

IMPROVEMENT OF COVERCRETE QUALITY BY CRACK CONTROL SYSTEM IN YAMAGUCHI PREFECTURE IN JAPAN

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ABSTRACT: Yamaguchi prefecture in Japan has established crack control system of massive concrete structures by cooperating works among the local government, private companies, and academic institutions. One of the essential components of the system was to achieve appropriate concrete construction following standard specifications. Due to that achievement, massive concrete crack was well controlled, and furthermore, covercrete quality was much improved, that was confirmed with Surface Water Absorption Test developed by the authors.

Another essential component of the system was database of concrete construction fully opened in the website of the prefecture. We analyzed the database with some viewpoints, and several important findings related to good controlling of cracking and durability design of concrete structures. It was clearly exhibited that covercrete quality measured by Surface Water Absorption Test had good correlation with Durability Points calculated by “Recommendations for Durability Design of Concrete Structures -Draft” proposed by JSCE. In the future, we will be able to analyze the effect of each component of construction works on durability of concrete structures, that should be fed back to durability design system.

KEYWORDS: crack control system, covercrete quality, surface water absorption test

1. INTRODUCTION

Thermal crack in massive concrete structures is harmful for durability and serviceability of structures and is not easy to control. It is not easy because the occurrence of thermal crack and the width of crack are affected by so many factors. Now in Japan, this initial crack problem is a severe problem in construction system, due to strict instructions by the government regarding securing quality of structures. Initial crack problem leads to severe confliction between owners and contractors.

Yamaguchi prefecture in Japan (Fig.1) has established crack control system of massive concrete

structures by cooperating works among the local government, private companies, and academic institutions. One of the essential components of the system was to achieve appropriate concrete construction following standard specifications like JSCE code. Due to that achievement, massive concrete crack was well controlled, and at the same time covercrete quality was much improved which was confirmed with Surface Water Absorption Test (SWAT) developed by the authors (2011, 2012).

Another essential component of the system was database of concrete construction fully opened in the website of the prefecture. We analyzed the database with some viewpoints, and several important



Yamaguchi prefecture is one of 47 prefectures in Japan, at the west end of Honshu.

Figure 1 Location of Yamaguchi prefecture

findings were obtained related to constructing durable concrete structures.

1.1 Objectives

In this research, the crack control system of massive concrete structures established by Yamaguchi prefecture is explained. The core components of the system are explained, and the effectiveness of the system for crack controlling is analyzed.

Next, it is clearly exhibited that covercrete quality measured by SWAT is improved by the crack control system. It is also exhibited that the covercrete quality measured by SWAT had good correlation with Durability Points calculated by “Recommendations for Durability Design of Concrete Structures -Draft” proposed by JSCE (1995).

Based on the investigated results, the real meaning of crack controlling is discussed.

2. CRACK CONTROL SYSTEM IN YAMAGUCHI PREFECTURE

Here, how Crack Control System in Yamaguchi prefecture was established is explained. The essential components of the system are explained. After that, the effectiveness of this system is shown by the results in actual structures.

2.1 How the system started

In 2001 in Japan, the Ministry of Land, Infrastructure and Transport gave an official notice on securing quality, and after that inspection of crack of concrete structures became strict.

In Yamaguchi prefecture, many problems between owners and contractors became remarkable, such as responsibility for crack repairing, etc. Yamaguchi prefecture started cooperating works among the local government, private companies, and academic institutions to control thermal crack. In 2005, testing constructions in actual structures were started where the effects of many kinds of material measures for crack control were investigated.

After starting the testing constructions in 2005, it was revealed that “crack derived from poor construction” was reduced drastically. One of that kind of cracks was the non-penetrating cracks at the bottom of top slabs of box culverts along the axis of culverts. This reduction must have been due to the level up of construction work because much attention was paid to this collaborating works. All the players involved realized that one of the keys to control crack is to achieve appropriate construction in order to avoid “crack derived from poor construction”.

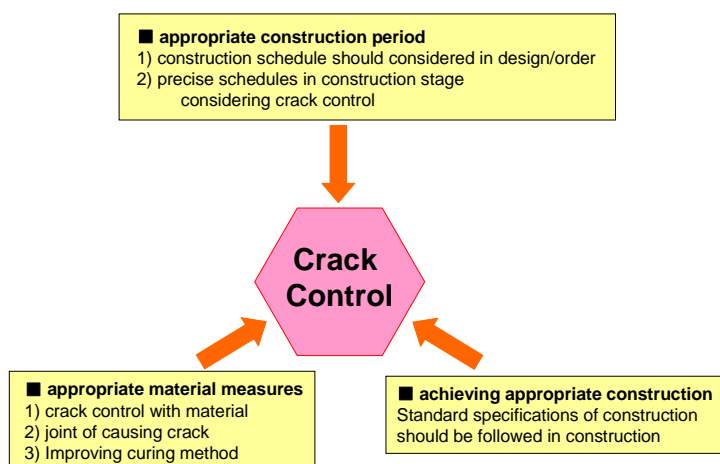


Figure 2 Three columns of Crack Control System

The most important lesson from the testing constructions was that all the players realized that some cracks cannot be controlled as harmless even when appropriate construction was conducted.

For those cracks, different from “crack derived from poor construction”, some countermeasures to control crack width have to be considered. The essence of Yamaguchi system is that the countermeasures are decided based on the database of “Concrete Construction Data”, records of the data of concrete construction of actual structures. As data is accumulated in database and analyzed, countermeasures will become systematic.

In Yamaguchi prefecture, Crack Control system was officially started in 2007. At present, target structures in this system are RC infrastructures where harmful thermal crack can be generated. Upper structures of bridges are not included.

2.2 Outline of Crack Control System

The crack control system has three columns, such as, (1) selecting appropriate construction period, (2) achievement of appropriate concrete construction, (3) appropriate material measures to control cracking (Figure 2).

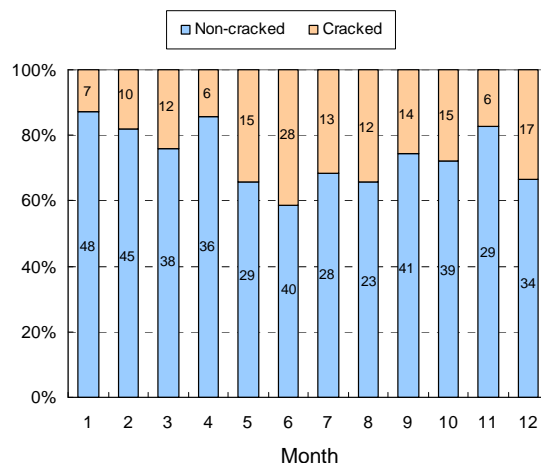


Figure 3 Cracking ratio in each month

2.2.1 Appropriate construction schedule

As shown in Figure 3, results of testing in actual structures showed that the ratio of cracking became higher when placing of concrete was conducted in summer season (from around May to September) and in the end of year and in the end of business year (March).

Therefore, as the first column of the system, appropriate construction schedule should be considered in design/order stage, and precise schedule should be decided in construction stage considering crack control.

2.2.2 Appropriate concrete construction

The second column of the system (Figure 2) is to achieve appropriate concrete construction at site. It is not easy to achieve a condition that standard specifications are followed in all the sites. To achieve this condition, Yamaguchi prefecture developed “Check Sheet to Grasp Construction Conditions” as one of the components in the systems (Figure 4). Inspectors of Yamaguchi prefecture will bring this sheet to check construction conditions at sites.

Standard specifications are precisely described for example in JSCE code, however, 27 items were chosen from them and summarized in the check

Information about the site, lift, contractor, time, etc.

27 items Related to Concrete construction

【 施 工 状 況 把 握 チェックシート (コンクリート打設時) 】

事務所名	山口土木建築事務所		工事名	〇〇県道 道路改良工事		工区	1	
構造物名	〇〇橋 A1橋台		部位	たて壁		リフト	2	
請負者	〇〇建設 (株)		確認者	〇〇技師				
配合	27-8-20BB		確認日時	2006/5/25(木) 7:30~12:00				
打込み開始時刻	予定	8:00	実績	9:10	打設開始時気温	22.0℃	天候	曇のち晴
打込み終了時刻	予定	12:00	実績	13:30	打設量 (m3)	100	リフト高 (m)	3.0
施工段階	チェック項目						記述	確認
準備	運搬装置・打込み装置は汚れていないか。						-	○
	型枠面は湿らせているか。						-	○
	型枠内部に、木屑や結束線等の異物はないか。						-	※1
	かぶり内に結束線はないか。						-	○
	既コンクリート表面のレイダンス等を取り除き、ぬらしているか。						-	○
	コンクリート打設作業人員に余裕を持たせているか。						5人	○
	パイプレータの予備を準備しているか。						4台中1台	○
運搬	発電機のトラブルがないよう、事前にチェックをしたか。						-	○
	練混ぜはじめてから打ち終わるまでの時間は適切か。						50分	○
打込み	ポンプや潤滑性を確保するため、先送りモルタルの圧送等の処置を施したか。						-	○
	鉄筋や型枠は乱れていないか。						-	○
	垂直かつ打込み位置近くに打設し、横移動させていないか。						-	○
	一区画内のコンクリートは、打込みが完了するまで連続して打ち込んでいるか。						-	○
	コンクリートの表面が水平になるように打込んでいるか。						-	○
	一層の高さは、40~50cm以下か。						50cm	○
	2層以上に分けて打ち込む場合は、上層のコンクリートの打込みは、下層のコンクリートが固まり始める前に行っているか。						-	○
締固め	ポンプ配管等の吐出口から打込み面までの高さは、1.5m以下としているか。						約1.8m	※2
	表面にブリーディング水がある場合には、これを取り除いてからコンクリートを打ち込んでいるか。						-	○
	パイプレーターを下層のコンクリートに10cm程度挿入しているか。						-	○
	パイプレーターは鉛直に挿入し、挿入間隔は50cm以下か。						-	○
養生	締め固め作業中に、振動機を鉄筋等に接触させていないか。						-	○
	パイプレーターでコンクリートを横移動させていないか。						-	○
	パイプレーターは、穴が残らないように徐々に引き抜いているか。						-	○
	硬化を始めるまでに乾燥するおそれがある場合は、シートなどで日よけや風よけを設けているか。						-	○
要改善事項等	コンクリートの露出面を湿潤状態に保っているか。						-	○
	湿潤状態を保つ期間は適切か。						10日間	○
	型枠および支保工の取外しは、コンクリートが必要な強度に達した後であるか。						-	○
※1 型枠内部に結束線 (3本) が落ちていたため、打設前に取り除かせた。 ※2 排出口から打込み面までの高さが、明らかに1.5m以上であるため、口答で改善指示した。 上記※1、※2についての改善と、次回打設時も施工状況把握を行うことを、工事打合せ簿にて指示する。								

confirmed

two instructions

Figure 4 Example of Check Sheet to Grasp Construction Conditions

sheet. When some of the items are not followed at sites, inspectors will give instructions to improve and record them in the sheet.

“Concrete Construction Data” is opened, which must contribute to improve the motivations of players engaged in this system.

The format of the check sheet is opened in HP of Yamaguchi prefecture. Important items of standard specifications are shared between contractors and inspectors, which has led to improving of construction conditions.

2.2.3 Material measures for crack control

The third column of the system (Figure 2) is to take appropriate material measures to control crack. It was proved by testing in actual structures in 2005 that some cracks could not be controlled as harmless even when appropriate construction was conducted. In those cases, appropriate material measures should be considered in design stage based on accumulated construction results.

Adding to this check sheet, Yamaguchi prefecture developed e-learning movie for learning basic matters of construction, and has held symposiums many times. Almost all the information including

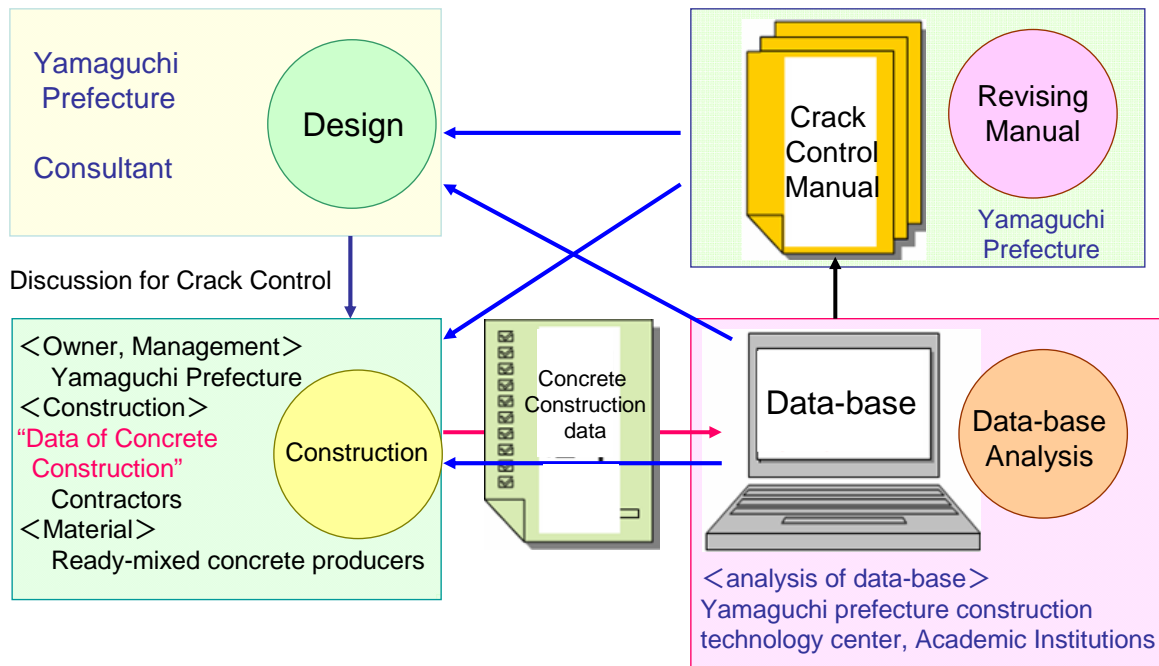


Figure 5 PDCA cycle of Crack Control System in Yamaguchi prefecture

In the case of side walls of box culverts, Yamaguchi prefecture recommends to set appropriate numbers of joints for causing cracks considering the season of placing.

In the case of vertical walls of abutments, to add reinforcing bars to control crack width has first priority. In the case of thin parapet walls of abutments, in addition to adding reinforcing bars, the usage of expansive additive will be considered.

At present, “Crack Control Measures Manual” is summarized based on construction results, and it is included in the particular specifications of Yamaguchi prefecture.

Material measures adopted in actual construction are recorded with cracking conditions in “Concrete Construction Data”. In this system, the effects of material measures are verified each time and recorded.

The essence of this system is that “Concrete Construction Data” with appropriate construction is recorded, where the effects of material measures are verified and obtained knowledge are fed back to

manual, design, and construction. (Figure 5)

2.3 Improvement of Construction Conditions

Total results of “Check Sheet to Grasp Construction Conditions” are summarized in Figure 6. Crack Control System by Yamaguchi prefecture was officially started from 2007. It can be seen in this figure that the number of rots where instructions for improvement were not given is increasing. After the 2nd half of 2008, in around 90 % of total rots, no instructions from inspectors were necessary to improve the conditions of construction.

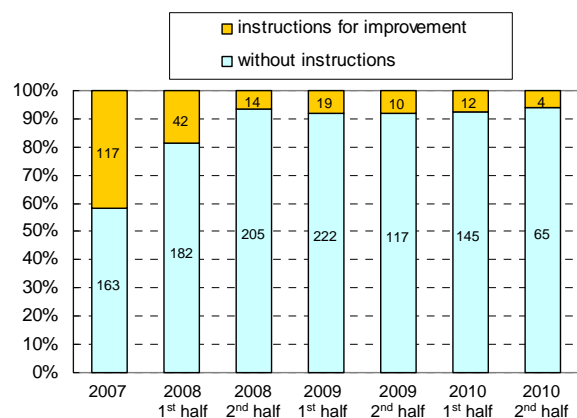


Figure 6 Ratio of construction rots with and without instructions for improvement from inspectors based on “Check Sheet to Grasp Construction Conditions”

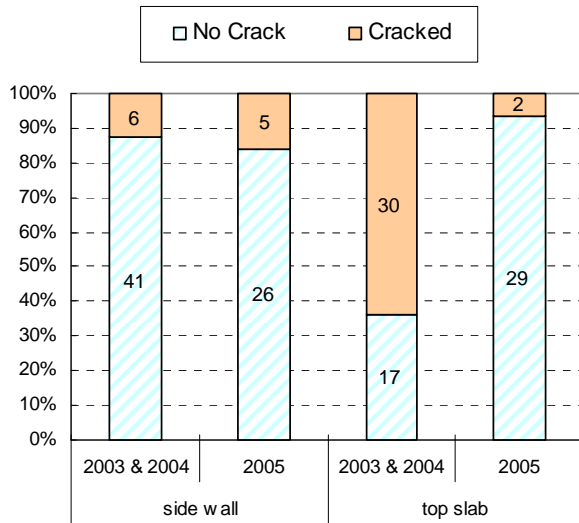


Figure 7 Cracking ratio of box culverts

This kind of simple check sheet can be utilized in concrete construction to achieve appropriate construction.

2.4 Effects of system on crack control

Crack Control System in Yamaguchi prefecture has shown good results in controlling cracking as harmless. Here, some results are exhibited.

Figure 7 shows the ratio of No crack and cracked members of box culverts. In 2005, testing construction started. Just after the testing construction started, longitudinal non-penetrated cracks on the bottom of top slabs were reduced drastically. The two rots with cracks were tested with welded wire mesh and FRP sheet. In all other 29 rots, no crack was observed without any special material measure.

This longitudinal cracks in top slabs can be regarded as “crack derived from poor construction”.

Figure 8 shows the effects of reinforcing bars on crack control in vertical walls of abutments. The cracks in abutments are not recognized as “crack derived from poor construction”, therefore,

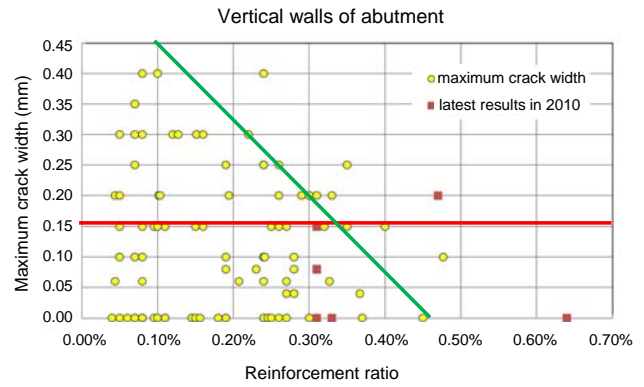


Figure 8 Effects of reinforcing bars on crack control in abutment

reinforcing bars should be added to control crack width.

At present, Yamaguchi prefecture sets 0.15mm as the criteria to judge penetrated cracks as harmful. Therefore, judging from the results in Figure 8, reinforcement ratio should be larger than 0.30%.

3. INVESTIGATION OF COVERCRETE QUALITY BY SURFACE WATER ABSORPTION TEST

In this section, we will investigate covercrete quality of concrete structures in Yamaguchi prefecture by Surface Water Absorption Test (SWAT) developed by the authors. We will show that covercrete of structures after the crack control system started is better than that of structures before the system was established. Furthermore, a possibility will be shown to analyze the effects of construction factors on covercrete quality utilizing the relationship between SWAT results and “Recommendation for Durability Design of Concrete Structures” published by JSCE.

3.1 Surface Water Absorption Test

In this research, to investigate covercrete quality of concrete structures in Yamaguchi prefecture, Surface Water Absorption Test (SWAT) is used. SWAT is a

simple and completely non-destructive surface water absorption test with variable water head developed by the authors(Figure 9) (2011,2012).

The test device consists of a water cup with graduated tube. Inside diameter of the cup is 80 mm and height of the tube from center of the cup is 300 mm (Figure 10). Once the apparatus is filled with water, drop in water level is recorded for 10 minutes started at 10 seconds after the starting of the filling time. In the present SWAT system, water level is automatically measured by the sensors attached to the lower part of the water cup to monitor the water pressure. From the observed data the Water Absorption Factor (WAF) is calculated that is defined as “the rate of water absorption in ml/m²/s”.

Mechanism of water transport is capillary absorption under the application of water head. The following equation proposed by Levitt (1970) for the Initial Surface Absorption Test (ISAT) was based on the mechanism of the viscous flow through fine capillary and is also applicable for this test.

$$y = at^{-n} \quad (1)$$

where,

y : instantaneous rate of water absorption at any time in ml/m²/s

t : time in seconds

n : coefficient regarding the reduction of rate of water absorption with passage of time

a : y-intercept: water absorption rate at 1 second

When Eq. (1) is plotted on a log-log scale a straight line is obtained with slope “ n ” and y-intercept “ a ” as shown in Fig.11. The value of “ a ” varies according to the quality of the surface concrete. It is observed that value of “ a ” is high for concretes with surface micro-cracking and is less for the concretes without micro-cracking. According to

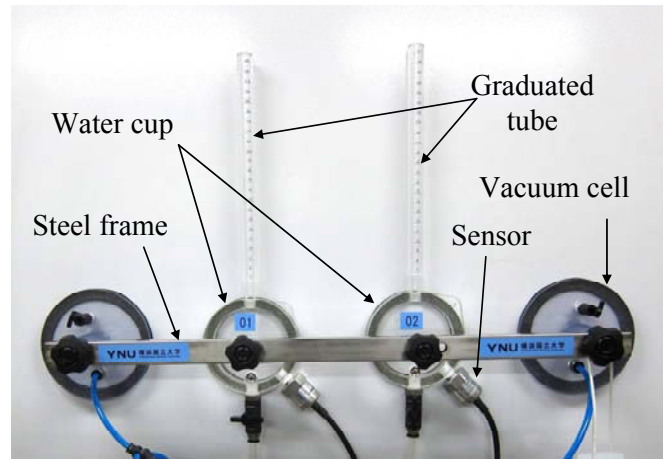


Figure 9 SWAT system

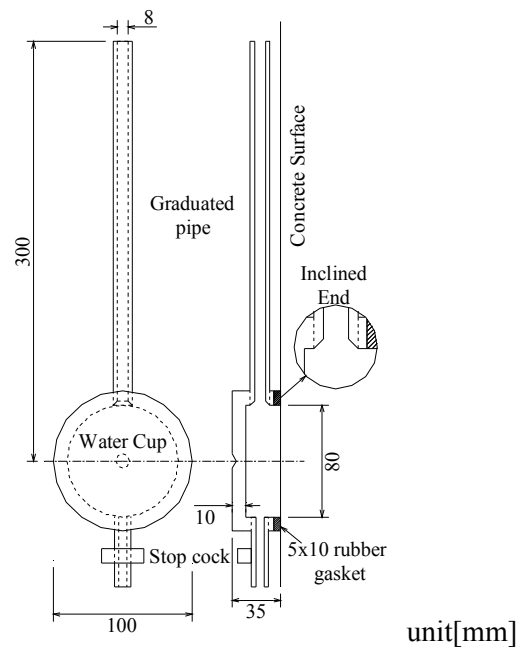


Figure 10 Details of water cup for SWAT

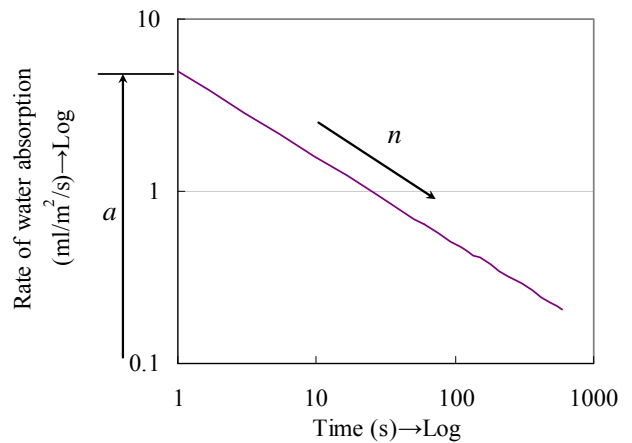


Figure 11 Water absorption rate obtained from SWAT

Levitt, the value of “*n*” varies between 0.3-0.7 (0.5±0.2). It has been realized that the value of “*n*” is related with the moisture content and the distribution of microstructure in depth direction from the surface. In addition to indices “*a*”, and “*n*”, another index “*WAF*10”, the instantaneous rate of water absorption in ml/m²/s at 10 minutes is also calculated from the test data. It represents the quality of concrete with some depth from the surface.

According to Dhir, et. al. (1987) only surface layer up to 10 to 15 mm can be tested by surface water absorption test. However, this depth can be sufficient to distinguish the materials and curing condition.

3.2 Outline of “Recommendations for Durability Design of Concrete Structures - Draft”

JSCE (1995) proposed “Recommendations for Durability Design of Concrete Structures -Draft” in 1995. This is really a unique way of durability design considering almost all the construction factors. In this system, durability point is calculated for each construction factor based on the method described in the recommendation.

In this durability design system, durability of a structures verified by confirming that Durability Index T_p , the total summation of durability points is larger than Environment Index S_p , which is decided considering environment conditions.

T_p consists from points in 8 groups;

- 1: design, member shape, reinforcement details, design drawing
- 2: thermal crack, flexural crack
- 3: special form, surface treatment
- 4: concrete materials
- 5: fresh properties of concrete
- 6: concrete construction
- 7: reinforcement work, form work, support work

8: specific matters about PC

In this research, the summation of points in group 4, 5, 6 are compared with SWAT results. This is because constructions factors in those 3 groups will be closely related with covercrete quality.

3.3 Investigated Covercrete Quality

Two box culverts in Yamaguchi prefecture were investigated with SWAT. The detailed information of the culverts are shown in Table 1. One culvert was constructed before the Yamaguchi system started. The other was constructed in the system. They were investigated at the same time in the end of 2011.

We should note that this culvert constructed before the system had the same kind of joint to cause cracks as used in the present system. This is because, when this culvert was constructed, some players were already taking care of controlling crack of culverts. Therefore, the authors think the quality of this culvert is not the typical one in terms of covercrete quality before the Yamaguchi system started.

Table 1 Information about box culverts

Name	Cement	W/C	Tested age	Number of measurement
before system	Slag cement	-	more than 5	34
Sesegawa	Slag cement	0.53	4 years 5-8	48

Figure 12 shows the investigation results with SWAT of the culverts. We have already verified that the distribution of water absorption rates at 10 minutes in limited conditions is closed to normal distribution. In Figure 12, each curve was shown with obtained average value and standard deviation assuming that normal distribution can be applied. Each box culvert has 6-8 blocks (1 block is around 10m length).

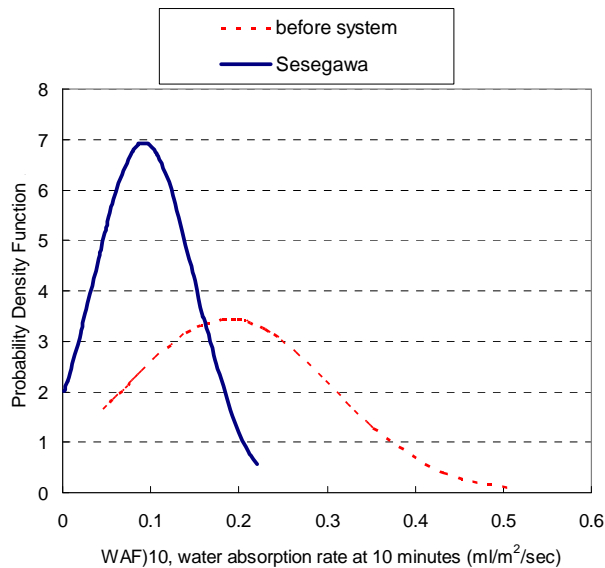


Figure 12 SWAT results for box culverts in Yamaguchi

Sesegawa box shows the smaller average value and smaller distribution, which shows good and stable quality. It was confirmed that Crack Control System was also effective to improve covercrete quality.

3.4 Correlation between water absorption rate and durability point

Figure 13 shows the relationship between water absorption rate at 10 minutes and summation of durability points calculated based on the reference (JSCE, 1995).

10 lifts of abutments and 2 blocks of box culverts were investigated. The average of water absorption rate at 10 minutes was calculated for each rot and used for Figure 13. Durability points were calculated utilizing Concrete Construction Data.

As described in 3.2, durability points in only 3 groups from 8 groups in total are used. In 3 lifts of abutment, expansive additive was used, however, 10 points by the usage of expansive additive were not added in this research, which showed higher

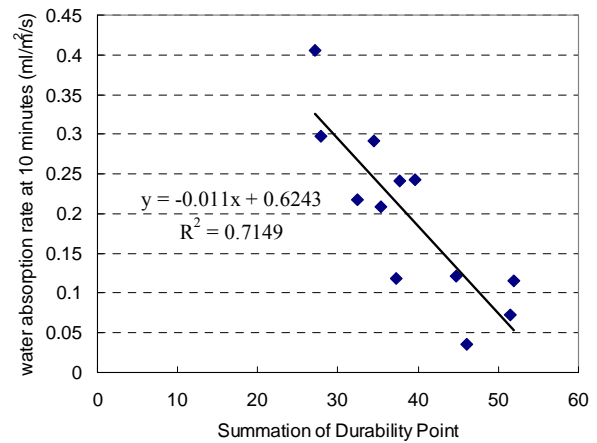


Figure 13 Relationship between SWAT results and durability points

correlation coefficient.

Figure 13 shows a large correlation coefficient R of 0.846. There is a possibility that we can analyze the effects of construction factors on covercrete quality utilizing this method.

4. CONCLUSIONS

In this research, Crack Control System developed by Yamaguchi prefecture in Japan was introduced. This is a good management system by cooperating works among all the players engaged in construction. Some results of actual structures were introduced to show the effectiveness of this system to control thermal crack. In this system, covercrete quality was also improved, which was verified by Surface Water Absorption Test (SWAT) developed by the authors.

The covercrete quality of structures were investigated by SWAT. Durability points were calculated for those structures utilizing Concrete Construction Data based on “Recommendations on Durability Design of Concrete Structures - Draft” by JSCE. Swat results and durability points showed good correlation. We will be able to analyze the

effects of construction factors on covercrete quality.

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