Control of Thermal Cracking due to Heat of Cement Hydration

- Verification method by past construction experience -

1. Control of Thermal Cracking in JSCE Standard Specification-2012

(1) Outline of verification related to thermal cracking

Thermal cracks in concrete structures are harmful for durability and serviceability. Therefore, it shall be verified that thermal cracks in a structure do not affect the required performance of the structure. However, the control of thermal cracks is not easy because the occurrence of thermal cracks and the crack width are affected by many factors: environmental conditions, shape and dimension of the structure, reinforcement, construction method, and the mix proportions of concrete. For instance, it is difficult to uniformly determine the dimensions of structural members that should be treated as mass concrete structures due to concern about the possibility of cracking due to the hydration of cement, as they vary depending on the type of structure, materials used, and construction condition. In the 2012 JSCE Standard Specification, as a rule of thumb, a relatively large slab having a thickness of 80 to 100 cm or more, and a wall with a restrained bottom having a thickness of 50 cm or more, may be considered as mass concrete structures. If, however, rich mix concrete is used, as in the construction of prestressed concrete structures, a thinner member may need to be treated as mass concrete structure depending on the restraint conditions.

In the 2012 JSCE Standard Specification, two verification methods for thermal cracking are described. **Figure 1** shows the flowchart for verification related to thermal cracking. If it is difficult to determine the occurrence of thermal

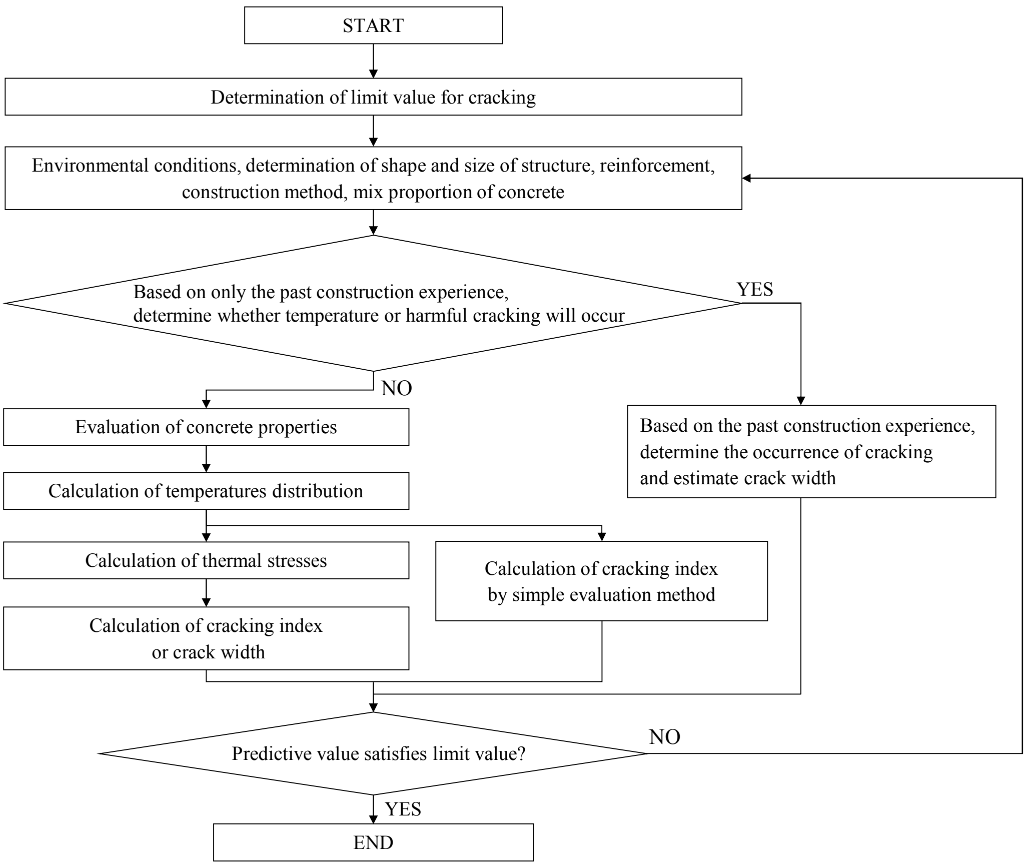

Fig.1 Flowchart for verification related to thermal cracking

cracks based only on the past construction experience, a thermal stress analysis shall be carried out [1]. It should be noted that the verification method for thermal cracks is not necessarily limited to these two methods. A combination of past construction experience, advanced analysis, and a simple evaluation method can be more effective. If improvement of the prediction accuracy and convenience is expected, the verification method should probably be modified.

(2) Verification method by construction experience

Thermal cracking is sensitive to the effects of the construction conditions and the environment. Therefore, in some cases, the evaluation based on actual construction experience can be more reliable than that based on an advanced numerical analysis. In cases where many structures of the same type are constructed, such as in the construction of a reinforced concrete viaduct, verification may be omitted if it is know from past construction experience that the cracks occurring at the construction stage do not affect the required performance of the structure. It should be noted that the verification by past construction experience is not the subjective evaluation depending only on the experience and intuition of a designer and an engineer, but the objective evaluation by specific evidence, such as previous construction records.

In recent years, database technologies have developed rapidly. It is expected that various prediction techniques will be established using databases. Yamaguchi prefecture, one of the local governments in Japan, started coordinating work among the local government, private companies, and academic institutions to control thermal cracks, and established the crack control system. The characteristic of this crack control system is to prepare countermeasures based on the database of the construction data, which are records of the actual concrete construction. In the next chapter, the outline of collecting and utilization methods of the database in this crack control system is introduced as one example of the verification method based only on the past construction experience.

2. Introduction of Crack Control System in Yamaguchi Prefecture

(1) Outline of crack control system

The crack control system in Yamaguchi prefecture was officially started in 2007. At present, the purpose of this system has become to ensure the quality of concrete surface based just on the control of cracks. The target structure in this system is RC and PC structures. For further details, please refer to previous articles [2][3].

This crack control system has three pillars, as shown in **Figure 2**: (i) appropriate construction period, (ii) achievement of appropriate concrete construction, and (iii) appropriate material measures.

As shown in **Figure 3**, the ratio of cracking was higher when placing of concrete was conducted in summer season (from around May to Sep.), in the end of year (Dec.), and in the end of Japanese business year (Mar.). Therefore, as the first pillar of this system, the appropriate construction schedule is considered in the design and order stages, and precise scheduling is carried out for the construction stage considering crack control.

The second pillar of the crack control system is to achieve the appropriate concrete construction. Since it was not easy to achieve a condition following the standard specifications in all the sites, Yamaguchi prefecture developed the check sheet to grasp the construction conditions as one of the components in the systems. Inspectors of Yamaguchi prefecture use this sheet to check construction conditions. The format of the check sheet is available on the web site of Yamaguchi prefecture [4]. Important checking items from the standard specifications are shared to the contractors and inspectors, which can lead to the improvement of construction conditions. Almost all the information, including the concrete construction data, is opened, which can contribute to improving the motivation of the stakeholders engaged in this system.

The third column of the crack control system is to take appropriate material measures to control cracking. As mentioned above, some cracks could not be kept as harmless, even when appropriate construction was conducted. In these cases, appropriate material measures should be considered in the design stage based on accumulated construction results. In the case of side walls in box culverts, Yamaguchi prefecture recommends to set an appropriate number of joints considering the season of concrete placing. In the case of vertical walls in abutments, adding reinforcing bars to control the crack width has to be the first priority. In the case of thin parapet walls in abutments, in addition to adding reinforcing bars, the usage of expansive additive will also be considered.

The crack control measures manual is currently summarized based on the construction results. The material measures adopted in actual construction are recorded along with cracking conditions in the concrete construction data. In this system, the effects of material measures are verified and recorded. As shown in **Figure 4**, the effects of material measures are verified and the obtained knowledge is fed back to manuals, designs, and construction.

(2) Improvement of construction conditions

Total results of the check sheet to grasp construction conditions are summarized in **Figure 5**. This figure indicates that the number of lots without instructions for improvement is increasing. After the 2nd half of 2008, approximately 90% of

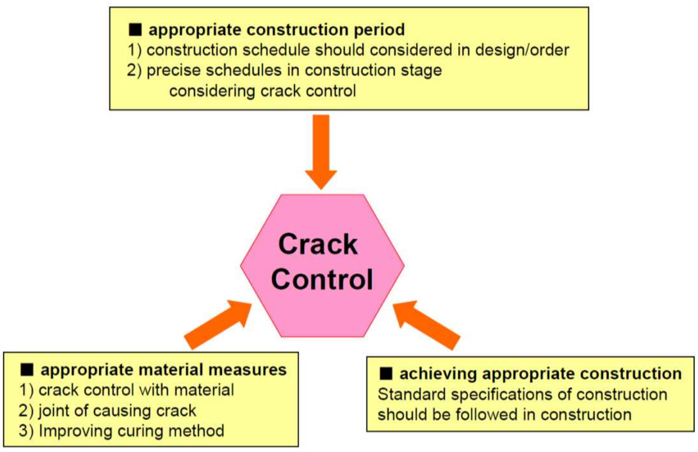

Fig.2 Three columns of crack control system[3]

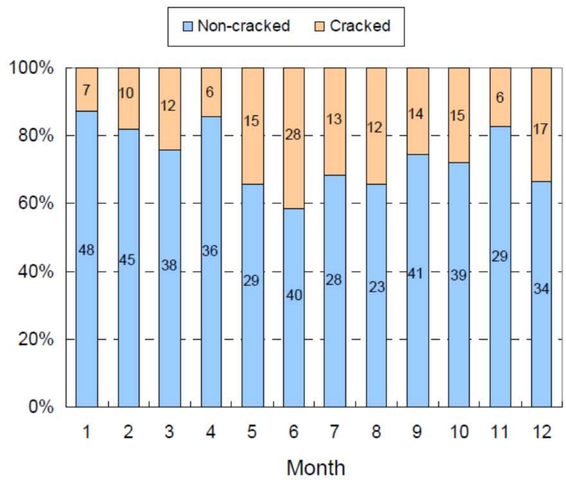

Fig.3 Cracking ratio in each month[3]

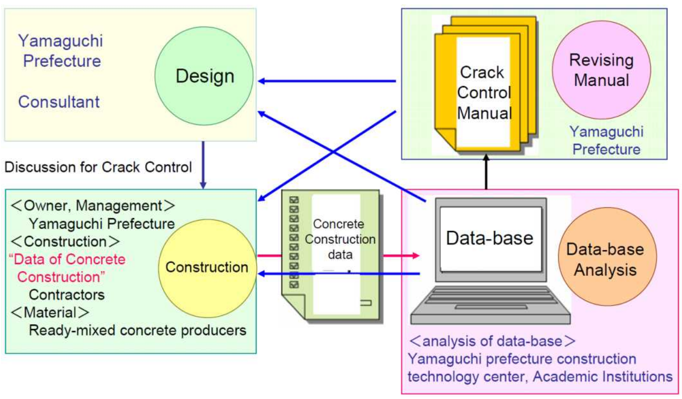

Fig.4 PDCA cycle of Crack Control System in Yamaguchi prefecture[3]

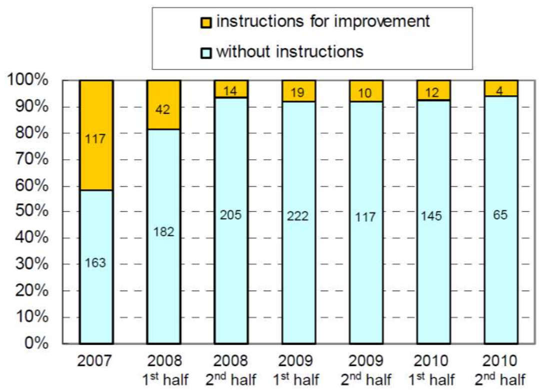

Fig.5 Ratio of construction lots with / without instructions for improvement from inspectors[3]

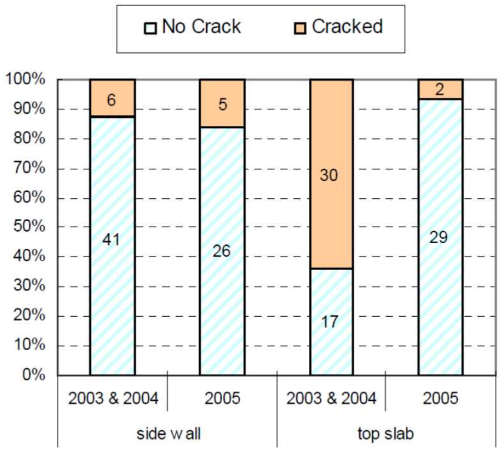

Fig.6 Cracking ratio of box culverts[3]

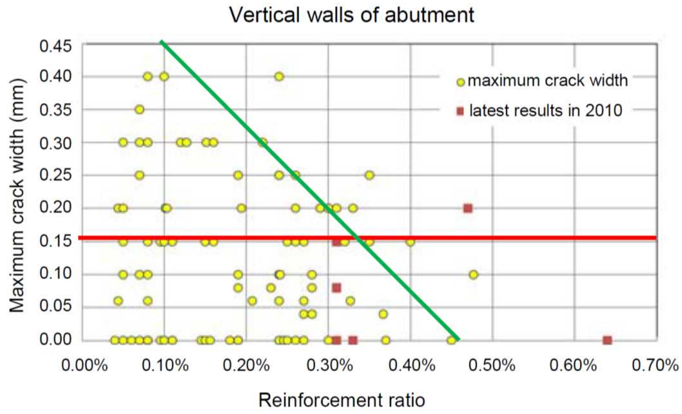

Fig.7 Effect of reinforcing bars on crack control in abutment[3]

the total lots did not require instructions from inspectors to improve the conditions of construction. This simple type of check sheet can be utilized in concrete construction to achieve appropriate construction. The crack control system has shown good results in controlling cracking. **Figure 6** shows the ratio of non-cracked and cracked members of box culverts. Just after the testing of construction started in 2005, longitudinal non-penetrated cracks on the bottom of top slabs were reduced drastically. Two lots with cracks were tested with welded wire mesh and FRP sheet. In all of the other 29 lots, no cracks were observed without any special material measure. These longitudinal cracks in top slabs can be regarded as the cracks derived from poor construction. **Figure 7** shows the effects of reinforcing bars on crack control in vertical walls of abutments. The cracks in abutments are not recognized as the crack derived from poor construction. Therefore, reinforcing bars should be added to control crack width. Yamaguchi prefecture set 0.15 mm as the crack width criteria for judging penetrated cracks as harmful. Therefore, from these results, the reinforcement ratio should be larger than 0.30%.

3. Summary

The control of thermal cracks is not easy work because the occurrence of thermal cracks is caused by many factors. In some cases, the evaluation based on previous construction records can be more reliable than based on an advanced numerical analysis. This report introduced the verification method by the past construction experience in the 2012 JSCE Standard Specification and the crack control system in Yamaguchi prefecture. In recent years, database technology has been developed. It is expected to lead to the establishment of various prediction techniques by using databases in the future.

References

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