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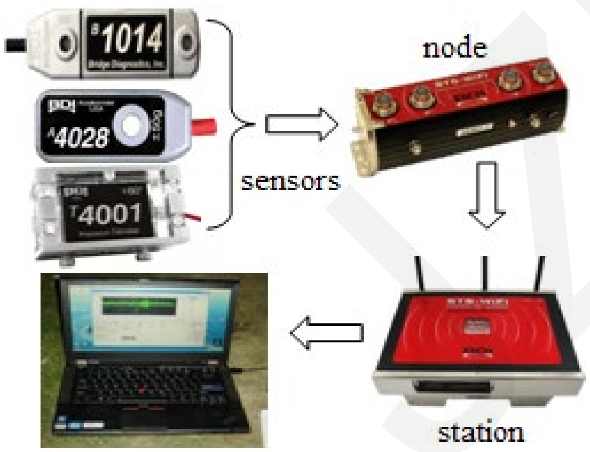
Dynamic response analysis of airport pavements during aircraft taxiing for evaluating pavement bearing capacity

Key words: Airport pavement; Non-destructive test; Aircraft-pavement coupling; Fundamental frequency; Acceleration; Finite element model

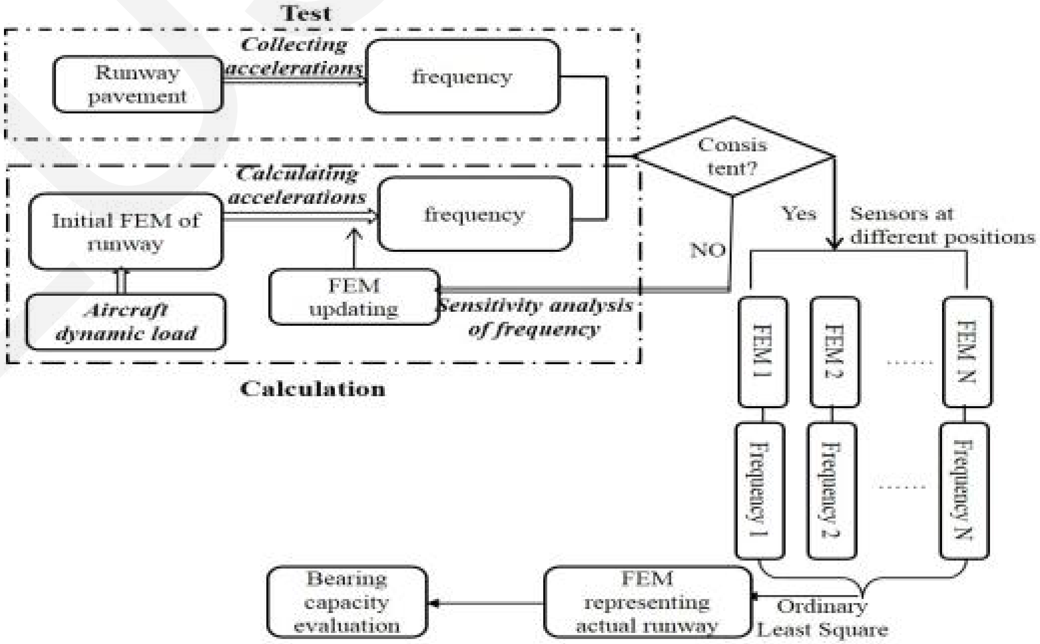
METHOD

- A new method to analyze airport pavement bearing capacity using vibration in runways during aircraft taxiing and finite element updating was proposed. The new method overcomes shortcomings of existing tests, such as flight suspension and simulated loading.

- The testing system includes various sensors (acceleration, strain and tilt), a wireless data transmission node, a wireless base station and data collection terminals. In this method, only the acceleration sensors are used to collect the acceleration of the pavement.



Testing System

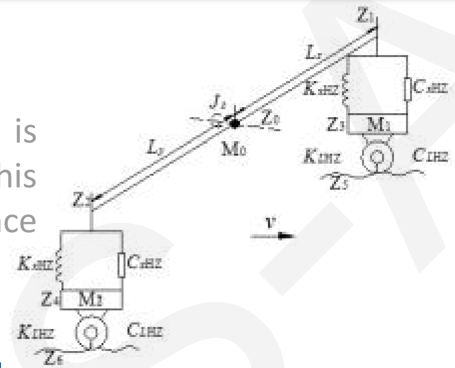


Flow chart of the proposed test method

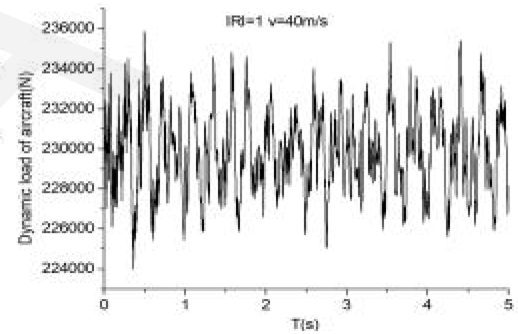
KEY PROBLEM

- Aircraft dynamic load

The force imposed on the pavement by aircraft is influenced by the roughness of the deck and lift. In this study, this was obtained by solving the dynamic balance equations of the aircraft-pavement coupled system.



Four degrees of freedom of aircraft model

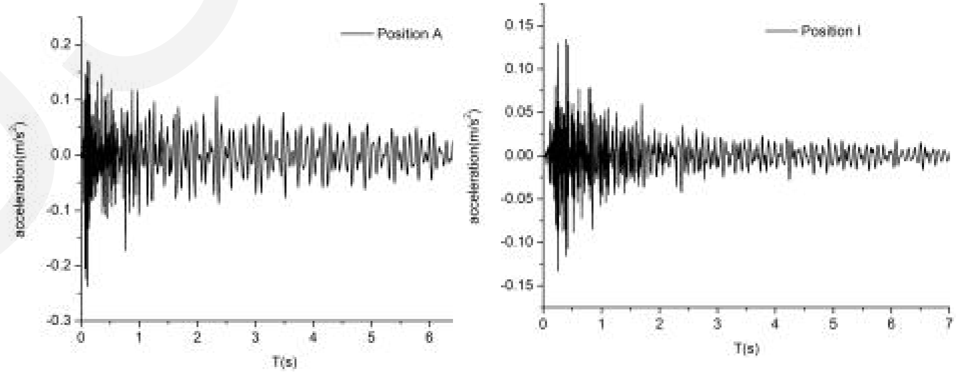


Random dynamic load (one landing gear, IRI=1)

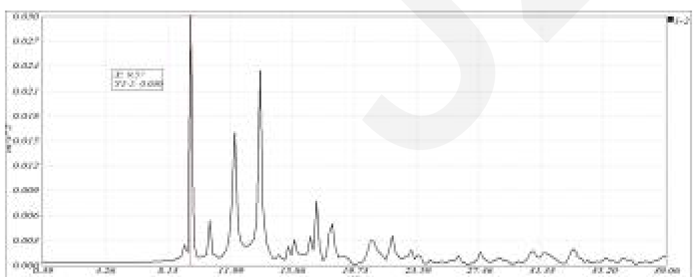
- vibration responses across and along the runway

Pavement width direction：Data on vibration in the width direction of the pavement were collected and spectrum curves obtained by FFT to analyze the vibration change across the pavement.

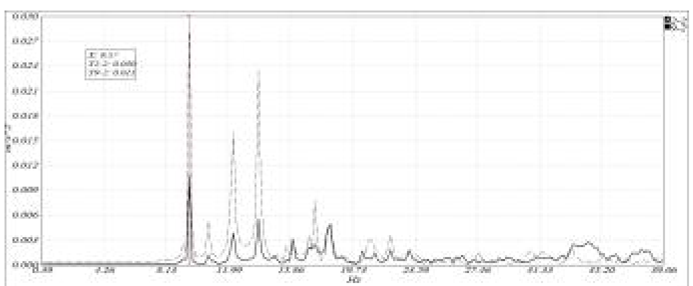
Pavement depth direction：In the finite element simulation, a number of nodes at a distance of 12 m away from the center line were selected as observation points to analyze the vibration along the depth direction.



Acceleration curves of observation points A （pavement surface） and I （11m deep from the soil surface）



Acceleration spectrum curves at pavement surface

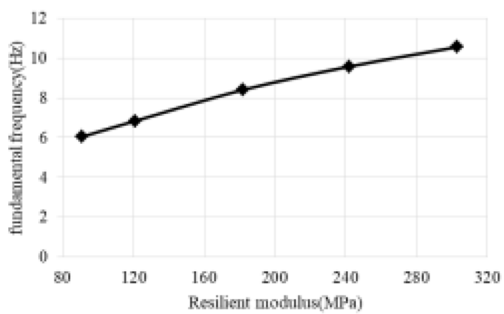


Acceleration spectrum curves at different depths

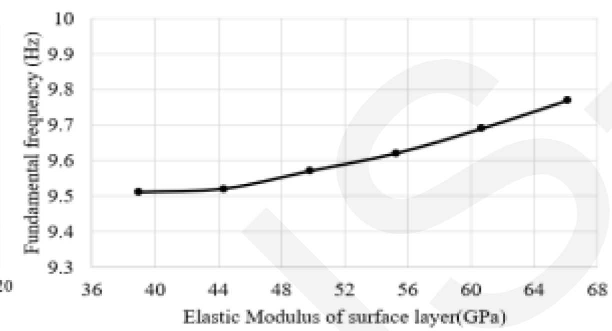
KEY PROBLEM

- Finite element model updating

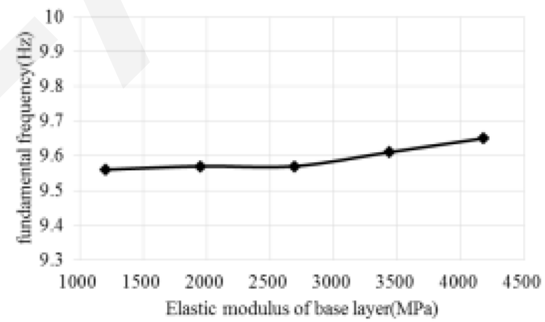
A sensitivity analysis of frequencies is carried out to make sure FEM updating is scientific and effective.



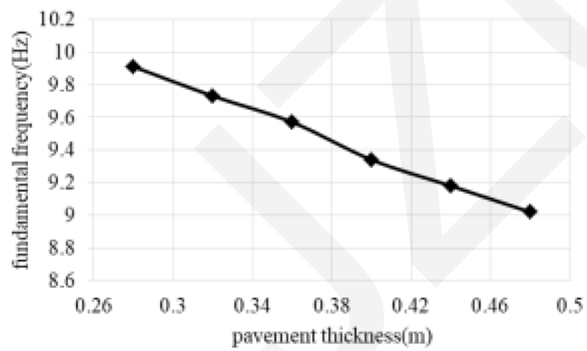
Effect of soil-based dynamic elastic modulus on fundamental frequency



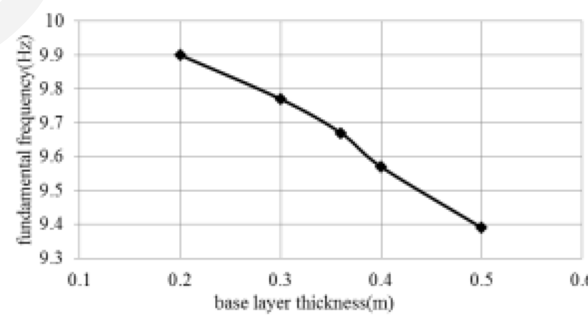
Effect of concrete dynamic modulus on frequency



Effect of base layer dynamic modulus on frequency



Effect of concrete thickness on frequency

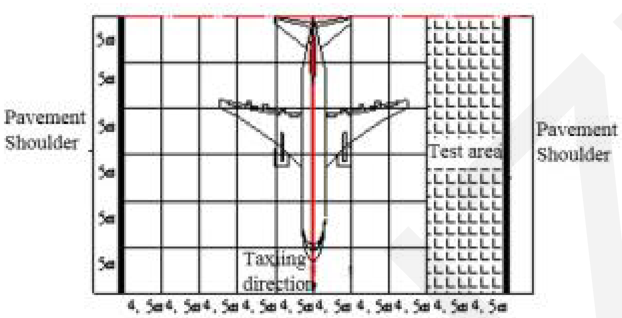


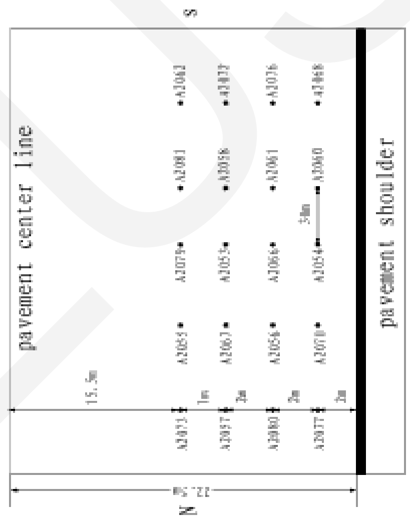
Effect of base layer thickness on frequency

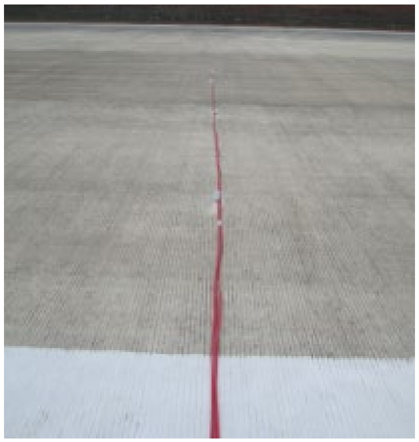
FIELD TEST AND ANALYSIS

Field tests were conducted at an airport in Yunnan Province, China. The cement concrete runway at the airport is 2,350 m long and 45 m wide. The airport is classed as 4C and can be used for mainstream aircraft in civil aviation, such as the Boeing737 and Airbus A320.

A total of five test lines numbered from 1 to 5 were instrumented in the pavement. The distance between test lines was 30 m. There were four acceleration sensors on each test line. They were installed in the concrete pavement from 15.5 to 22.5 m away from the centerline of the runway to cover the normal taxiing of the aircraft.





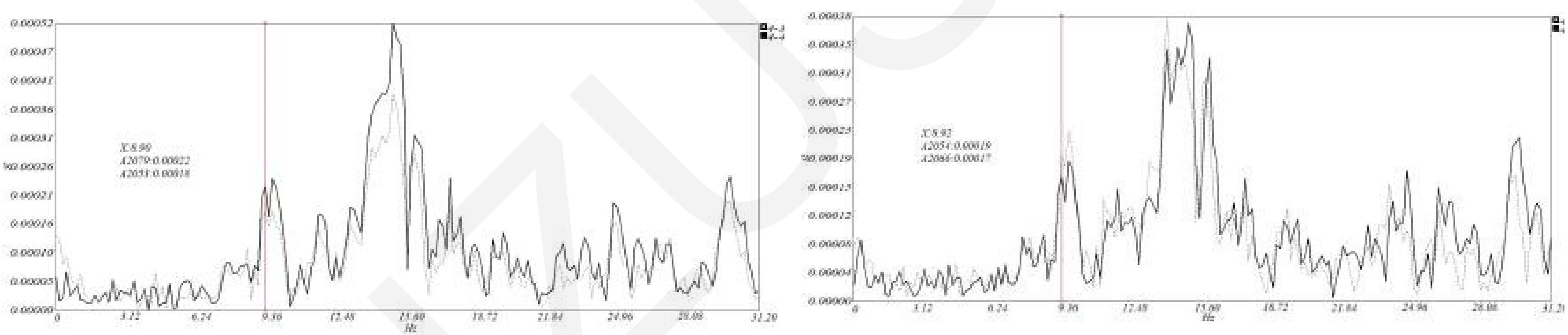


Layout of sensors in the test area

FIELD TEST AND ANALYSIS

The acceleration signals of the pavement during the taxiing of multiple B737-800 aircraft were collected in the test. Figures 12 and 13a-d present the acceleration signals of sensors numbered A2079, A2053, A2066, and A2054, located from the centerline to the shoulder on the No. 3 test line during the taxiing of aircraft at two different times.

FFT was performed on the acceleration signals caused by aircraft taxiing at 15:55, and the tested fundamental frequency of the pavement was found to be 8.90 Hz.



(a) A2079 (4-4) and A2053 (4-3)

(b) A2066 (4-2) and A2054 (4-1)

Spectrum curves of four sensors on test line 3

After FEM updating , it can be seen that the dynamic resilience modulus of the soil foundation is 196 MPa (i.e. when the static resilience modulus is 65 MPa), and the dynamic elastic modulus of the cement stabilized base is 3435 MPa (i.e. when the static modulus is 2000 MPa), the calculated frequency is 8.96 Hz and the error is reduced to 1.75% after fitting by least squares.

RESULTS AND CONLUSIONS

- Aircraft dynamic loads are obtained by solving dynamic balance equations of an aircraft-pavement coupled system. When the aircraft is taxiing on the same pavement at a speed of more than 15 m/s, the dynamic load of the aircraft decreases as the taxiing speed increases under the influence of lift. When the speed is constant, (i.e. when the lift is unchanging), the aircraft load increases significantly with the increase of IRI.

- The fundamental frequencies at the center of the pavement are basically the same as those at the far side of the pavement on the cross section; the first-order frequencies of nodes in the pavement in the depth direction stay the same, only the amplitude of the frequency spectrum decreases.

- The effect of the soil resilient modulus on the vibration frequency is most significant. When the soil resilient modulus changes from 91 to 303 MPa, the fundamental frequency increases by up to 42.6%, from 6.02 to 10.55 Hz. The effects of surface thickness and base thickness on the vibration frequency are less significant, and the effects of the elastic modulus of the surface layer and base layer are the least significant.

- By comparing the fundamental frequency of measured and calculated signals, back-calculated moduli are obtained. The credibility of the moduli has been proved by the Beckman beam method.

- In conclusion, The results of our analysis show the potential of using surface acceleration to evaluate the structural condition of a pavement. Future work needs to be conducted to validate the proposed analysis method with different pavement structures and loading conditions.