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Water Pressure Variation Properties Research in Non-ballasted Track Crack Interior Under Fatigue Loading

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ABSTRACT
This paper reports the experimental study of water pressure properties inside crack of Non-ballasted track structure. Pre-existing crack concrete specimens with 510 × 1290 × 80mm dimensions were produced, and fluid-fracture interaction tests under cyclic loading were performed. The water pressure were measured at different locations inside cracks and with different loading frequencies as well as amplitudes. By using the experimental data, then is employed to investigate the water pressure distribution inside cracks affected by both the frequency and amplitude under cyclic loading. From this study, it was determined that the water pressure of cracks alternates between positive and negative values under cyclic loading, and increase with the increase of crack depth, loads amplitude and loads frequency. Furthermore， the relationship between the water pressure, loads amplitude and loads frequency can be fitted into a polynomial expression.

KEY WORDS: Non-ballasted track, Fluid-solid interaction tests, Water pressure

1 INTRODUCTION

WITH the rapid development of high-speed railway technology, a new era of high-speed railway was imminent. SONG XiaoLin et al. (2014) have proposed that a number of new high-speed railway lines have been put into service in China, with operation speeds usually of 300 km/h and maximum speeds of as much as 350 km/h. Yang Yang et al. (2015) have proposed that high-speed railways need more smooth and stable track to ensure the continued running safety and riding quality of the electric multiple unit (EMU) as train speed increases.

Conventional ballasted railway tracks require periodical tamping due to uneven settling of the ballast during operation. The sleeper panel must be adjusted frequently to maintain the smoothness of the rail surface. Previous experience has shown that this kind of maintenance work is significantly increased for high-speed railways.

As Qianfeng Wang et al. (2016), Railway Construction (No. 754) and Robertson, C. et al. (2015) mentioned, the non-ballasted track, a concrete slab instead of a ballast bed to support the running train can enormously reduce maintenance and maintain constant serviceability conditions over a long service life. Therefore, a variety of non-ballasted tracks have been applied to many newly built high-speed railways because of their notable advantages in terms of structure stability, durability and track smoothness.

CRTS Ⅱ slab track system is one of the CRTS series of non-ballasted track structure, has been successfully used in the Beijing-Tianjin intercity railway, Shanghai-Hangzhou, Ningbo-Hangzhou, Hefei-Bengbu, Beijing-Shijiazhuang, Shijiazhuang-Wuhan, Tianjin- Qinhuangdao, Hangzhou-Changsha etc., more than 10 high-speed railway or passenger line. Figure1 shows a Sketch of the CRTS II slab track system.

However, just as Zhai W M, et al. (2014) and ZHU Sheng-Yang, et al. (2012) have proposed, these non-ballasted tracks suffer from various degrees of damages due to crack, most frequently on the track plate or road bed, Figure 2 shows an example of cracked non-ballasted track in Cheng-yu line. The areas having high rainfall or serious water logging, the non-ballasted track structure cracks growth much faster than those in dry areas.

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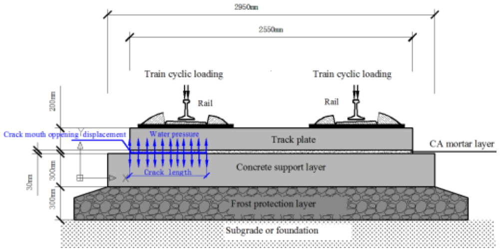

Figure 1: The CRTS II slab track in the subgrade section consists of rail, fastener system, pre-stressed concrete slab, CA mortar layer and concrete support layer (Figure 1).

Consequently, the CRTS II slab track properties will continually degrade; as a result, extra maintenance of the deteriorated track must be carried out frequently. It is therefore essential to investigate the water pressure performance inside crack and to influence on dynamical water pressure characteristics. Xu Gui-hong (2013) have proposed that, the effect of water -caused damage on track-service properties has become an important issue as well. (see figure 2).

Figure 2: Example of damages on non-ballasted track. Shown is Cheng-yu line. The left panel depicts water accumulation between the supporting layer and the CA mortar, and the right one presents a crack on the track plate

Some research has analyzed the relationship between concrete crack growth and water pressure, Such as: Brühwiler and Saouma V.C, et al. (1995) presented the results of fracture experiments, where in a crack is subjected to hydrostatic pressure; Akira Shinmura, et al. (1997) determined that the presence of a hydrostatic pressure reduces not only the fracture energy of concrete but also the bond between reinforcement and concrete; G. Alfano, et al. (2006), on the basis of the experiment, proposed a damage–friction model based on a new multi-scale approach for the interface. G. Debruyne,et al.(2012) described the successive fast crack growth and arrest, driven by a discontinuity in fracture toughness; Farrokh,et al. (2005) developed a theoretical model of transient water pressure variations along a tensile seismic concrete crack, and performed experimental tests to validate the proposed model.

Although there are many researches in damage of non-ballasted and the relationship of crack propagation and water[14-19], such as: Elisa Poveda, et al(2015), have proposed a numerical study on the fatigue life design of concrete slabs for railway tracks. Lianhai Zhang, et al (2016), have showed An investigation of pore water pressure and consolidation phenomenon in the unfrozen zone during soil freezing. Zhao Pingrui, et al (2014), showed Experimental study of temperature gradient in track slab under outdoor conditions in Chengdu area. And LI Zongli, et al (2014), showed an analysis of Water Infusion in Rock Mass or Concrete Fracture Under Constant Water Head. Most of them are based on the assumption of hydrostatic pressure[20-24]. Little research has been conducted on the dynamic load, load frequency and load amplitude. This article deals with the water pressure behavior in crack of non-ballasted track under cyclic dynamic load. A series of laboratory tests were performed to assess the effect of loading frequency and loading amplitude on the water pressure in crack. These experiments were then numerically simulated by a finite element. Based on the experimental and numerical investigation, a theoretical model is developed for transient water pressure variations in crack of non-ballasted track.

2 EXPERIMENTAL

2.1 Specimen

IN this investigation, an ordinary Portland cement produced in the Guizhou cement plant in China was used, and all its properties were in accordance with the Chinese standard of Common Portland Cement. Natural river fine sand was adopted as fine aggregate, with a fineness modulus of 1.8. Natural river pebble was used as coarse aggregate (diameter ranging from 5 to 30 mm). Water was tap-water. Water-cement ratio was 0.5, and the mix proportions by weight of the mixture are shown in Table 1.

In order to study the water pressure in cracks of non-ballasted track, the reduced-scale track structure with precast crack was produced in the “MOE Key Laboratory of High-speed Railway Engineering” of Southwest Jiao tong University for crack water pressure tests.

Table 1 Mix proportion of concrete specimen

Material	Mix ratio	Remarks
Cement	246 kg/m3	P.O 42.5
Fly ash	123 kg/m3	
Breeze	41 kg/m3	
Fine aggregate	847 kg/m3	
Coarse aggregate	1036 kg/m3	
Water	157 kg/m3	
water reducer	3.7 kg/m3	
(28d)Compression strength of concrete	48.7 Mpa	

Since, the original size of CRTS Ⅱ non-ballasted track structure is too large to production and transport for the laboratory difficult, the width, length and thickness of track plate and cement treated base were considered as 510, 1290mm, and 80mm respectively. But crack opening displacement is 3mm no reduction. The production of the track structure with crack process is as showed in figure 4.

The test specimens were cured under laboratory conditions for 30 days, and the completed track plate specimen is shown in Figure4. In this tests model the elasticity modulus and Poisson ratio were taken as 20Gpa and 0.17 for concrete. The volumetric mass and strength of concrete was considered 2400kg/m^3 and 40Mpa.

2.2 Experimental procedures

The experimental setup, shown Figure 5, consists of three main parts: a cyclic dynamical loads system, a computer controlled data acquisition system, and water pressure sensor. The water pressure was monitored using the high sensitivity water pressure sensor supplied by Chengdu Taisite Company.

The frequency of the test cyclic loading is related to the speed of the train. When the speed of train are 200km/h~400km/h (55m/s~111m/s), can calculate the wheel loads frequency between 3-9Hz according to the relevant parameters of type CRH2 high speed locomotive (see table2).

The crack full filled water see Figure 6, the high-precision digital pressure sensor was inserted into crack to measure water pressure which connected to the computer, and the computer can directly save and display the results of the water pressure under cyclic loading.

The load amplitudes chosen were 45±20, 50±25, 55±30, 60±35, 65±40, 70±45. The loading curve applied on the test specimen by servo-hydraulic universal testing machine is set to a sinusoidal curve, the 60±35kN curve as shown in Figure 7. A total of 24 tests were conducted, see Table 3~Table 7.

(a): Cast-in-situ concrete of the cement treated base

(b):The steel plate with 500×400×3mm dimensions was placed in the middle part of the track plate

(c) Cast-in-situ concrete the track plate with precast crack

(d): Before the final solidification of concrete, the steel plate was removed and slab with precast crack was produced

Figure 4 The production of the track structure with crack process

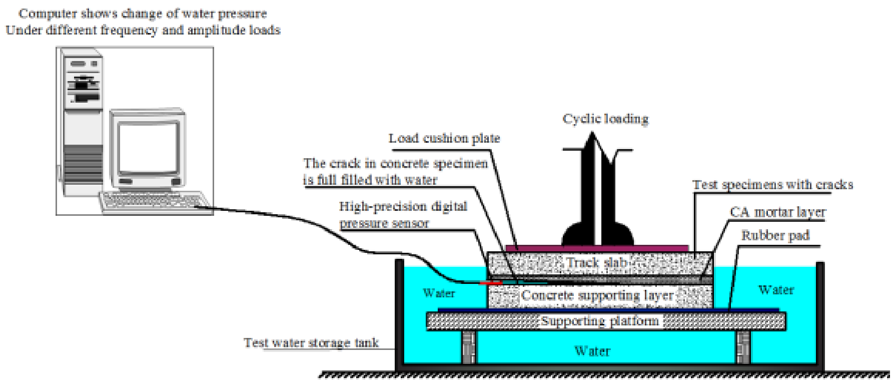

Figure 5: Schematic view of test set up

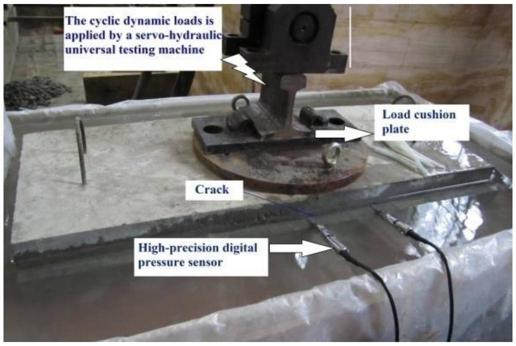

Figure 6: High-precision digital pressure sensor measure water pressure

Table 2: Parameters of type CRH2 high speed locomotive

Components	Parameters	Components	Parameters
Train Type	CRH2	Axle-load of Bogies	14t
wheel-base bogie	2.5m	vehicle length	25m
Bogie center distance	17.5m	Head car length	25.7m

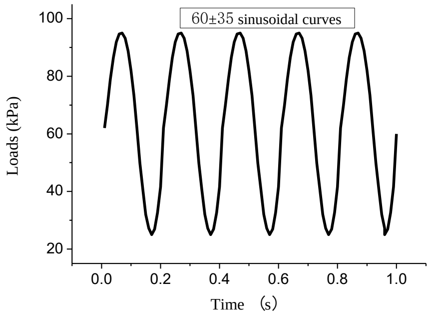

Figure 7: The sinusoidal curves are set on the servo-hydraulic universal testing machine.

Figure 8 shows the arrangement of monitoring points in order to evaluate the water pressure properties in crack of specimens. Point 1 and4, 2 and 5, 3 and 6, were 50, 100 and 150 mm away from the crack mouth respectively.

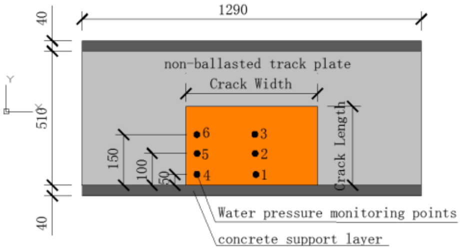

Figure 8 Monitoring point layout

3 TEST RESULTS AND DISCUSSION

3.1 *Water pressure at different points*

THIS section mainly analyses the change characteristics of crack water pressure under cyclic load in different monitoring points. The relevant parameters and arrangements for the tests are shown in Table 3.

Table 3 Water pressure test arrangement (1)

Test number	1 ~6
Crack width	500mm
Crack length	300mm
Load frequencies (Hz)	5
Mean Fatigue load (Sinusoidal)±Amplitude	60±35(kN)
Monitoring site	Point1 to point 6
Test objective	Water pressure analysis at different points

Figure 9, Figure 10 and Figure 11 illustrates the water pressure-time curves for monitoring points1, 2 and 3 in table 3.

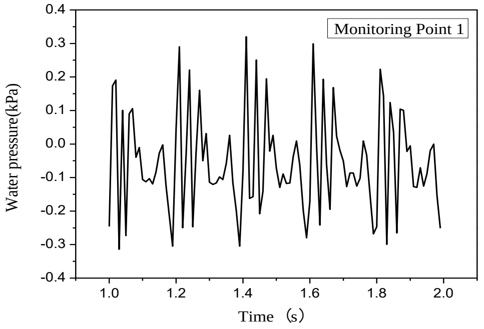

Figure 9: **Water pressure variation of monitoring point 1**

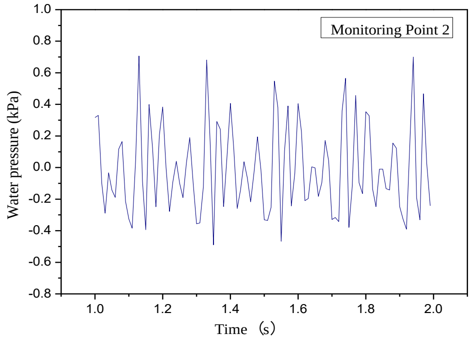

Figure 10: **Water pressure variation of monitoring point 2**

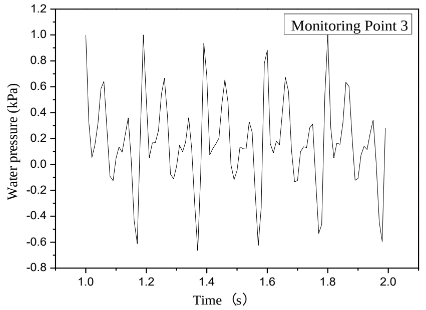

Figure 11: **Water pressure variation of monitoring point 2**

Figure 9, Figure 10 and Figure 11, show that water pressure will be produced in crack when the cyclic loads applied on the track plate. Furthermore, the water pressures rapid builds up or disappear as the loading applied or offload. When the load reaches the maximum value, the water pressure also has a peak value.

When the load frequency is 5Hz, there are 5 big peaks in the 1s .The pressure of each peak is similar but not identical. After each big peak, there will be a few small peak, this is caused by the shock nature of the water.

Through the comparison of the peak water pressure of the 1, 2 and 3 monitoring points, it is known the water pressure increases with the increase of the crack depth. The maximum at monitoring point 3 is 1kPa.

Water pressure variation of monitoring points 4, 5 and 6 are reported in Figure 12, Figure 13 and Figure 14.

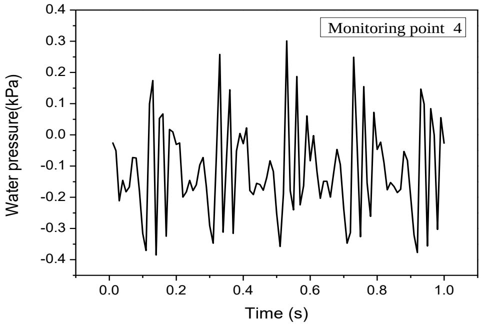

Figure 12: **Water pressure variation of monitoring point 4 in test 1**

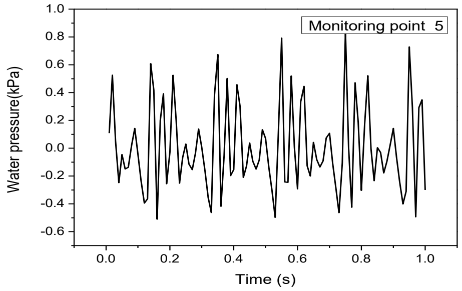

Figure 13: **Water pressure variation of monitoring point 5 in test 1**

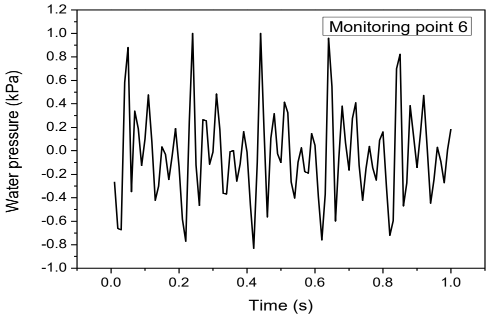

Figure 14: **Water pressure variation of monitoring point 6 in test 1**

The water pressure maximum for monitoring points 1~6 are 0.31, 0.71, 1.0, 0.31, 0.83 and 1.02 kPa. Through the comparison of the peak water pressure of the 1, 2, 3, 4, 5 and 6 monitoring points, they were indicated that the water pressure in crack is not same at different positions under the same load frequency (5Hz) and amplitude (60±35kN).

From monitoring points 1 to 3 (or 4 to 6), with the increase of crack depth, water pressure increased. The water pressure for monitoring points in the middle part of the crack is a lightly bigger than those of the both sides.

3.2 The effect of Crack width on water pressure

This section mainly analyses the change characteristics of crack water pressure under different crack width in different monitoring points. The relevant parameters and arrangements for the tests are shown in Table 4.

Table 4 Water pressure test arrangement (2)

Test number	7	8	9
Crack width (mm)	300	500	700
Crack length(mm)	300mm		
Load frequencies	5（HZ）		
Mean Fatigue load (Sinusoidal)±Amplitude	60±35(kN)		
Monitoring site	Point1 to point 5		
Test objective	Analysis of the influence of crack width on Water pressure		

The results of the water pressure tests as obtained in this investigation are given in table 5 and figure 15.

Table 5 test results

Monitoring site	Crack width (mm)		
	300mm	500mm	700mm
Point 1	0.264	0.973	1.074
Point2	0.318	1.565	1.903
Point3	0.624	2.546	3.658
Point4	0.634	3.055	6.008
Point5	0.852	3.658	6.702

It can be seen from the table5 that the water pressure at the same point increases with the crack width increasing, such as point 2, when the crack width is 300mm, 500mm and 700mm, the corresponding water pressure is 0.318kPa, 1.565kPa and 1.903kPa respectively.

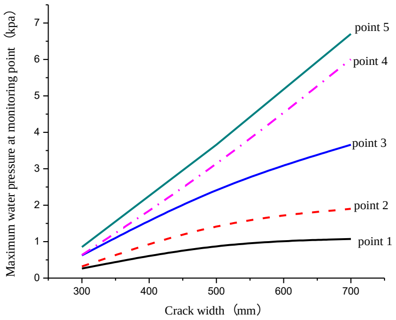

Figure 15 Test results for different crack width

It can be observed from figure15 that the data points raise approximately along a straight line, which indicates that the crack width is a important factor for water pressure.

3.3 The effect of Crack Length on water pressure

This section mainly analyses the change characteristics of crack water pressure under different crack length in different monitoring points. The details of the parameters and arrangements for the tests are shown in Table 6.

Table 6 Water pressure test arrangement

Test number	10	11	12
Crack width	500mm		
Crack length(mm)	200	300	400
Load frequencies	5Hz		
Mean Fatigue load (Sinusoidal)±Amplitude	60 kN±35kN		
Monitoring points	Point1 to point 3		
Test objective	Analysis of the influence of crack length on Water pressure		

The results of the water pressure tests as obtained in this investigation are given in table 7.

Table 7 Test results

Monitoring points	Crack length (mm)		
	200mm	300mm	400mm
Point 1	0.458	0.973	1.032
Point2	1.121	1.565	1.883
Point3	1.894	2.546	2.688

It was observed from the table 7 that the water pressure at the same point increases with the crack length increasing, such as point 2, when the crack width is 200mm, 300mm and 400mm, the corresponding water pressure is 1.121kPa, 1.565kPa and 1.883kPa respectively.

3.4 The effect of load Frequency on water pressure

In this section, the effect of the load frequency on water pressure will be investigated.

The results for maximum water pressure and load frequency relationship for monitoring point 2 in table 8 tests are reported in Figure 16.

Table 8 Water pressure test arrangement

Test number	13~18
Crack width	500mm
Crack length	300mm
Load frequencies (Hz)	3,5,7,9,11,13
Mean Fatigue load (Sinusoidal)±Amplitude	60±35(kN)
Monitoring points	Point 2
Test objective	Analysis of the influence of load amplitude on Water pressure

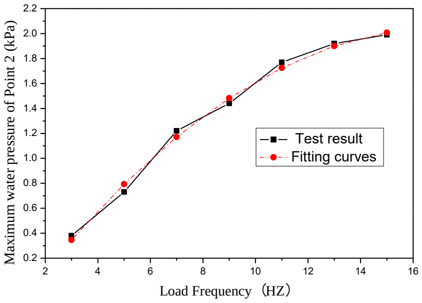

Figure 16: The relationship between load frequency and water pressure for point 2

It can be seen from Figure 16 that the maximum water pressure in crack increases with the load frequency at the same monitoring point 2.

The relationship between load frequency and water pressure in cracks can be fitted as:

$$P = -0.0085n^2 + 0.291n - 0.4515$$

where P is the maximum water pressure in kPa, and n is the load frequency in Hz.

The load frequency is obtained by the conversion of train speed and bogie center distance, therefore, the train speed is an important factor that affects water pressure in cracks. The higher the train speed, the larger water pressure in cracks.

3.5 The effect of load amplitude on water pressure

In this section, the effect of the load amplitude on the maximum water pressure will be investigated. The details of the parameters and arrangements for the tests are shown in Table 9.

In tests table 9, as shown in Figure 17, with the increase of load amplitude, the water pressure also increased. When load amplitude is 20kN, the pressure is 0.281kPa. When the load amplitude was 30kN, the corresponding pressure was 0.543kPa. When the load amplitude was 40kN, the corresponding pressure was 1 kPa. When the load was 45kN, the corresponding pressure was 1.365kPa.

Table9 Water pressure test arrangement

Test number	19 ~24
Crack width	500mm
Crack length	300mm
Load frequencies	5Hz
Mean Fatigue load (Sinusoidal)±Amplitude (kN)	45±20, 50±25, 55±30, 60±35, 65±40, 70±45
Monitoring site	Point2
Test objective	Analysis of the influence of frequency on Water pressure

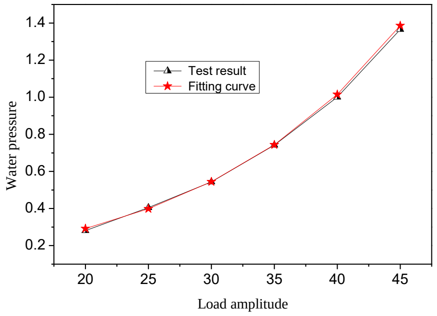

Figure 17: The relationship between the maximum water pressure and load amplitude for monitoring point 2.

The relationship between the maximum water pressure of monitoring point 2 and loads amplitude can be fitted as:

$$P = 0.084e^{0.0623f}$$

where f is the loads amplitude in kN.

4 CONCLUSIONS

The aim of this paper is to evaluate the properties of water pressure inside crack under cyclic loading, and provide a scientific data for the study of the water damage of non-ballasted track.

The reduce-size track plate was be made and a series of laboratory tests were performed to assess the effect of crack width, crack length, load frequency and load amplitude on the water pressure in crack. Test results show that: crack length, load frequency and load amplitude are important factor that affects the water pressure in cracks.

(1) The shape of the crack has an effect on the water pressure inside the crack. With the increase of crack width and length, the crack water pressure increases.

(2) The train speed is an important factor that affects water pressure in cracks. The higher the train speed, the larger water pressure in cracks.

(3) For the same point with the increase of load amplitude, the water pressure also increased.

These findings have benefits in terms of maintain and design for non-ballasted track structure.

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Yang Rong-Shan is a professor at SouthWest JiaoTong University in Chengdu, china. He received his High speed railway engineering and doctoral degrees from the SouthWest JiaoTong University. He has conducted research in the area of ballastless track damage and has been involved in fracture mechanics of concrete and Fluid-solid coupling dynamics. In this paper, he completed the guiding work of the thesis.