Study on Water Pressure and Velocity in Cracks of Slab Track

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Abstract. The essence of slab track damage under the coupling effect of train load and water is a coupled hydro-mechanical (HM) fracture, and the core technology is the water pressure calculation. Finite element software ANSYS and CFX are used to analyze the water pressure and speed of slab track cracks under high speed train loads. The results show that, the maximum water pressure appears at the crack tip under loading, and decreases along the crack. The value of water pressure is proportional to load amplitude, square of loading frequency and inversely proportional to crack aperture. On the contrary, the maximum water velocity appears at the crack mouth, and increases along the crack. The value of velocity is proportional to load amplitude, proportional to loading frequency, and inversely proportional to crack aperture. The presented theory can be applied to the stress study of slab track water crack.

Introduction

Due to the superior performance of high stability, excellent ride quality, and low maintenance, the slab track as the main track form has been widely used for high-speed railway systems. However, the interfacial crack is ubiquitous because of the improper construction and maintenance, and its propagated deterioration under the repeated train load and temperature variations is a concern. The site investigation indicates that the crack propagation is faster in the rain rich and poor drainage areas relative to the arid areas. This demonstrates that the coupling effect of train load and moisture may play an important role in the process of crack propagation[1-2].

The essence of slab track damage under the coupling effect of train load and moisture is a coupled hydro-mechanical (HM) fracture. There are some literatures on HM fracture research; In the tests research, the crack propagation under mechanical load and hydrostatic pressure were considered, and it was determined that the internal hydrostatic pressure reduces the fracture properties of concrete; In the theoretical research, micro-fracture mechanics was adopted to analyze the effects of pore water pressure on the crack propagation, and the pore water in the cracks had the effect of accelerating the crack growth[3-6].

In the research described in the paper, the finite element software ANSYS and CFX were used to analyze the water pressure and velocity distribution in the crack of slab track. The presented theory can be applied to the HM fracture analysis of slab track.

Damage of Slab Track

![Figure 1. Slab track (dimensions in mm).](image)
The slab track is composed of the rail, fastener, track slab, mortar adjustment layer and supporting layer, as shown in Figure 1. Due to the superior performance of high stability, excellent ride quality, and low maintenance, the slab track as the main track form has been widely used for high-speed railway systems. Up to now, the laying length has exceeded 10000 km.

Under the action of the train load, the water in the crack of slab track will produce a certain pressure and velocity, and scours the crack surface repeatedly. The fine particles stripped from crack surface will be brought out by water, and lead to the slurry phenomenon at the crack mouth, as shown in Figure 2(a). Under the coupling effect of the train load and water, the gap between the supporting layer and track slab is gradually increasing after a period of time. Eventually, the hollowed-out will occur under the track slab, as shown in Figure 2(b). In addition, the hydrodynamic pressure acts on the crack surface, which is a driving force to accelerate the propagation rate of crack. When the stress intensity factor of the crack tip exceeds the fracture toughness of the material, the crack becomes unstable and faces major fracture immediately.

![Figure 2. Damage forms of slab track.](image)

**Water Pressure and Velocity Analysis in Slab Track Interface Crack Calculation Model**

In this paper, the calculation model is shown in Figure 1. In order to analyze the effects of loading frequency, load amplitude, crack aperture and crack length on hydrodynamic pressure in the crack of slab track, the finite element analysis softwares ANSYS and CFX were used to perform the fluid-structure interaction analysis. The crack was assumed to be located at the interface between the support layer and mortar layer, the crack length \( L = 0\text{–}1.2 \text{ m} \) and the crack aperture \( h = 1\text{–}5 \text{ mm} \). When the crack is filled with water, it is considered as the Newtonian fluid, and the compressibility is neglected. The load is applied equally on the platform, and the fixed constraint is applied at the bottom of the model without considering the influence of the elastic foundation. The mesh for calculation model is shown in Figure 3. The corresponding calculation parameters are shown in Table 2.
Table 1. Calculation parameters.

| Projects         | Detail of parameters |
|------------------|----------------------|
| **Solid domain** |                      |
| Track slab       | Elastic modulus      |
|                  | 36 GPa               |
|                  | Poisson’s ratio      |
|                  | 0.2                  |
| CA mortar layer  | Elastic modulus      |
|                  | 9 GPa                |
|                  | Poisson’s ratio      |
|                  | 0.34                 |
| Support layer    | Elastic modulus      |
|                  | 25.5 GPa             |
|                  | Poisson’s ratio      |
|                  | 0.2                  |
| **Fluid domain** |                      |
| Density          | 998.2 kg/m$^3$       |
| Coefficient of dynamic viscosity | 1.002×10$^{-3}$ pa·s |
| Reference pressure | 0 pa                 |
| Domain type      | Single domain        |
| Boundary condition | No slip wall         |
|                  | Dynamic grid         |
| **Load**         |                      |
| Train type       | CRH 3                |
| Train speed      | 200 km/h             |
| Axle load        | 160 kN               |
| Wheel base       | 2500 mm              |
| **Solver control** |                     |
| Analysis type    | Fluid-structure interaction |
| Total time       | 0.1s                 |
| Time step        | 0.001s               |

Results and Analysis

Effect of Loading Frequency. Under the same load amplitude of 75 kN, and at the loading frequency of 10, 20, 30 and 40 Hz, the distributions of velocity and pressure in the crack of slab track are shown in Figure 4 and 5. The crack length $L$ is 1m, and the crack aperture $h$ is 3mm.

As shown in Figure 4(a), the maximum value of velocity appears at the crack mouth, and increases from the crack tip to crack mouth. The distribution regularity of velocity can be explained by the mass conservation. At the loading stage, the water is pushed out due to the mutual extrusion of the crack surfaces, and the velocity of flow increases gradually along the crack while the permeability of crack walls is neglected. Figure 4(b) shows that the velocity increases with the increase of loading frequency, and is in linear relation to the loading frequency.

![Figure 4](image-url)
As shown in Figure 5(a), the maximum value of pressure appears at the crack tip, and decreases from the crack tip to crack mouth. The distribution regularity of pressure can be explained by the momentum theorem. The increase of velocity along the crack indicates the increase of momentum. According to momentum theorem, the directions of increased momentum and resultant force acting on the control volume are identical. That is the reason why the pressure decreases along the crack. Figure 5(b) shows that the pressure increases with the increase of loading frequency, and is proportional to square of loading frequency.

![Figure 5](image1.png)

**Effect of Load Amplitude.** At the same loading frequency of 10Hz, and under the load amplitude of 60, 75, 80 and 100 kN, the distributions of velocity and pressure in the crack are shown in Figure 6 and 7.

As shown in Figure 6, the maximum value of velocity appears at the crack mouth, and increases from the crack tip to crack mouth. Furthermore, the velocity increases with the increase of load amplitude, and is in linear relation to the load amplitude.

![Figure 6](image2.png)

As shown in Figure 7, the maximum value of water pressure appears at the crack tip, and decreases from the crack tip to crack mouth. Furthermore, the pressure increases with the increase of load amplitude, and is in linear relation to the load amplitude.

![Figure 7](image3.png)
Effect of Crack Aperture. Under the load amplitude of 75 kN, and at the loading frequency of 10Hz, the distributions of velocity and pressure in the crack with different apertures 1, 2, 3, 4, 5 mm are shown in Figure 8 and 9.

As shown in Figure 8, the maximum value of velocity appears at the crack mouth, and increases from the crack tip to crack mouth. Furthermore, the velocity decreases with the increase of crack aperture, and is inversely proportional to the crack aperture.

As shown in Figure 9, the maximum value of water pressure appears at the crack tip, and decreases from the crack tip to crack mouth. Furthermore, the pressure decreases with the increase of crack aperture, and is inversely proportional to the crack aperture.

Figure 7. Effect of load amplitude on water pressure.

Figure 8. Effect of crack aperture on velocity.

Figure 9. Effect of crack aperture on water pressure.
**Effect of Crack Length.** Under the load amplitude of 75 kN, and at the loading frequency of 10Hz, the distributions of velocity and pressure in the crack with different lengths 0.2, 0.4, 0.6, 0.8, 1, 1.2 mm are shown in Figure 10 and 11.

As shown in Figure 10, the maximum value of velocity appears at the crack mouth, and increases from the crack tip to crack mouth. Furthermore, the velocity decreases with the increase of crack length, and is proportional to cubic polynomial of crack length. Under the action of train load, the water in the crack of slab track will produce a certain velocity, and scours the crack surface repeatedly. The fine particles stripped from crack surface will be brought out by water, and lead to the slurry phenomenon at the crack mouth. Afterwards, the gap between the supporting layer and track slab is gradually increasing after a period of time scouring. Eventually, the hollowed-out will occur under the track slab.

![Figure 10. Effect of crack length on velocity.](image)

As shown in Figure 11, the maximum value of water pressure appears at the crack tip, and decreases from the crack tip to crack mouth. Furthermore, the pressure decreases with the increase of crack aperture, and is proportional to cubic polynomial of crack length. The water pressure generated due to the action of high-frequency train load acts on the crack tip, and becomes a driving force to accelerate the propagation rate of crack. When the stress intensity factor of the crack tip exceeds the fracture toughness of the material, the crack becomes unstable and faces major fracture immediately.

![Figure 11. Effect of crack length on water pressure.](image)

In conclusion, when the crack shape remains constant, the train speed and axle load are two important factors affecting the hydrodynamic pressure in the crack of the slab track. Water pressure increases significantly with the increase of speed and axle load, and is proportional to square of train speed and in linear relation to axle load.
Conclusions

In this paper, the water pressure and velocity distributions in the crack of slab track under high-frequency train load were studied. The water pressure is determined synthetically by the fluid viscosity, crack shape, and load characters. When the crack aperture is greater than 2mm, the effect of viscosity is negligible under the high-frequency load. The maximum value of water pressure appears at the crack tip under loading, and decreases along the crack. The value of water pressure is proportional to load amplitude, square of loading frequency and inversely proportional to crack aperture. On the contrary, the maximum value of velocity appears at the crack mouth, and increases along the crack. The value of velocity is proportional to load amplitude, proportional to loading frequency, and inversely proportional to crack aperture.

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