The influence of road surface grooving on the bearing capacity of airport road surface is analyzed

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Abstract: Abstract: this paper is mainly to analyze splash water test pavement slot effect on airport pavement bearing capacity, according to the FAA requirements, computing pool water storage requirements, and put forward the pool building, this paper adopts the simulator ChangDao surface modeling, analysis of structures, pools on the pavement when the slot effect on airport pavement bearing capacity, explore the pool to build new methods to provide theoretical support for the follow-up.

Key words: Airport pavement; grooving; The bearing capacity

1. Introduction

In order to verify the impact of water splashing on aircraft engines during taxiing, taking off and landing on waterlogged runways, water splashing tests were carried out on the newly developed aircraft. The splash test needs to build a pool on the airport pavement to meet the test requirements. This paper focuses on the technical analysis of the impact of the installation and removal of water tank test facilities on the runway during the splashing test of aircraft, and demonstrates the impact of grooving on the runway, providing theoretical support for the subsequent splashing test of new aircraft to build a pool.

2. Significance and Background

According to the FAA splash test requirements, the new aircraft should be verified before obtaining evidence of its indicators, in line with the requirements of airworthiness certification, before obtaining airworthiness certificate. This thesis mainly embarks from the splash water test, the test mainly through a complete under the specified conditions of water taking off and landing test to simulate the flight test, or in a series of large enough to not interfere with the spray splatters to simulate water demonstration area, the simulation test can achieve more stable results, also can identify and analyze the response of the engine. The main purpose of the splashing test is to verify that the splashing will not damage the aircraft structure and affect the engine, atmospheric data and other related systems in the process of taxiing, taking off and landing on the waterlogged runway. The second is to obtain the aircraft performance data on the polluted runway as the input of the manual performance data.

It is known that the pool used in splash test is mainly built in two ways at home and abroad. One is the way of slotting and plugging rubber dam commonly used in the airport road surface abroad, but there is no precedent of this method in China. The other is the adhesive method, which has been used in a domestic project. The first channel surface slotting method can make the rubber dam of the pool more firmly nested into the groove. At present, this method is more commonly used abroad, but it needs to cut and slotted the airport channel surface layer, which will damage the channel surface. The second adhesive method has been used in the splashing test of a domestic project. This method is nondestructive to the airport pavement, but in the process of taxiing, it may be easy to grind out the rubber dam in the groove due to the large power, which is prone to FOD and other safety hazards.

In order to deeply analyze and explore the method of building a pool on the airport pavement, this paper takes a 4D airport as the basis and simulates the slotting of the airport pavement through the airport modeling method, analyzes and demonstrates the influence of the pavement slotting on the airport pavement, and provides theoretical support for splashing test.

3. Test plan

3.1 Brief introduction to airport road surface

A 4D airport, the road surface is cement concrete road surface， The length and width of the runway is 3600*60m, and the thickness of the pavement surface is 34cm.The upper base (cement-stabilized macadam base) is 20cm, the lower base (graded macadam base) is 20cm, the size of track panel is 5*5m, the thermal expansion groove is filled with silicone, and the PCN value of the runway is 63.There is a 6mm deep gutter along the heading distribution on the pavement. There are two longitudinal slopes of the runway. The transverse slope of the runway is double-sided and the slope is 1%. Taxiway length and width is 3600*23m.

3.2 Water tank construction scheme

3.2.1 Pool size

Water splashing test needs to set up a pool on the airport runway. Since the runway has a horizontal and longitudinal slope, in order to control the water depth on the slope of the airport runway, the water tank must be separated.In order to reduce grooving on the track surface, combined with the track panel size, a pool of 100*30m was built in the middle section of the runway (within the range of 1300m to 1500m from the south section of the runway) in this test. The channel width of the front wheel was 3m, the channel width of the main wheel was 8.5m, and the dam body of the pool was 10m apart along the course, among which the pool was located at 1.5m on both sides of the center line of the runway. The installation position of the pool is shown in Figure 1. Schematic diagram of slotting is shown in Figure 2.

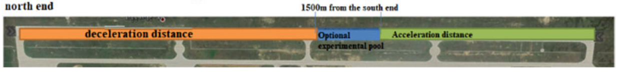


FIG. 1 Pool installation position

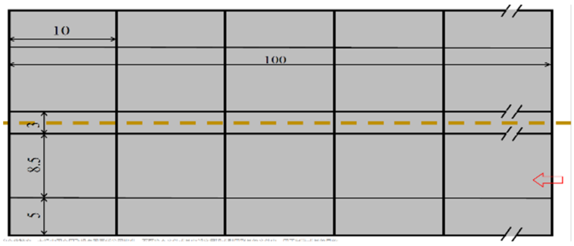


FIG. 2 Schematic diagram of slotting

3.2.2 Pool construction

In order to reduce the cutting of the airport pavement, the existing thermal expansion tank should be used as much as possible, that is, the existing thermal expansion tank should be dug out (remove the silicone filler) and inserted into the rubber belt to build the test tank. However, considering the geometrical size of the aircraft and the transverse slope of the runway, it is still necessary to cut two 100m water tanks along the heading (longitudinal cutting along the runway) at positions of 1.5m each on the center line of the airport runway.

These newly cut grooves can be designed to be identical to the existing thermal expansion grooves on the runway by using the same process used to excavate the existing thermal expansion grooves with the same road cutting machine and the same technology. The grooves required to construct the tank are 8mm wide and 3cm deep.

The pool is constructed with rubber belts, that is, rubber belts are inserted into the grooves. The water tank can be connected with the rubber belt at simple room temperature (no adhesive or other fixing device is required). The rubber belt can be cut in advance according to the length of the design of the test water tank. The rubber belt should match the size of the groove.

After consulting a lot of information, foreign splash test mostly adopt rubber belt scheme, about this groove - rubber belt scheme, you can expand to read NASA report“Problem areas associated with the construction and operation of the landing research runway at NASA Wallops Station” [RD-7].And this scheme has been widely used since the 1960s in splash tests, where rubber bands are extremely difficult to break even in water tank tests on large multi-wheel landing gear aircraft, whose tyres are large and under high pressure. At present, there are no adverse reactions in the operation of slotted airports in foreign countries. Please refer to Annex 1 for the operation of slotted airports for splash test in foreign countries.

3.2.3 Pool water injection

The section installed in the test tank will be filled with water, so it is necessary to ensure that the water level in the tank meets the test requirements during the whole test phase, so there are higher requirements for the sealing of the tank.

3.2.4 Pool to dismantle

A splash test is carried out on the waterlogged runway. After the test is completed, the rubber strip can be removed from the trench to remove all FOD on the runway. The new trench and the existing thermal expansion groove can be treated in the same way as the airport thermal expansion groove and backfilled with silicone filler.

4. Technology demonstration

4.1 The theoretical analysis

4.1.1 Runway strength analysis

a)The surface layer thickness

Under normal circumstances, the strength of the runway surface at both ends of the airport is high, and its design strength is considered according to the design full takeoff weight or maximum full takeoff weight, and the thickness of the runway surface in the middle section can be appropriately reduced compared with that at both ends. According to "Civil airport cement concrete pavement design code", the thickness of cement concrete slab, flight zone index ii for A, B should not be less than 200mm, flight zone index for C, D, E, F should not be less than 240mm.

The whole runway of the target airport is constructed according to a design index (34cm thick), with grooves in the middle of the runway and a length of only 100m. According to the design specification, "when the runway width is not less than 45m and parallel taxiways are set, Concrete slabs in the middle of the runway (at least 800m away from the entrances at both ends of the runway) can be reduced to 0.9 times the thickness of concrete slabs at the end of the runway."It can be reduced by 3.4cm, that is, after the runway is slotted, the surface thickness of the middle section of the airport is still within the design specification, and meets the mandatory standard of the minimum thickness of the runway panel.

b)PCN calculate

Through qualitative analysis of PCN, that is, PCN calculation of slotting (3cm deep) section, that is, assuming that the overall thickness of the middle section of the target airport pavement changes from 34cm to 31cm (in the most unfavorable case, the actual pavement thickness is still mostly 34cm), and assuming that the 90-day design bending and tensile strength of concrete is 5.25mpa, The PCN is 52 when the plane thickness is 31cm, but the actual PCN is higher than 52. If grooving is carried out on the plane, simulation modeling is carried out for the airport.

c） Length-width ratio analysis

According to the requirements of the civil airport cement concrete pavement design code, the length to width ratio of pavement blocks should be less than 1.25. The runway thermal expansion groove is constructed before the cement is dried and cut into 3cm depth and 4mm width. After the cement is dried, the expansion groove can expand to 6-8mm and form natural cracks at the bottom. The new grooves are located at 1.5m on both sides of the center line of the runway, and are cut after the track surface is completely dry. The 3cm installation groove is a false seam, and the 5*5m plate cannot be cut. In other words, after grooving, it can still be a complete plate, without forming a narrow plate of 1.5*5m, which does not conflict with the design specification of the track surface.

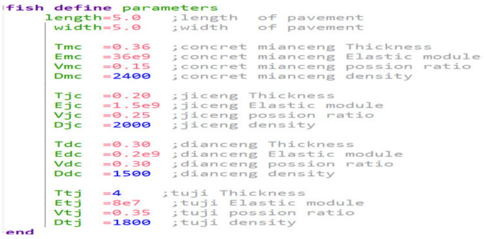
4.2 Finite element modeling simulation demonstration

4.2.1 Finite element modeling

In this finite element modeling, FLAC3D software was used to establish a 5*5m channel panel. By loading the finite element model, the bearing capacity of the complete channel panel and the slotted rear panel was analyzed. The slot position is 1.5m at the middle line of the runway, the geometric dimension is 8mm wide and 3cm deep,The analysis object is mainly the surface layer of pavement structure, without considering the plastic deformation of soil foundation, so the surface layer, base layer, cushion layer and soil foundation are all set as elastic constitutive model. The model parameters of pavement structure are shown in Table 1. Modeling part of the code, see Figure 3; The geometric model is modeled as shown in Figure 4.

Table 1 Model parameters of pavement structure

The structure layer	The thickness of the pavement	Modulus of elasticity (MPa)	Poisson's ratio	The density of the pavement (kg/m^3)
The surface layer	0.34	36000	0.15	2400
At the grass-roots level	0.20	1500	0.25	2000
Cushion layer	0.30	200	0.30	1500
Soil base	4	80	0.35	1800



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fish define parameters
    length=5.0    ;length   of pavement
     width=5.0    ;width    of pavement

     Tmc   =0.36  ;concret mianceng Thickness
     Emc   =36e9  ;concret mianceng Elastic module
     Vmc   =0.15  ;concret mianceng possion ratio
     Dmc   =2400  ;concret mianceng density

     Tjc   =0.20  ;jiceng Thickness
     Ejc   =1.5e9 ;jiceng Elastic module
     Vjc   =0.25  ;jiceng possion ratio
     Djc   =2000  ;jiceng density

     Tdc   =0.30  ;dianceng Thickness
     Edc   =0.2e9 ;dianceng Elastic module
     Vdc   =0.30  ;dianceng possion ratio
     Ddc   =1500  ;dianceng density

     Ttj   =4    ;tuji Thickness
     Etj   =8e7   ;tuji Elastic module
     Vtj   =0.35  ;tuji possion ratio
     Dtj   =1800  ;tuji density
end
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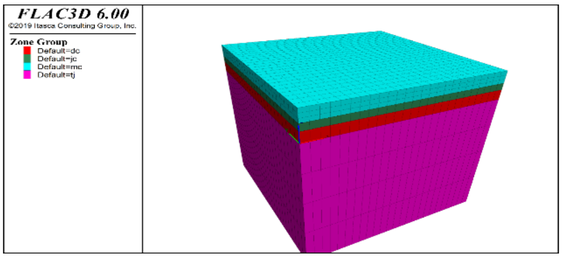
FIG.3 models some of the code



(a) The geometric model

(b) Slot position

(c) Slot details

FIG.4 Slot details

4.2.2 Aircraft wheel seal confirmed

It is assumed that the contact stress between the airplane tire and the track surface is evenly distributed within the range of wheel printing, and the size is equal to the tire pressure. In view of the different wheel load, tire pressure and tire type will affect the shape of aircraft single wheel imprint, currently in many countries (such as China, the United States and Canada, etc.) airport runway design, the wheel imprint is assumed to be a combination of rectangle and two semicircles (i.e., combined wheel imprint).See Figure 5 (a). Since semicircle is not beneficial to the establishment of finite element model in the finite element modeling process, the wheel printing area can be converted into rectangle for modeling calculation through the area equivalence principle, as shown in FIG. 5 (b).

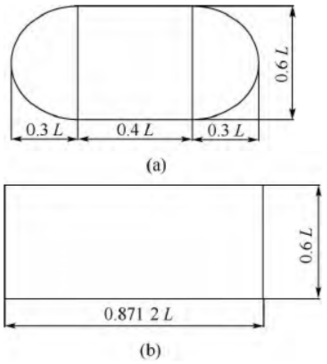


FIG.5 Wheel print area (L is wheel print length)

The calculation of wheel print area, length and width are shown in Formula (1), (2) and (3) respectively. In this loading, 737 was selected as the wheel load size of the reference model. According to the calculation, the length of wheel mark of this loading is 0.5m, the direction is along the middle line of the runway, the width is 0.3m, and the load size is 1.4mpa. The inner spacing of wheel printing is 0.3m, and the distance between loading position and center line is 3.8m.

$$A = \frac{P}{1000q} \qquad (1)$$

$$L = \sqrt{\frac{A}{0.5227}} \qquad (2)$$

$$W = 0.6L \qquad (3)$$

Type in the: A ——Aircraft single wheel wheel printing area，unit m^2;

q——Single wheel contact pressure on main landing gear of aircraft，Take tire pressure（take1.4MPa）；

W——Round printing width

4.2.3 Aircraft load

a)Stress and strain analysis under load at normal take-off and landing position

Aircraft load was carried out on normal pavement and slotted pavement panel respectively, and bending settlement value of pavement layer was analyzed under the action of aircraft load. This loading was under static load loading condition, and wheel load was loaded (static load)，As shown in Figure 6.

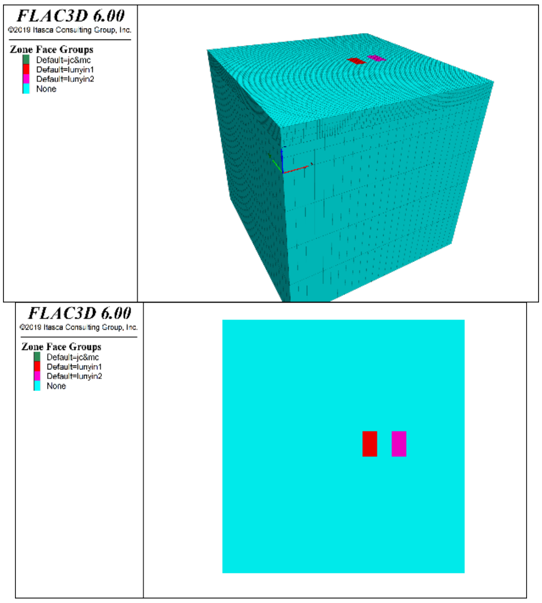


FIG.6 Wheel load loading (static load)

When the wheel load is static, the maximum deflection value at different positions of normal track surface and slotted track surface is calculated within the range of 0-5m, as shown in Table 2 and Figure 7.

Table2 Bending and settling values of normal and slotted surfaces

x/m	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	Max deflection
normal	4.537	4.591	4.810	5.202	5.791	6.501	7.252	7.405	7.002	6.509	6.322	7.415
grooving	4.532	4.585	4.799	5.167	5.785	6.502	7.255	7.409	7.006	6.512	6.324	7.419

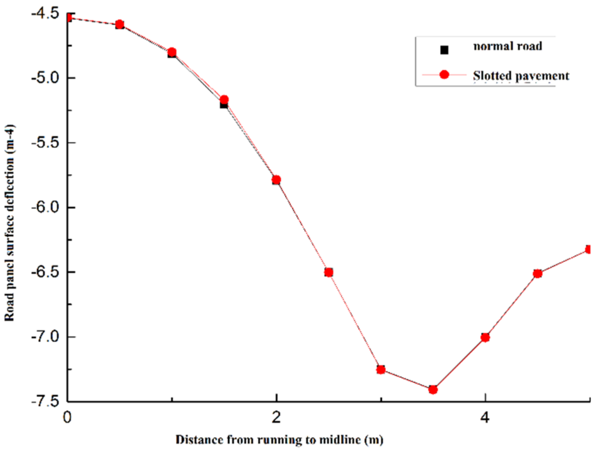
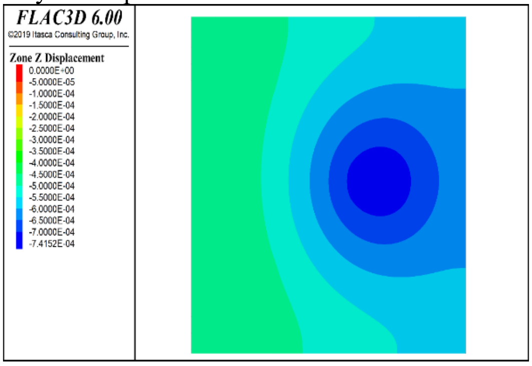


FIG.7 Comparison of deflection and subsidence of road surface

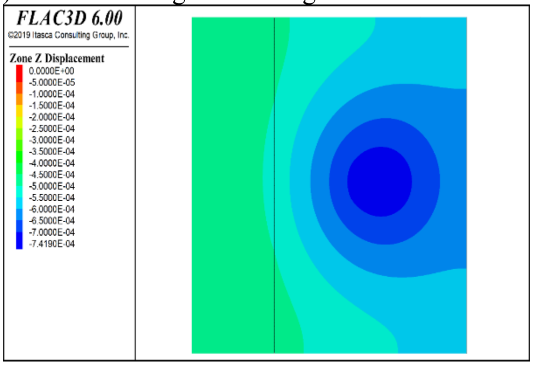
Combined with Table 2 and Figure 7, it can be seen that the curve of deflection of normal track surface and slotted track surface is almost the same under the same aircraft load at the same position. The maximum bending weight of the slotted surface is 7.419×10^{-4} m， Maximum deflection of normal track surface is7.415×10^{-4}m，It indicates that the stiffness (resistance to deformation) of the track panel at the same position is slightly reduced after the grooving：

$$(7.419\times10^{-4}-7.415\times10^{-4})\div7.415\times10^{-4}=\mathbf{0.54\%}$$

By comparison, the left side of the slotted track is slightly lower than that of the normal track (both less than 0.01m). The normal track is shown in Fig.8 (a), and the surface of the slotted track is shown in Fig.8 (b). This value indicates that the groove has a slight influence on the load transfer capacity of the pavement.



(a)Surface bending and sinking cloud of normal track

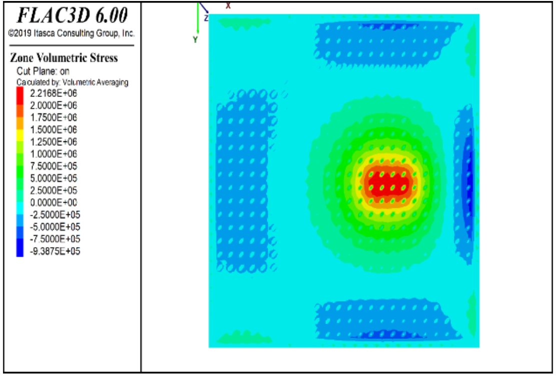


（b） Surface bending and settling cloud picture of slotted surface

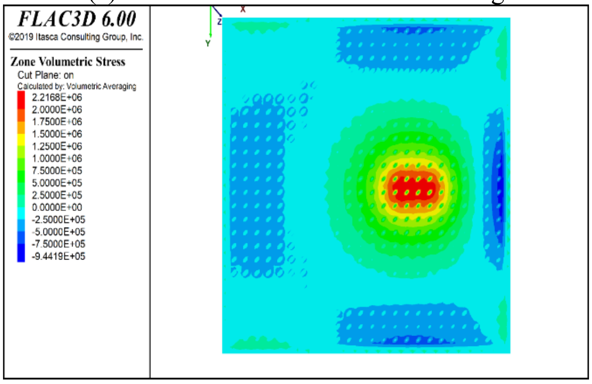
FIG.8 Surface bending and settling cloud picture of slotted surface

The design strength of pavement cement concrete shall adopt the bending tensile strength of 28 days. The airfield index ii is A, B, the design strength of cement concrete is not less than 4.5mpa;The design strength of cement concrete should not be less than 5.0mpa for airports with index ii of C, D, E and F. The compressive strength of cement concrete materials is usually much higher than the flexural strength. The design strength index of cement concrete pavement panel refers to the flexural strength.Therefore, by observing the bending and tensile strength at the bottom of the runway panel under the load of the aircraft wheel, we can judge whether it exceeds the allowable stress range. In the normal takeoff and landing state (that is, the aircraft track is 3.8m away from the middle line of the runway), the stress calculation cloud diagram of the normal and slotted tracks is shown in FIG. 9. The stress state of each part of track panel is shown in Table 3.

It can be concluded that the maximum normal stress and maximum shear stress at all places on the normal and slotted surfaces are less than the designed bending and tensile strength, and the maximum stress at the bottom of the plate under load is 2.22mpa,far less than the design strength of 5.0mpa, and the range of change is very small, the groove has a small impact on the overall surface, the maximum difference is not more than 5%, that is, after the groove panel in the normal rise and fall of the aircraft will not cause bending and tensile damage risk to the plate bottom, does not affect the normal use.



(a)Stress cloud of normal track loading



(b)Stress cloud of slotted surface loading

FIG.9 Stress cloud of slotted surface loading

Table3 Stress state of each part of track face plate(MPa)

location		Place of loading		Edge in the middle		voids	
		The surface of the plate	The bottom of the plate	The surface of the plate	The bottom of the plate	The surface of the plate	The bottom of the plate
Normal pavement	σ_{Max}	4.16	**2.22**	1.05	1.01	0.01	0.06
	τ_{Max}	0.26	0.81	0.56	0.63	0.03	0.05
Slotted surface	σ_{Max}	4.17	**2.22**	1.04	1.01	0.01	0.06
	τ_{Max}	0.26	0.81	0.54	0.63	0.03	0.06

Considering crosswind and other conditions, the main landing gear tire acted on the slot, namely, the position of the most unfavorable load, and the bending of the normal track surface and the slotted track surface, as shown in FIG. 10, and the stress and strain cloud diagram, as shown in FIG. 11. At this time, the maximum bending value

increases compared with the normal take-off and landing of the aircraft position： $7.526 \times 10^{-4} - 7.419 \times 10^{-4} = 0.107 \times 10^{-4}$m.
The stiffness of main landing gear tire on slot opening is lower than that of normal main landing gear wheel track distribution**1. 4**%.

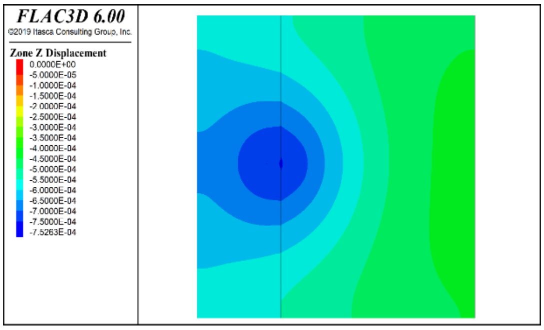


FIG.10 Cloud picture of road surface bending and settling under wheel load on groove

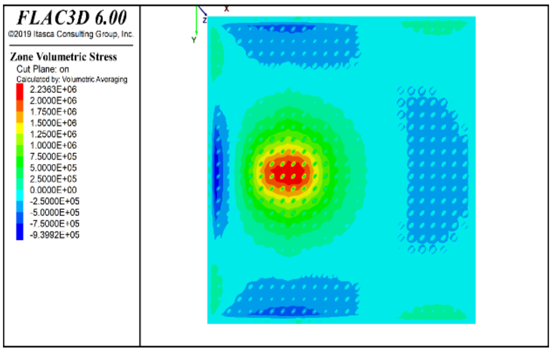


FIG.11 Stress cloud diagram at the most unfavorable load on slotted surface

By comparing the main damage index of the front and rear grooving panels -- the variation of the tensile stress at the bottom of the plate, the tensile stress at the bottom of the plate under the action of the wheel load of the main landing gear on the groove is 2.24mpa, which increases by 0.02mpa compared with the normal rise and fall, and the ratio is 0.9%. All of them did not reach the design bending tensile strength of the panel, so there would be no bending and tensile damage risk to the bottom of the plate. To sum up, slotting at 1.5m of runway middle line has little influence on bending settlement and stress strain of cement concrete pavement.

5. Conclusion

In summary, the theoretical analysis and finite element modeling analysis above, combined with the operation status of the target airport, can be concluded as follows:
1) Slotting has little influence on the runway surface. According to the finite element model simulation calculation, the grooving has little influence on vertical bending and stress of airport pavement, and has little influence on bearing capacity of pavement；

2）Slotting damages the appearance of the pavement, adding two 100m*8mm*3cm cracks and increasing the maintenance cost in the later period. However, the probability of cracks in the pavement is almost the same as that in the normal airport pavement. FOD can be avoided by strengthening the pre-flight patrol and follow-up maintenance detection；

3）For the filling of thermal expansion and cold contraction joints, after the splashing test, the rubber belt insertion part is filled with aggregate, and the same material can be used to fill the thermal expansion and cold contraction joints of the original airport surface.

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