directly the condition of rebar corrosion.

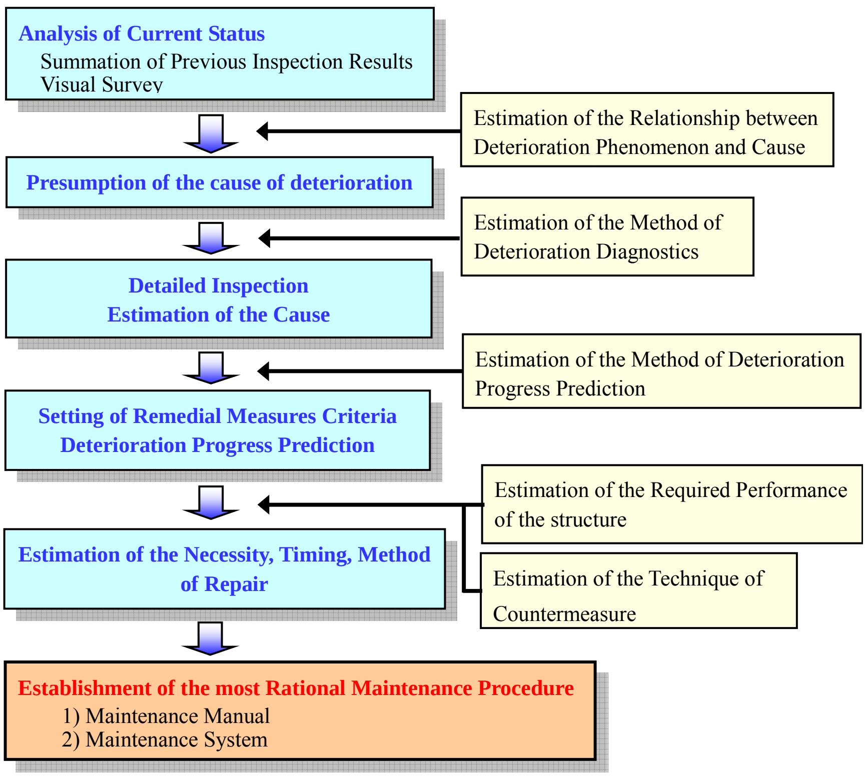

Figure 3 Examination Process for establishing a systematic maintenance method

2.2 The deterioration prediction and the

examination of repair criteria

Chloride ion penetration was predicted using "Fick's 2nd law of diffusion". And carbonation was predicted using "square root t law" The results of the detailed inspection were used for the both prediction

1) Fick's 2nd law of diffusion

$$C(x,t) = C_0(1 - erf\frac{x}{2\sqrt{Dt}})$$

Where

$C(x,t)$ = Chloride ion content at the depth of x(cm) and at time t (years) (kg/m^3)

C_0 = Chloride ion content on the concrete surface (cm)

D = Apparent diffusion coefficient of chloride ion (cm^2/year)

erf = error function

2) Square root t law

$$y = b\sqrt{t}$$

Where

y = Carbonation depth at time t (mm)

t = Time t from construction (years)

b = the carbonation rate coefficient (mm/√years)

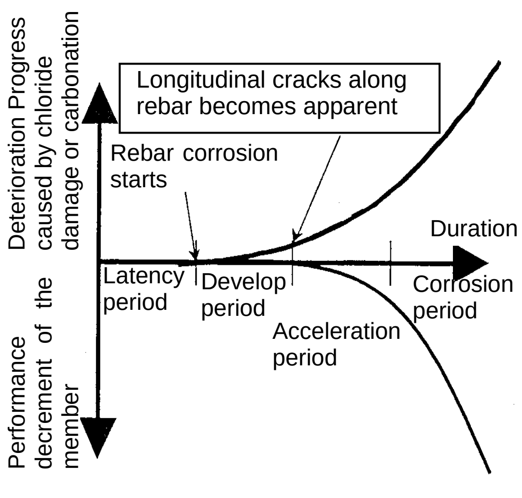

Figure 4 Deterioration progress process caused by chloride attack, or carbonation

Meanwhile, to determine the repair timing it is necessary to establish repair criteria regarding chloride ion content and uncarbonated depth.

As shown in Figure 4, it is defined that the performance decrement of structure begins at the time when longitudinal cracks along rebar becomes apparent because rebar corrosion will be accelerated rapidly after this timing. We provisionally decided to equate this timing with "the timing for repair".

However the relationship between the chloride ions content near the rebar, uncarbonated depth and the moment when the longitudinal cracks along rebar occur can not determinate, it becomes easier to manage concrete structures if these relations are to be apparent.

Therefore we came out these relationships regarding our structures using our results of the visual survey and detailed inspection descrided section 2.1. And we decided to manage our structures by means of these relationships.

By comparing the deterioration prediction results to repair criteria, we estimated the repair timing of our structures.

These criteria would be reviewed by the accumulation of future inspection results for further improvement of our maintenance activity.

3. MAINTENANCE PROCEDURE OF CONCRETE STRUCTURES IN THE LNG TERMINALS OF OSAKA GAS

Through the efforts stated in chapter 2, we have created "The Maintenance Manual" and "The Maintenance System" to carry out the maintenance of the concrete structures more reasonably.

3.1 The Maintenance Manual

"The Maintenance Manual" describes the appropriate maintenance means considering characteristics of structures and environmental condition etc. for concrete structures in our LNG terminals.

This Manual includes specific maintenance procedure such as the concept of maintenance, the ways of survey, inspection and remedial measures. And we carry out the maintenance activity according to this manual.

3.1.1 Contents of Maintenance Manual

(1) Basic Concept of the Maintenance

The basic concept of our maintenance is the following.

1) Mainly the maintenance procedure against chloride attack and carbonation is provided. Maintenance must be carried out to prevent from decreasing the performance of structures caused by rebar corrosion.

2) Maintenance specifications are decided for the classification set for each structure. The classifications are decided based on the impact for gas supply and disasters when the facilities damages etc. The classification is divided into three classes as shown Table 1.

Table.1 Classification for maintenance

Class	Definition	Relevant structures
A	Either of the following is the condition for being grouped as Class A 1) Damage of the structure raises extensive shutdown of gas supply 2) Damage of the structure causes large-scale disaster 3) Implementation of remedial measures is difficult or very costly after deterioration progress	LNG Tank foundation slab LNG Jetty facilities Intake facilities
A’	Design thickness of cover concrete of the structure is thin	Buildings
B	Except Class A	Others

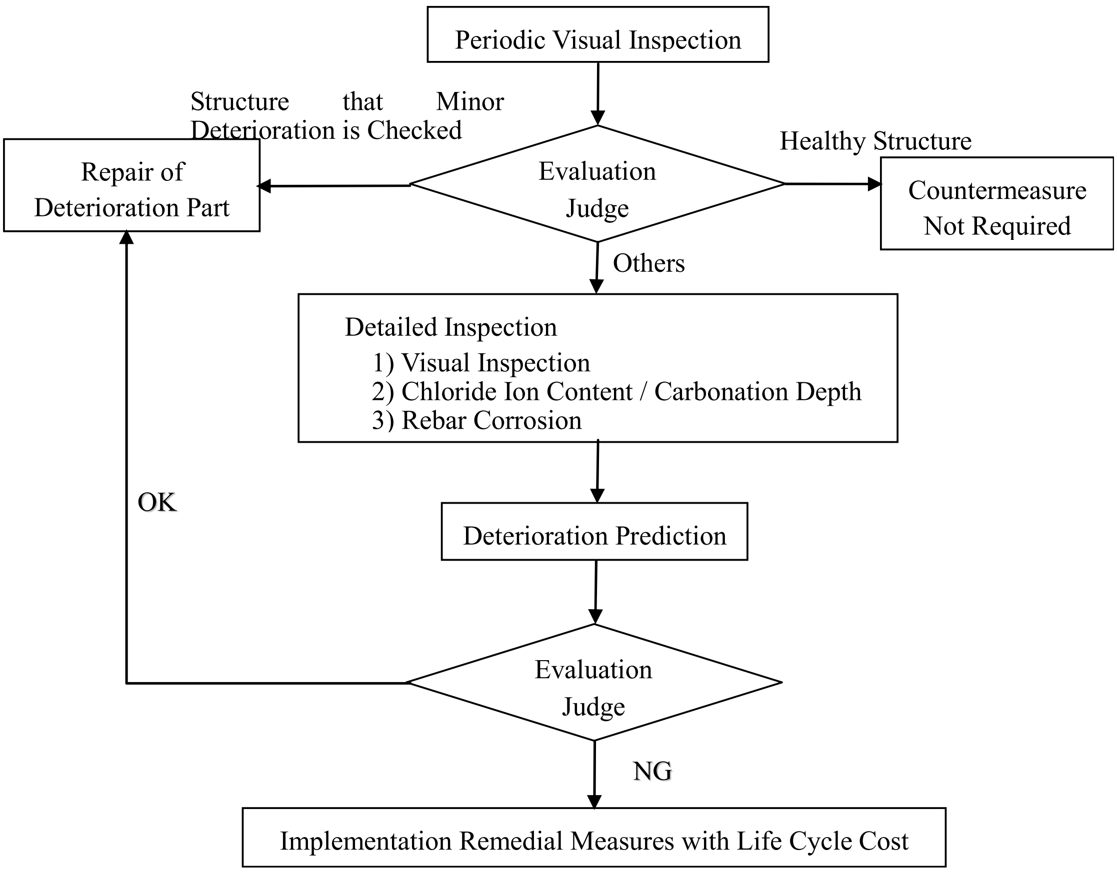

Figure 5 Maintenance flow of concrete structure in LNG terminal of Osaka Gas

Figure 5 shows the maintenance flow described in the manual. At first we check the current status of all concrete structures in our LNG terminals periodically. We call this check “periodic visual inspection”. And we evaluate whether detailed inspections are required based on the results. Detailed inspections are carried out to judge necessity of repair, determine repair specification and predict deterioration progress. Detailed inspection includes visual inspection, inspection of chloride ion content, carbonation depth and rebar corrosion to satisfy the foregoing purpose.

The repair specification taking into account LCC is selected for the structures evaluated that repair works are required. On this stage the LCC optimization system described in chapter 3.2 provides various plans of repair.

(2) Periodic Visual Inspection

Periodic visual inspection will be conducted for the concrete structures focusing on the below three defects.

1) Cracks (Especially longitudinal cracks along rebar)

2) Spalling, peeling, cross sectional loss, steel exposure

3) Rust exudation

The inspection period is set at every 5 years for the structures in the maintenance class A, 7 years for the structures in the class B.

In this inspection, we check the presence, type, pattern and general amount of deterioration. From the result, the necessity of detailed inspection is judged.

(3) Detailed inspection

Detailed inspection is performed for the structures which have major deterioration. Chloride ion content and uncarbonated depth is measured using core sample for the deterioration prediction. And the degree of rebar corrosion is checked by chipping test.

In this visual inspection, the amount of deterioration is recorded for repair.

(4) Remedial measures

The manual includes the specification, method and procedure etc. of repair. The manual especially includes replacing cover concrete, epoxy resin injection, and coating in detail because these methods are comparatively adopted. Other methods of repair as electric protection are also included. In addition, the results of durability test of various coating we carried out are included.

3.2 Development of Maintenance System of Concrete Structures

We accumulated a database on all the data relating to inspections etc. which was specifically developed for the civil structures in the LNG terminals in order to facilitate maintenance in the future.

This system was made specifically for our LNG terminal structures.

The composition of the maintenance system is shown in Figure 6. The database consists of structure information, survey and inspection results, repair and reinforcement results etc. This system also has “Deterioration Prediction System” and “LCC optimization system” utilizing the data stored in the database system. In addition the system has the function that evaluates deterioration factor, bearing capacity and serviceability of the structures from the data of the results of visual survey.

3.2.1 Database system

The structure information includes the year of commencement, specified mix proportion of the concrete and construction outline etc. are registered.

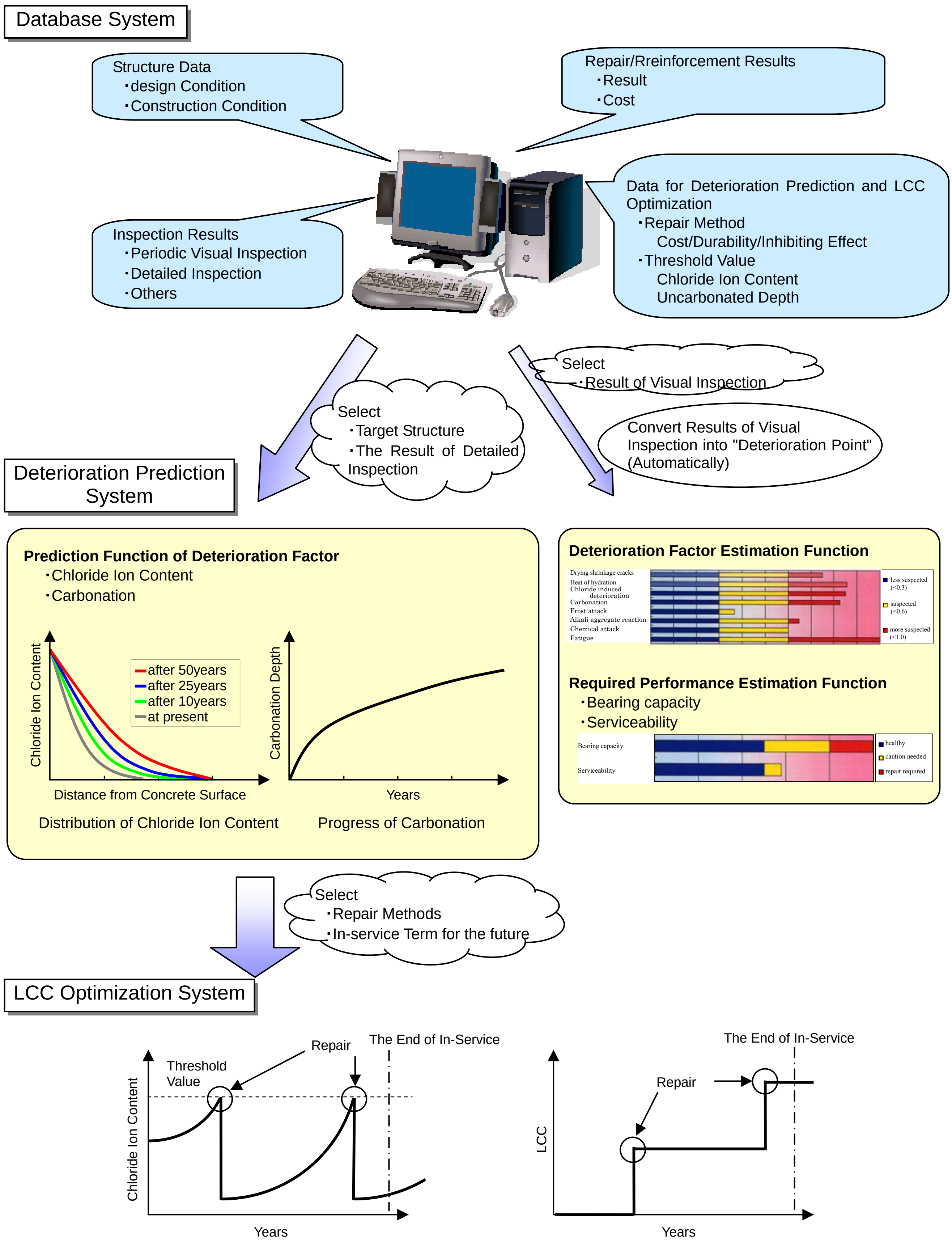

Figure 6 The Composition of the Maintenance System

The check results such as the visual and detailed inspection results can be input. The status of defects such as cracking, spalling and peeling etc, and the degree of rebar corrosion is stored as visual inspection results. The data of detailed inspection such as chloride ion content, carbonation depth and compressive strength etc is recorded. These items matches the check items described in "The Maintenance Manual".

3.2.2 Deterioration Prediction System

This system has three functions: a deterioration prediction system, a deterioration factor estimation function and a function which estimates required performance such as bearing capacity and serviceability.

The deterioration prediction system predicts the deterioration progress of chloride ion penetration and carbonation using the results of detailed inspection. The deterioration prediction can be automatically performed just by linking to the database and choosing the detailed inspection results of the target structure. We adopt "Fick's 2nd law of diffusion" for chloride ion penetration, and "square root t law" for carbonation.

The deterioration factor estimation function and the estimation function of required performance like bearing capacity and serviceability are the other characteristics of this system. The deterioration factor and the bearing capacity and serviceability are estimated by converting the results of visual inspection into "deterioration points" based on the rule we determine originally.

3.3.3 LCC Optimization System

Designing the maximum cost-benefit maintenance plan is required in order to cut the maintenance cost down reasonably while keeping the required performance of the structure within the in-service period.

We developed the original LCC optimization system to calculate the most effective LCC. This system is the most characteristic function of our "Maintenance System".

This LCC optimization system is linked to the database, and it can automatically provide all maintenance plans. These solutions are without exceeding the threshold values set regarding the chloride ion content and the uncarbonated depth in cost order. In this system both chloride ion content and uncarbonated depth do not surpass each threshold value. In other words, preventative maintenance can be considered.

We adopt surface coating, cross sectional surface repair, desalination, re-alkalization, electric protection etc. and its combination as the candidates of remedial measures. And we determine the duration of these methods and the inhibiting effect against chloride ion penetration and carbonation.

The specialized engineers judge the solutions and select the most practical and reasonable maintenance plan from solutions provided by the optimization system.

An example of maintenance plan for chloride attack provided by the LCC optimization system is shown in Figure 7. "Pattern A" provides the maintenance plan that cross sectional surface repair is considered twice by the end of the in-service term. "Pattern B" proposes what the combination of cross sectional surface repair and surface coating is planned once. And "Pattern C" provides the other one that surface coating and desalination are planned. Either pattern satisfies the condition that chloride ion content does not surpass threshold value. But LCC is different each other. In these patterns, "Pattern B" should be chosen because LCC is the lowest and the condition of chloride ion content is satisfied.

Figure 8 shows a sample screen. On the display of

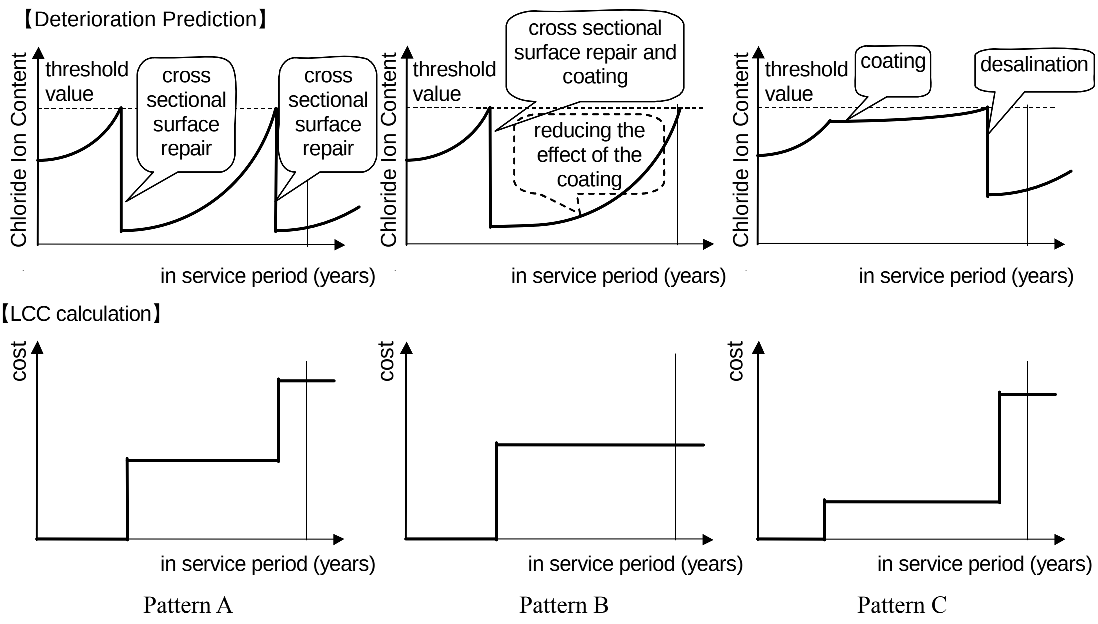

Figure 7 Example of proposed maintenance plan for chloride attack

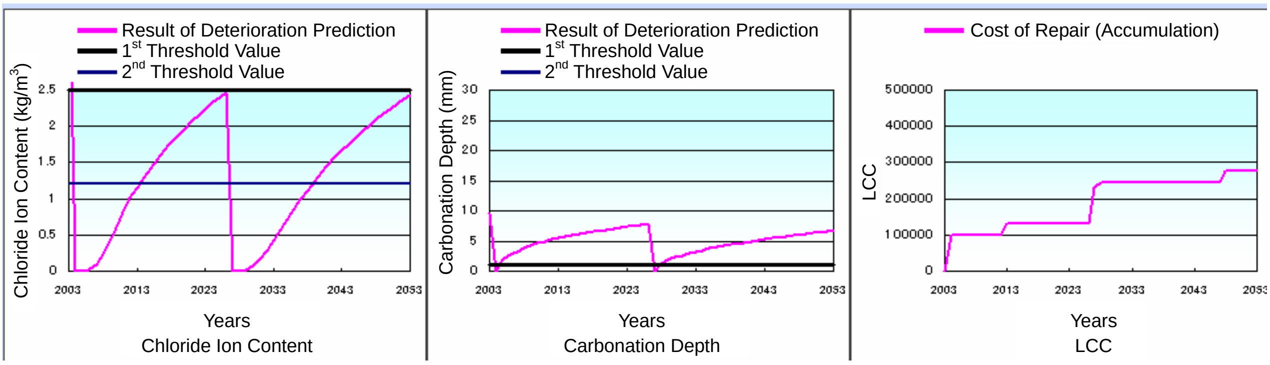

Figure 8 Sample screen of an optimized solution

personal computer we can see these graphs representing the time-series transition of chloride ion content, carbonated depth and LCC for a proposed repair plan. We can see these graphs for all plans proposed by the LCC optimization system.

4. Conclusion

Osaka Gas established the systematic, reasonable maintenance procedure of concrete structures in LNG terminals. We do maintenance according to the established maintenance procedure.

We hope to make our maintenance activity more reasonable by accumulating future inspection and practical results regarding repair and reviewing repair criteria.

Osaka Gas will keep increasing the efforts to operate the LNG terminals at a low cost as well as in a safe and stable condition and for the long-term.

REFERENCES

1. Japan Society of Civil Engineers : Standard Specification for Concrete Structures-2001 “Maintenance”,

2. Ushida, T., Fuchimoto, Y., Nishizaki, T. : Examination of Aged Civil Structure of LNG Terminal Facilities, Proc. of 22nd World Gas Conference Tokyo 2003,June 2003.