

Study on Cracks in Concrete Structures and the Database

Hongke Pan*, Ling Pi

School of Building Engineering, Xin Yu University, Xinyu City, Jiangxi Province, 338004, China

*Corresponding author's e-mail: panhk_sh@163.com

Abstract. Because of its material properties and low tensile strength, concrete structure has its inherent properties: structure is easy to crack, and even many times it is working with cracks. On the basis of extensive investigation, it is analyzed and summarized about the mechanism of cracks in concrete structures, the manifestation forms and occurrence characteristics and laws of various cracks this paper. Then a crack database is tried to establish to seek and summarize the relationship and laws between the types of cracks and the forms of crack distribution, so as to provide references and helps for quick inquiry, judgment and scientific prevention and control about cracks in engineering, and ultimately to improve the durability and service life of the structures.

1. Introduction

Cracks problem in various engineering construction process has attracted more and more attention of builders and researchers, which also play an important role in disease research. Many scholars have done a lot of research on cracks in concrete structures. *Wang T.M.* put forward the principle of "Resistance and release" for crack control [1]. In view of shrinkage crack of concrete structure, *Zhang Q.F.* combined with experience and experimental research analyzing the causes of concrete cracks and their influencing factors, and putting forward control measures of concrete structure shrinkage cracks [2]. *Shi M.Z.* put forward a kind of crack control method for prestressed concrete structures based on nominal tensile stress method [3]. *Dou Y.M.* et al. did the three-dimensional finite element simulation of early crack propagation in pavement based on the theory of linear elastic fracture mechanics, and investigated the effects of crack depth, overload and temperature on crack propagation [4]. *Yao J.T.* et al. systematically analyzed the reliability of crack control of concrete members under various conditions with non-dimensional form [5]. *Chen C.* et al. formulated scientific and reasonable treatment measures aiming at the second lining crack in a tunnel construction by methods of field investigation, analysis and summary, modeling and calculation [6].

During the investigation and study, our research group also found and summarized various forms of cracks, including regular, irregular, deep, shallow, basically appearing in the structure of the larger stress surface or stress points, such as both ends at beam and column, large concrete surface layer, tension zone at torsional members, shear Areas and vibrant parts.

To sum up, more research has been done on cracks in concrete structures and fruitful results have been achieved, but there is still a lack of systematic description and induction of various cracks, analysis of deep-seated causes of cracks, quantitative research on the impact of cracks on structural mechanical properties and systematic and scientific conclusion on prevention measures of various cracks. In addition, we have not established a powerful database which can describe and reflect the corresponding relationship between the various characteristics of cracks in various structures and their



internal and external causes. Therefore, some of the current protection and repair methods are often not cured radically, and ultimately it is difficult to effectively root out the cracks. "cure then appearance; the more treatment, the worse". To solve this problem fundamentally, it is necessary to have an objective and accurate analysis on the internal factors of cracks, analyzing the causes of cracks from angles of mechanics, structure and environmental characteristics and others, and establishing links and laws; putting forward prevention and repair plan according to the real internal reasons for cracks.

2. Forms and causes of cracks in concrete structures

The reasons for the formation of concrete cracks are very complex, and their performance is inequable in different structures. On the basis of a large number of field investigations and data collection, this paper considers that the cracks in concrete structures mainly include temperature cracks, shrinkage cracks, settlement cracks, load cracks and construction cracks. The following are a brief description of the forms and causes of these cracks.

2.1. Shrinkage cracks

Shrinkage cracks include two types: dry shrinkage crack and plastic shrinkage crack. Dry shrinkage cracks are caused by varying degrees of evaporation of water inside and outside the concrete. They are usually shaped by irregular hairline cracks on the surface of the component or cracks thin at both ends and wide at the middle (often between two bars and parallel to the bars). Plastic shrinkage cracks are mainly caused by the shrinkage stress exceeding the ultimate tensile strength of concrete due to high temperature or large wind force. Dry shrinkage cracks and plastic shrinkage cracks often occur before concrete final solidification.

2.2. Temperature cracks

Temperature cracks are more obvious in mass concrete structures, and the cracks are often deeper or even penetrating, which will cause great damage to the whole structure. For a member whose dimension in one direction is much larger than that in the other two directions, the crack direction is mainly perpendicular to the long side, and the cracks appear along the full-length section, with the middle dense; for the large-volume (three-dimensional) structure, there is no obvious law of cracks. The crack width does not change much along the full length. The width of cracks is affected more obviously by the temperature change: wider in winter and thinner in summer. Along the height of the cross-section, cracks are mostly in the shape of upper width and lower narrowness, but some cracks are also in the shape of jujube nucleus.

2.3. Load cracks

This is the most complex and common cause of cracks. The characteristics of cracks vary with loads. Theoretically, all kinds of stress forms such as tension, compression, bending, shear and torsion can produce corresponding crack forms; but generally, such cracks appear more in the tension zone, eccentric compression zone (bending zone), shear zone or the parts with larger cyclic load. For example, the cracks produced by the central tension penetrate the cross section of the member, and the space is approximately equal, and they are perpendicular to the stress direction; the bending area or (large) eccentric compression area generally appears cracks perpendicular to the tension direction starting from the edge near the maximum bending moment section, and gradually develop to the neutral direction; the shear area may develop oblique compression failure or shear compression failure, and oblique cracks more than 45 degrees along the beam end and abdomen will occur during oblique compression failure. In addition, short and dense cracks parallel to the stress direction may appear when the center compression is too large.

2.4. Construction cracks

Construction cracks refer to the cracks caused by unreasonable construction technology, wrong sequence or poor construction quality in the process of concrete structure pouring, manufacturing,

formwork support, transportation, hoisting and other construction. The shape, trend and development of cracks vary according to concrete improper construction factors, such as surface or shallow cracks easily caused by improper early curing of concrete; cracks perpendicular to the stressed steel bar may be formed by surface pollution, too small or too large protective layer; the lack of stiffness of the formwork during construction causes deformation, which is easy to form cracks consistent with the deformation of the mould.

2.5. Settlement cracks

The cracks formed mainly due to the uneven settlement of the foundation have various shapes, some are still in a period of change, and the crack width is generally large, sometimes up to several centimeters. Cracks are mainly divided into shear cracks and flexural cracks according to their stress forms. The common cracks are the eight-character shape cracks and oblique cracks on the wall. Settlement cracks often occur in the lower part of the building, and the cracks on the bottom are larger than the upper ones.

3. Mechanics analysis of structures

Among the analyses of the causes of cracks in the upper section, it is very important to analyze the mechanism of the structure at the mechanical level, including the mechanical analysis of the whole and local structure. Further explanation is given below.

Concrete structures are subjected to various loads during construction and service, and various internal forces and deformations will inevitably occur within the structure. If the strength or stiffness of the structure is insufficient, various damage deterioration phenomena, including cracks, may occur on the surface or inside the structure. Therefore, after a detailed analysis of the structure environment and the establishment of the structure of the overall or local mechanical model, we can do the mechanics analysis of the structure in various working conditions, and judge, interpret or predict structural cracks, furthermore we can put forward a scientific treatment program. Especially for some projects with a long history, the design process was mostly based on the approximate calculation of plane problems, and the geometry and mechanics model used to do numerical calculation were not established. The analysis results can play an important role in eliminating the various structural and mechanical causes leading to cracks. For example, through mechanical analysis, it can be found that the eccentric compression zone, tensile stress zone, stress concentration zone, overload zone, bending, shearing and torsion complex stress zone, or other improper design or conditions change place, take reasonable measures.

4. Repair and protection measures for cracks in concrete structures

With a clear understanding of the causes and manifestations of cracks, we can carry out scientific repair and take protection measures. The construction management of concrete structure should be strengthened to avoid or reduce the occurrence of concrete cracks. For the existing cracks, we should carefully analyze their causes and development laws, distinguish between harmful cracks or harmless cracks, and treat the harmful cracks scientifically.

The common repairing measures for structural cracks include surface treatment, grouting, filling and structural reinforcement. Among them, surface treatment is mainly aimed at the surface cracks or very small cracks which are difficult to be filled into the slurry. These cracks are generally stable or self-healing, so only needing surface treatment generally. The grouting method is mainly applicable to reparation of concrete cracks which have an impact on the structure integrity or have anti-seepage requirement. Filling method is generally aimed at thick cracks or cracks that grouting method is difficult to achieve the effect. Filling materials can be directly filled into the cracks. Structural reinforcement method mainly aims at the situation that cracks need to be reinforced due to insufficient or decreasing structural strength. The reinforcement measures mainly include cross-section reinforcement method, adhesive steel reinforcement method, embedded steel method, injection-anchor method, carbon fiber reinforcement method, prestressed method and so on.

For the above-mentioned five types of cracks, we can take corresponding protective measures according to their causes and characteristics to avoid or reduce the harm. For example, for load cracks, accurate design and calculation should be guaranteed to ensure the quality of raw materials and components (structures) procurement and construction, to avoid their strength or stiffness can not meet the requirements. For construction cracks, the construction process should be strictly operating procedures, reasonable construction sequence and progress, especially the concrete pouring, vibration, maintenance, demoulding and other links.

5. Engineering example analysis

A highway tunnel was designed as multiple-arch tunnel, with 255 meters long and the maximum buried depth 63 meters. The surrounding rock is gray, cinnamon sandstone or mudstone, with joints and cracks development, displaying gravel-like by strong weathering. The down-line of the tunnel was constructed firstly. There were different size cracks on the side wall and mid-board of the second lining having been done when excavating the up-line, particularly in the tunnel entry and export, and the cracks still developed and changed. The cracks have different shapes, including vertical, inclined, longitudinal, several cross-shaped, X-shaped, and some larger cracks consisted of a group of small slashes, most of which show a clear shear fault distribution.

5.1. Cracks monitoring data

Twenty-two representative crack measuring points were laid on the spot. The monitoring data show that the cracks in different locations of the tunnel present different changes and developments. Due to the adoption of certain emergency measures, the overall change is not significant. Limited to space, only a few points are selected here to record their characteristics and trends. See Table 1.

Table 1 Arrangement of cracks measuring points and cracks characteristics in tunnel

number	position	attitude and characteristics	Overall change in crack width	Volume of change in crack width			
				Positive maximum (mm)		Negative maximum (mm)	
S2	down-line K259+849 middle wall	The upper part leans out of the hole and the lower part stands upright. width 0.5-1mm.	Slightly fluctuating	0.2570		-0.1860	
S8	down-line K259+816 middle wall	Close to upright, narrow upper and lower width, terminated in upper part of middle wall, maximum width 8mm	Variation, overall slightly reduced	0.4193		-0.1467	
S12	up-line K259+831 middle wall	Vertical, open 0.6 mm, and 2.8mm (top)-4mm (bottom) outward on the right side.	Fluctuating, slightly increased	radial	axial	radial	axial
				0.5812	0.6950	zero	zero
S16	up-line K259+805 middle wall	Nearly upright, with wide upper part (7mm) and narrow lower part (4mm)	overall slight decrease	zero		-1.2570	
S18	down-line K259+636 side wall	Nearly horizontal, wavy, 0.5 to 2mm wide	Relatively stable	0.2870		-0.1440	
S21	down-line K259+785 middle wall	Near erect, wavy, 1 to 2mm wide	Slightly fluctuating	0.9962		zero	

5.2. Cause analysis of cracks

The tunnel's cracks occur after a long period of time when the second lining of the down-line is completed and after unloading and disturbance of the up-line construction. From the description of the cracks characteristics, it is precisely due to the existence of shear cracks caused by the bias and sliding of the high slope and the resulting uneven force. According to the statistics and development trend of

monitoring items, the deformation of tunnel is obviously controlled after adopting the balanced eccentric pressure methods, and monitoring data of soil pressure in the field monitoring section also show the existence of larger eccentric pressure.

Mechanical analysis of cracks: According to the information of deformation and displacement monitored during construction, the load on lining structure can be calculated by using the theory of back-analysis. If the mean value of inversion load and monitoring load is taken as the input value to calculate the internal force of the structure, the actual stress situation of the structure can be analyzed objectively, so as to judge the causes of structural cracks and other diseases, or to guide the design of tunnel by feedback analysis. Here a typical monitoring section is taken as an example to obtain actual surrounding rock pressure. The position of the monitoring instrument is shown in Fig.1 (only a single arch of symmetrical multi-arch tunnel is shown in the diagram). The calculated and measured values of the surrounding rock pressure are shown in Table 2.

Then the internal force of the second lining structure is calculated by using the above mean loads as input values. By comparing with the shear design value of the secondary lining section calculated according to the highway design code, it is found that the shear force at the middle wall of the tunnel is obviously unsatisfactory (the maximum shear value of this section has reached 1632KN, and the design value is 1125KN), which leads to the cracks due to shear failure here.

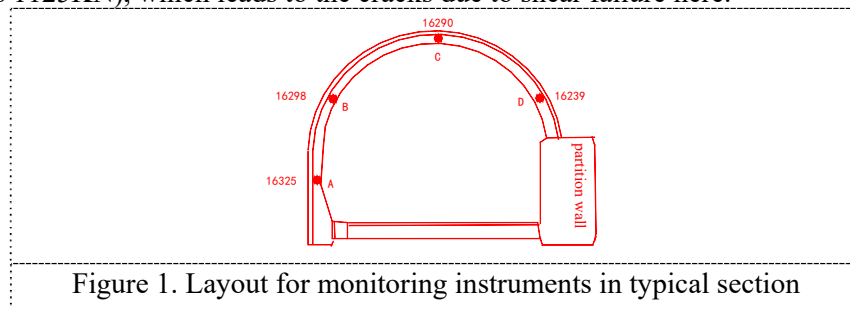


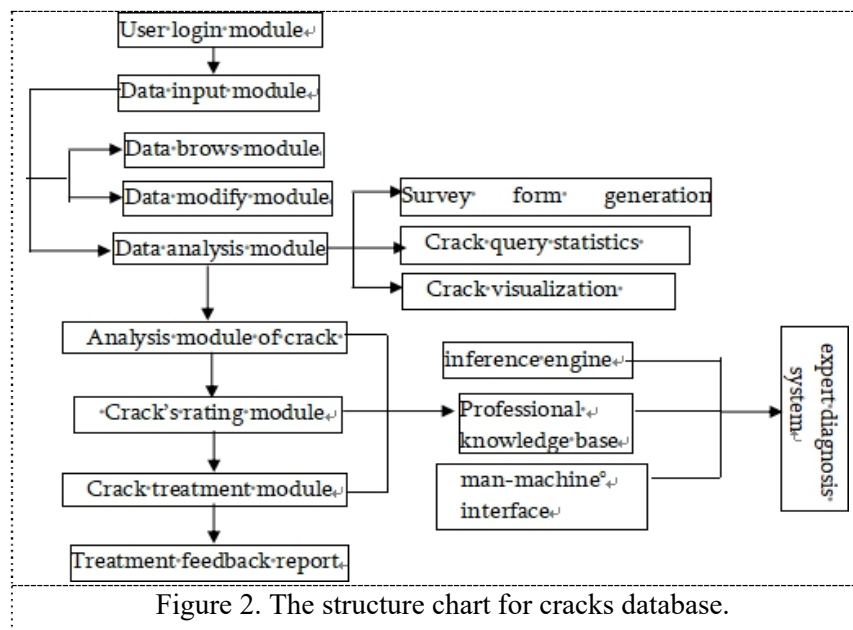
Figure 1. Layout for monitoring instruments in typical section

Table2. loads by back-analysis and by measurement in typical section

Items	Measuring positions			
	16325	16298	16290	16239
displacement (mm)	0.47	0.42	0.31	0.65
back-analysis loads	802	626	438	991
Measured values	926	893	742	1186
Mean values (KPa)	864	759	590	1088

6. Establishment of crack database

Through a great deal of investigation, analysis and statistics, we can develop and establish a database which integrates all kinds of cracks in main concrete structures. The database is made up of many modules and has powerful functions. It has a detailed analysis and introduction of the database process, logical structure design, factor coding, data analysis, and the realization process of each function. Figure 2 is a module diagram of the database.



The information contained in the database includes: the detailed description of the morphological characteristics of various cracks and their distribution maps, the analysis of the formation mechanism of various morphological cracks, and the suggestions of crack treatment methods. For example, the description of cracks morphology includes: (1) the extent direction of cracks (for regular cracks: longitudinal, circumferential and oblique; for irregular cracks: reticulate, radial, random, and crossed). (2) the depth of cracks: surface, perforated and deep. (3) length of cracks: thorough-long cracks, long cracks, and local short cracks. (4) The width of cracks: upper wide below narrow, below wide upper narrow, outer width and inner narrowness, etc.; maximum, minimum and average crack width. (5) crack offset: it can be divided into vertical offset and horizontal offset. (6) crack density and crack spacing. (7) specific location that cracks exist in the interior or the surface of the component, such as the crack initiation and termination position, dip angle, etc. The description of all aspects of the above cracks can be drawn into detailed charts and corresponding to their respective causes. It is convenient for engineering to quickly make a scientific judgment of the causes of the cracks and form a preliminary treatment scheme based on the observation and measurement of the cracks.

7. Conclusion

Based on the investigation and study of the types, forms, distribution characteristics and laws of cracks in various concrete structures, combined with the analysis of the mechanical properties and environmental characteristics of concrete structures, the causes of cracks are explored from a deep level, the common crack forms of various main structures are analyzed systematically and comprehensively, and the close connection between the causes of cracks and their manifestation is established. On this basis, scientific and effective methods and measures for the prevention and repair of cracks in various concrete structures are put forward. Finally, based on the research results, a powerful and abundant database is established, which mainly includes the functions of "causes - forms - treatment", so that engineers or technicians can easily infer the causes of cracks according to the appearance of cracks, then find scientific prevention and cure methods. The method of crack analysis and preventive measures established in this paper have reference value for the consideration of cracks in the design and construction of practical projects.

Acknowledgments

The research described in this paper was financially supported by projects of science and technology research of Jiangxi Provincial Education Department (Grant No. GJJ171061) and (Grant No. GJJ161182).

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