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Research on the Practical Use of a Construction Database for Preventing Cracks in a Concrete Structure

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ABSTRACT

Prevention of cracks in concrete is important in order to achieve long life of the structure and it is necessary to predict the formation of a crack at an appropriate stage before construction begins. In this paper, to prevent a crack forming in an abutment, analyzing past construction records is proposed. By analysis of a record database, the relationship of the crack width to the size of abutments (width, thickness, height), steel rod ratio, placing interval, the highest curing temperature of the concrete, and the number of cured days, was determined. In the case of bridge abutments, it was found that as the steel rod ratio increases, the width of crack decreases. Additionally, the boundary at which a crack does not form was established from the correlation between the size of the bridge and the crack width.

Keywords. Crack, Past concrete construction records, Database, Crack prevention

1. INTRODUCTION

In recent years, the deterioration of many concrete structures, built at a time of high economic growth, has begun to occur. Additionally, construction reliability is affected by defects in the structure resulting from a crack. If a crack is generated at an early stage it damages the facing and affects the durability of the structure. Even if these defects are repaired, it is expected that they would have an influence the long-term performance of the structure. Therefore, in order to prevent this negative impact on the functionality by early deterioration and to prolong the life of a structure, it is important to predict crack at an appropriate the stage before construction. Furthermore, when the occurrence of a problem is predicted, important countermeasures can be discussed and implemented. The cracks in concrete have been studied from the perspective of material characteristics and structure conditions, and are a fundamental problem in construction. As a result, the probability of crack formation is expressed as the crack index in temperature stress analysis. There are, however, still some problems in the accuracy of the analysis. Many new technologies have been developed for crack control, but this adds to production costs and because of this increased expense there has been a slow adoption of this new technology.

Empirical know-how about cracks in concrete has been accumulated on the construction site i.e. information about crack formation being controlled by curing or construction technology based on the experiences of the constructor. At a concrete construction site, however, the generation of an initial crack is still an important problem.

Engineers at the Yamaguchi prefecture engineered a system of countermeasures against cracks (Tamura, 2012). They constructed a database consisting of the records of past concrete construction at construction sites. This paper reports on the characteristics of a crack in an abutment from of the Yamaguchi prefecture's database.

2. CRACK PREVENTION SYSTEM AND DATABASE FROM THE YAMAGUCHI PREFECTURE

2.1. Outline of the System. The concept of the cracks countermeasure system with high quality of concrete structures from the Yamaguchi Prefecture is shown in Figure 1. The cracks countermeasure of structure is discussed from the design to construction phases in this system. All of the construction records are collected in a database. The method of the cracks countermeasure of a newly constructed structure is determined by analyzing this database. The system has a PDCA circle (Plan, Do, Check, Action) design incorporated.

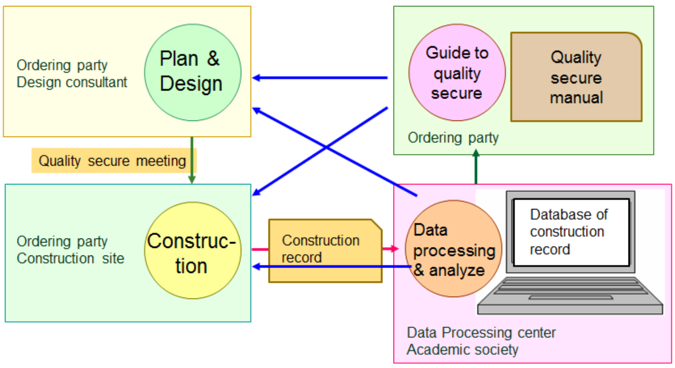

Figure 1. Concept of the crack prevention system from the Yamaguchi prefecture

2.2. Construction Records Database. The database of concrete construction at the Yamaguchi Prefecture was started in 2006. The data of about 1000 blocks is stored as of 2012. In the database records of concrete construction of various structures (bridge abutments, box culverts, retaining walls, and others) are recorded. An example of the information recorded in the database is shown in Figure 2, and consists of:

1) Information on the structure, including size, the amount of steel rods, etc.
2) Information on the concrete including mix proportioning, aggregate, manufacturer, etc.
3) Records of the concrete construction including construction organization, the curing method, the temperature change of the concrete, etc.
4) Crack occurrence

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Database of the crack prevention system

	Name of structure		Month	Type of structure			Size				Material				Reinforcing ratio(%)			Concrete			Maximum crack width(mm)	Reference number (PDF file)
	Name of structure	Member		Kind of structure	Structure	Lift No.	Height(m)	Thickness (m)	Length (Width) (m)	Joint distance (m)	Cement	Chemical agent	Additive	Reinforcing member	Final design	Initial plan	Counter measure	Comp. strength (N/mm²)	Initial temp.(℃)	Maximum temp. (℃)		
71	四十八瀬川橋	A2橋台	2月	RC	橋台	胸壁	1.3	0.5	10.1	−	高炉B種	AE減水剤	---	---	0.62	---	×	38.7	18.0	33.4	0.00	H18-A-908-04
72	国道2号高架橋（仮称）	A1橋台	4月	RC	橋台	たて壁①	2.7	2.2	20.3	−	高炉B種	AE減水剤	---	ガラス	0.21	---	○	35.7	18.0	62.2	0.10	H18-A-009-02
73	国道2号高架橋（仮称）	A1橋台	5月	RC	橋台	たて壁②	2.7	2.2	20.3	−	高炉B種	AE減水剤	---	ガラス	0.21	---	○	31.6	21.0	69.3	0.03	H18-A-009-03
74	国道2号高架橋（仮称）	A1橋台	6月	RC	橋台	たて壁③	2.5	2.2	20.3	−	高炉B種	AE減水剤	---	ガラス	0.21	---	○	35.6	25.0	71.5	0.10	H18-A-009-04
75	国道2号高架橋（仮称）	A1橋台	6月	RC	橋台	胸壁①	2.2	0.5	20.3	−	高炉B種	AE減水剤	---	ガラス	0.32	---	○	36.8	27.0	55.4	0.20	H18-A-009-05
76	国道2号高架橋（仮称）	A1橋台	7月	RC	橋台	胸壁②	2.2	0.5	20.3	−	高炉B種	AE減水剤	---	ガラス	0.32	---	○	38.3	22.5	50.6	0.25	H18-A-009-06
77	国道2号高架橋（仮称）	A2橋台	12月	RC	橋台	たて壁①	2.7	1.7	25.0	−	高炉B種	AE減水剤	---	補強鉄筋A	0.33	0.19	○	32.4	13.0	52.0	0.06	H18-A-010-02
78	国道2号高架橋（仮称）	A2橋台	12月	RC	橋台	たて壁②	2.1	1.7	25.0	−	高炉B種	AE減水剤	---	補強鉄筋A	0.37	0.19	○	31.8	12.5	49.5	0.04	H18-A-010-03
79	国道2号高架橋（仮称）	A2橋台	2月	RC	橋台	たて壁③	2.5	1.7	25.0	−	高炉B種	AE減水剤	---	補強鉄筋B	0.48	0.19	○	32.6	11.0	50.4	0.10	H18-A-010-04
80	国道2号高架橋（仮称）	A2橋台	2月	RC	橋台	胸壁	2.2	0.5	25.0	−	高炉B種	AE減水剤	---	補強鉄筋B	0.64	0.32	○	33.5	11.0	30.0	0.20	H18-A-010-05
81	松坂橋	A1橋台	2月	RC	橋台	たて壁①	1.7	2.0	11.5	−	高炉B種	AE減水剤	膨張材	---	0.19	---	○	37.7	11.0	56.7	0.10	H18-A-011-01
82	松坂橋	A1橋台	3月	RC	橋台	たて壁②	3.5	2.0	11.5	−	高炉B種	AE減水剤	膨張材	---	0.19	---	○	38.7	12.0	46.5	0.35	H18-A-011-02
83	松坂橋	A1橋台	4月	RC	橋台	たて壁③	3.5	2.0	11.5	−	高炉B種	AE減水剤	膨張材	---	0.19	---	○	36.3	16.0	65.9	0.15	H18-A-011-03
84	松坂橋	A1橋台	4月	RC	橋台	たて壁④	1.7	2.0	11.5	−	高炉B種	AE減水剤	膨張材	---	0.19	---	○	33.9	19.0	60.3	0.00	H18-A-011-04
85	松坂橋	A1橋台	5月	RC	橋台	胸壁	2.0	0.5	11.5	−	高炉B種	AE減水剤	膨張材	---	0.32	---	○	36.3	23.0	52.9	0.03	H18-A-011-05
86	松坂橋	A2橋台	5月	RC	橋台	たて壁①	1.8	2.0	11.5	−	高炉B種	AE減水剤	---	補強鉄筋A	0.13	0.08	○	38.2	22.0	65.3	0.30	H18-A-012-03
87	松坂橋	A2橋台	6月	RC	橋台	たて壁②	3.6	2.0	11.5	−	高炉B種	AE減水剤	---	補強鉄筋A	0.1	0.08	○	38.2	28.0	70.8	0.20	H18-A-012-04
88	松坂橋	A2橋台	7月	RC	橋台	たて壁③	2.0	2.0	11.5	−	高炉B種	AE減水剤	---	ガラス	0.07	---	○	38.9	26.0	70.3	0.10	H18-A-012-05
89	松坂橋	A2橋台	7月	RC	橋台	胸壁	2.0	0.5	11.5	−	高炉B種	AE減水剤	---	ガラス	0.32	---	○	34.3	28.5	59.1	0.15	H18-A-012-06
90	金田ため池橋	本線A1橋台	3月	RC	橋台	たて壁①	5.4	2.0	11.6	−	高炉B種	AE減水剤	---	補強鉄筋A	0.21	0.19	○	37.6	11.0	58.2	0.04	H18-A-013-02
91	金田ため池橋	本線A1橋台	7月	RC	橋台	たて壁②	4.6	2.0	11.6	−	高炉B種	AE減水剤	膨張材	---	0.19	---	○	35.6	28.0	73.6	0.15	H18-A-013-03
92	金田ため池橋	本線A1橋台	7月	RC	橋台	胸壁	3.3	0.6	11.6	−	高炉B種	AE減水剤	膨張材	---	0.28	---	○	33.9	31.0	63.5	0.15	H18-A-013-04
93	金田ため池橋	BランプA1橋台	4月	RC	橋台	たて壁①	5.4	1.9	8.0	−	高炉B種	AE減水剤	---	補強鉄筋A	0.25	0.20	○	35.4	15.0	55.2	0.00	H18-A-014-02
94	金田ため池橋	BランプA1橋台	6月	RC	橋台	たて壁②	4.2	1.9	8.0	−	高炉B種	AE減水剤	---	補強鉄筋B	0.24	0.20	○	35.2	27.0	68.9	0.10	H18-A-014-03
95	金田ため池橋	BランプA1橋台	7月	RC	橋台	胸壁	3.0	0.6	8.0	−	高炉B種	AE減水剤	---	アラミド	0.65	---	○	31.7	25.0	52.0	0.04	H18-A-014-04
96	金田ため池橋	本線A2橋台	2月	RC	橋台	たて壁①	5.0	2.0	12.6	−	普通	AE減水剤	---	---	0.19	---	×	35.5	13.0	58.0	0.20	H18-A-003-02
97	金田ため池橋	本線A2橋台	5月	RC	橋台	たて壁②	4.8	2.0	12.6	−	普通	AE減水剤	---	---	0.19	---	×	33.8	20.0	66.6	0.20	H18-A-003-03
98	金田ため池橋	本線A2橋台	6月	RC	橋台	胸壁	3.1	0.6	12.6	−	普通	AE減水剤	---	---	0.27	---	×	34.9	28.0	61.5	0.25	H18-A-003-04
99	金田ため池橋	BランプA2橋台	3月	RC	橋台	たて壁①	4.5	1.9	8.0	−	高炉B種	AE減水剤	---	アラミド	0.2	---	○	37.6	8.9	48.6	0.00	H18-A-015-02
100	金田ため池橋	BランプA2橋台	5月	RC	橋台	たて壁②	5.0	1.9	8.0	−	高炉B種	AE減水剤	---	アラミド	0.2	---	○	32.6	23.0	65.4	0.10	H18-A-015-03
101	金田ため池橋	BランプA2橋台	7月	RC	橋台	胸壁	2.2	0.6	8.0	−	高炉B種	AE減水剤	---	アラミド	0.27	---	○		23.0	55.1	0.10	H18-A-015-04
102	金田ため池橋	CランプA2橋台	2月	RC	橋台	たて壁①	4.0	2.0	8.2	−	高炉B種	AE減水剤	---	ガラス	0.23	---	○	36.8	13.0	51.7	0.00	H18-A-016-02
103	金田ため池橋	CランプA2橋台	5月	RC	橋台	たて壁②	3.6	2.0	8.2	−	高炉B種	AE減水剤	---	ガラス	0.23	---	○	35.1	20.0	60.2	0.15	H18-A-016-03

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Figure 2. Database of the crack prevention system from the Yamaguchi prefecture (in Japanese)

3. ANALYSIS OF BRIDGE ABUTMENTS

3.1. Analysis of Bridge Abutment Data. The parameters for the abutments of a bridge length wall (foundation not included) used for analysis is shown in Table 1.The number of data samples is 165 in total, here one placing block is counted with one data. The crack survey was conducted about one month after the concrete was poured.

Table 1. The range of data from bridge abutments analyzed

Size of abutment (m)						Reinforcing ratio (%)		Temperature change*1) (℃)		Concrete placing interval (day)		Mold installation term (day)	
Height		Thickness		Length(Width)									
Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
0.6	5.4	0.5	3.0	3.1	25.0	0.04	0.64	5.0	49.9	3	104	2	74

*1) Maximum temperature-initial temperature of concrete

3.2. Relationship between the maximum width in the abutments and steel ratio. Figure 3 shows the relationship between the maximum width of a crack generated in abutments and the steel ratio. It is obvious that the crack width decreases as the steel rod ratio increases. Generally a crack of 0.2 mm or less is considered harmless. In order for the crack width to be 0.2 mm or less, Figure 3 indicates that it is necessary to have a steel rod ratio of 0.4% or higher.

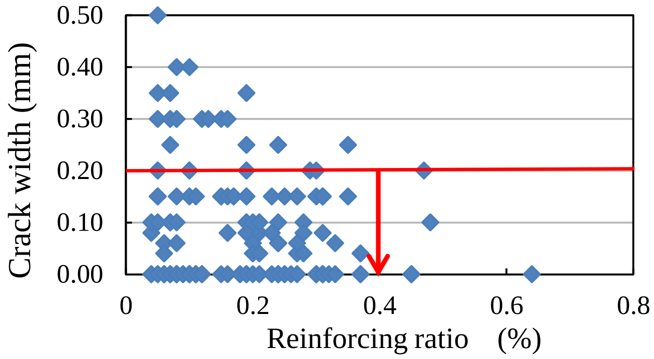

Figure 3. Relationship between the maximum crack width and steel ratio

3.3. Relationship between the maximum crack width and the size of abutments.

Figures 4-6 show the relationship between the size of one block of the abutments (height, width, and length) and the maximum crack width. From analysis of these figures the following can be confirmed:

- At a height block of 1.5 m or less a crack is not formed (zone (A) in Figure 4). - At a height block of 2.5 m or less a crack of 0.3 mm or less is generated (zone (B) in Figure 4).
- At a thickness of 0.5 m or less a crack is not formed (zone (C) in Figure 5).
- At a thickness of 1.3 m or less no cracks over 0.2 mm are generated (zone (D) in Figure 5).
- A crack is not generated when the abutment length (width) is 6.0 m or less (zone (E) in Figure 6).
- A crack of 0.2 mm or less forms when the length (width) of the abutment is 9.2 m or less (zone (F) in Figure 6).

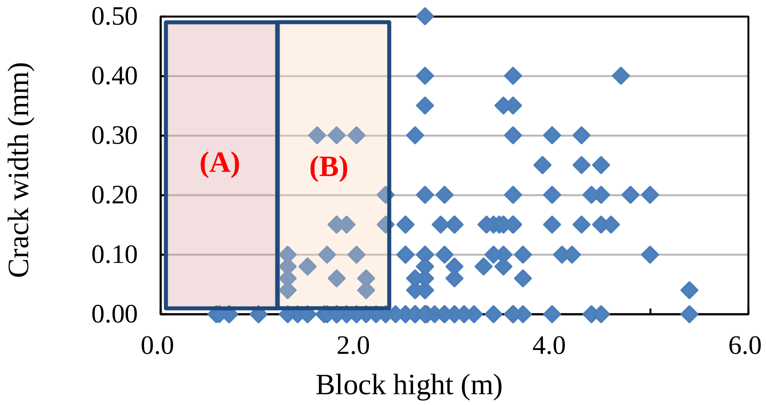

Figure 4. Relationship between the maximum crack width and abutment height of one block

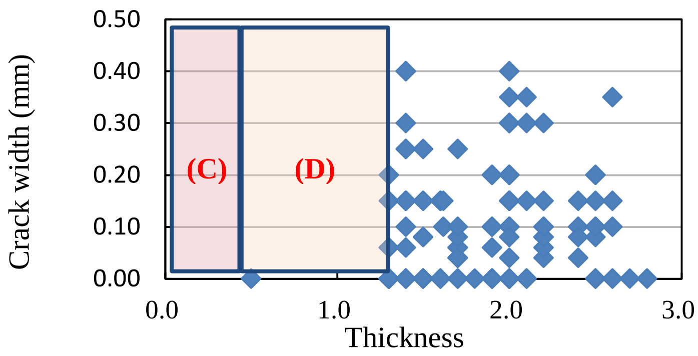

Figure 5. Relationship between the maximum crack width and abutment thickness

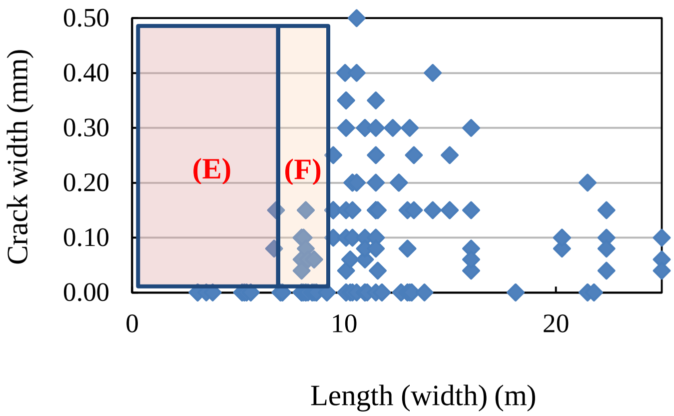

Figure 6. Relationship between the maximum crack width and abutment length/width

3.4 Relationship between the maximum crack width and the temperature change. Figure 7 shows the relationship between the temperature change and the maximum crack width. The temperature is change is the initial temperature at the time the concrete is poured subtracted from the maximum temperature generated by the heat of hydration during concrete hardening.

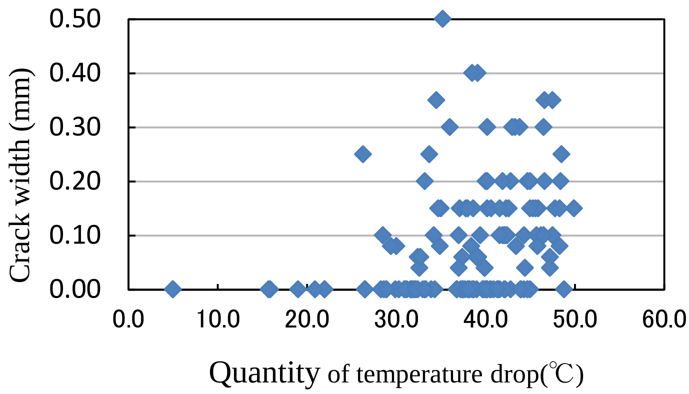

Figure 7. Relationship between the maximum crack width and the temperature change

Figure 7 shows that the maximum crack width increases as the temperature change increases. When the temperature change is 34 ^{O}C or less, however, the crack formed is less than 0.2 mm.

3.5 Relationship between the maximum crack width and the concrete placing interval. Figure 8 shows the relationship between the placing interval and the maximum crack width. If the interval of construction of the block placed previously and the block newly placed opens, the elastic coefficient of the concrete placed previously will become high, and the degree of restraint to the concrete placed newly will become high. Therefore, crack width increases as the placing interval increases. When the placing interval is 15 days or less, however, the crack width is 0.2 mm or less.

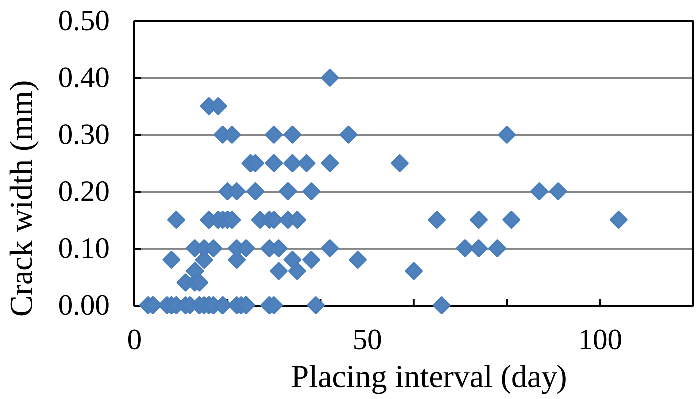

Figure 8. Relationship between the maximum crack widths and the placing interval

3.6 Relationship between the maximum crack width and the mold installation time. Figure 9 shows the relationship between mold installation time and the maximum crack width. The mold also performs the function of curing, so there is a tendency for the maximum crack width to become smaller as mold setting time increases. When the mold installation time is less than six days, the crack width is 0.2 mm or less (apart from one outlier in the data).

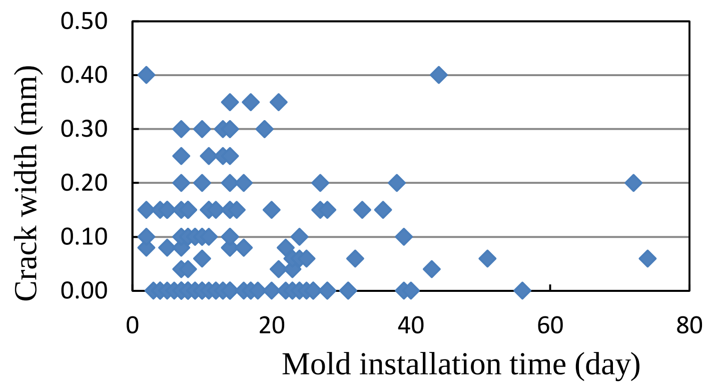

Figure 9. Relationship between the maximum crack width and the mold installation time

4. CONCLUSIONS

The concrete cracks in bridge abutments were analyzed using a database of past construction records. This analysis indicates the following:

1) Crack width decreases as steel ratio becomes increases. In order for the crack width to be 0.2 mm or less (at this size it is considered harmless), it is necessary to have a steel rod ratio of 0.4% or more.
2) The boundary conditions for crack occurrence can be correlated to the size (block height, thickness, length, or width) of a structure.
3) The maximum crack width increases as the temperature change during hardening increases. Generally, a temperature change of 34 ^{O}C or less forms cracks of 0.2 mm or less.
4) Crack width increases as the placing interval increases. When the placing interval is 15 or less days, the crack width is 0.2 mm or less.
5) There is a tendency for the maximum crack width to become smaller as mold setting time increases. When the mold installation time is less than six days, the crack width is 0.2 mm or less (apart from one outlier in the data).

By taking these relationships into account and by judicious selection of assembly conditions, concrete structures can be made to have only innocuous cracks.

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