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STUDY ON DISTRESS OF AIRPORT PAVEMENT FOUNDATION AND SOLUTION APPLIED TO NOI BAI INTERNATIONAL AIRPORT

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Abstract. The service quality and life of the runway, taxiway and apron pavement system heavily depends on the condition of its foundation, including base and/or subbase layers and subgrade. In the state of water-saturated condition, the strength of foundation would decline significantly, then inducing the downgrade of overall strength of the pavement. In the long term, the impacts from adverse environmental conditions and aircraft wheel loading will mix-up the materials of foundation layers, leading to the degradation of the original physical and mechanical properties of the original designed material. Furthermore, the accumulation of residual deformation and appearance of voids in the granular material can formulate the large holes beneath cement concrete slab. That, in turn, changes the load bearing model of the slab compared to the original design and causes the structural damage of the slab and threatens flight safety. Due to the complication of pavement foundation, the traditional treatment countermeasures usually need a long time for completion, while the airfield system often requires short and high-quality repair time. Therefore, there should be special solutions to satisfy the practical application. The article analyzes the cause, proposes the solutions for pavement foundation treatment and presents an initial application to Noi Bai International Airport. The findings of this study could be critical and significance basis for both academic and practical applications to maintain the service quality of airport construction infrastructure in Vietnam.

Keywords: foundation, subgrade, base, subbase, water saturated, airport pavement.

1. INTRODUCTION

Currently, Vietnam's airport system comprises of 22 airports, allocated throughout the country. The total area of runways, taxiways, and aprons up to nearly 20 million square meters. In that, except for a few newly built, most of these airports were constructed for a long time. The airfield pavement systems in the airports have been seriously degraded and needed to be urgently repaired and maintained, or even reconstructed. Therefore, in the near future, along with planning for reconstruction, maintenance needs to be intensively implemented to suppressing the deterioration process, improving service quality and prolonging the service life of the pavement system. In addition to focusing appropriate funding, an important goal is to research and deploy new and modern technologies suitable for Vietnam's conditions in the maintenance of the airport system [1].

In order to implement a sustainable infrastructure maintenance strategy, the effective repair activities should be conducted in time and effectively. For the airport pavement distresses, it is necessary to study and solve the following problems:

(1) Identify the causal factors affecting/inducing the working conditions/performance of the pavement foundation.

(2) Utilize or apply the appropriate survey technology to diagnose the working condition of the foundation and evaluate/investigate the overall strength or the performance status of the airfield pavement-foundation system.

(3) Propose feasible and relevant solutions for foundation treatment under continuous operation of the airport.

2. PAVEMENT DISTRESS AND POTENTIAL RISK FOR AIRCRAFT OPERATION AND CURRENT CONDITION OF VIETNAM AIRPORTS

2.1. Pavement foundation distress and potential risk

The quality of airport pavement is one of the most critical factors affecting the safety of aircraft operation on an airport. Although pavement quality is usually demonstrated on the surface layer, it is important to identify that the pavement is a unified system of pavement-foundation, where the foundation consists of base, subbase, subgrade layers, and simultaneously working under the impacts of aircraft wheel loading and effects of the surrounding environment including temperature, humidity, stormwater, groundwater and other man-made and natural agents. Distresses on the surface of the cement concrete pavement such as map cracking, pop-out, scaling, spalling, spalling along joints, etc. are usually easy to detect and identified as surface distresses. For the type of defects, there are effective and quick remedial measures to repair. However, the types of structural distresses such as slab crack, multiple slab crack or broken, transverse crack, D-crack, corner crack, meander crack, settling or heave, faulting, pumping, etc. are usually related to the malfunction of the foundation below the slabs. These pavement distresses may generate free object debris (FOD) which can be sucked into aircraft engine or runway or taxiway excursion during take off, landing or high-speed taxiing on the airfield.

In the state of water-saturated condition, the strength of foundation would decline significantly, then inducing the downgrade of overall strength of the pavement. In the long term, the accumulation impacts from adverse conditions and wheel loading would lead to mixed-up material of layers, then the original physical and mechanical properties of the original material will be downgraded. Besides, the appearance of residual deformation, and voids in the foundation material, can formulate large holes beneath the cement concrete slab.

In rigid pavement designation, there is a critical and common assumption that cement concrete slab will rest on the uniform elastic foundation, where the slab bottom will entirely contact the foundation. The holes or weak force-bearing capacity areas forming in the foundation, under wheel load, will generate stress concentration inside the slab. In general, it changes the load bearing model of the slab compared to the original design, and induces critical cracks in cement concrete slab, which may, in turn, threaten the flight safety.

2.2. Overall condition of airfield pavement at Noi Bai and Tan Son Nhat International Airports

The airfield rigid pavement system at Noi Bai International Airport (NIA) and Tan Son Nhat International Airport (TIA) have been seriously degraded due to the number of aircraft operations (landings or takeoffs) exceeding that of designation at many times. The adverse climatic conditions occurring at high frequency such as flood, heavy rain, high temperature…in the airport areas which not only directly affects the safety condition of aircraft operations, but also causes the serious problem of pavement-foundation of the runway, taxiway, and apron.

According to the construction profile provided by the Civil Aviation Authority of Vietnam (CAAV), the runway system of TIA was repaired and opened for use in June 2013. By the end of April 2018, the total number of aircraft operations (landings or takeoffs) on the runway system was about 2.3 times of the total designed operation. Similarly, at NIA, runway 1B was opened in 2003, but by the end of April 2018, the total number of aircraft operations on it was nearly 28 times of total designed number. Airports Corporation of VietNam (ACV), the possess all state-own civil airports in Vietnam, assessed that it would have to close the two runways systems if the pavement systems would not to be repaired, upgraded or renovated since there was high potential risk threaten the safety conditions of aircraft operated on that [1].

Facing the situation, in the COVID-19 pandemic time, when the number of flights seriously declined and negatively impacted the aviation sector over the World, the Government conducted the project to reconstruct the runway systems at NIA and TIA. The 4 runways and almost taxiway systems were renovated and fully opened for operation at the end of April 2022. However, the remaining cement concrete pavement areas of the two biggest airports are still very large. There are about 64% of the total area of the pavement (about 1,200,000 m2) at NIA, and about 76% remaining (1,350,000 m2) at TIA. The large airfield pavement area under overloading operation situations and adverse climate change conditions has continually deteriorated and needs to be maintained frequently. Similar situations have occurred at other airports. Therefore, solutions to repair and maintain the rigid pavement system, including foundation repair solutions, should be studied in the direction of integrating modern and advanced technologies, which can solve specific problems of the airfield component construction under continuous operating conditions and high quality requirements are necessary and significant.

3. INFLUENCE OF WATER-SATURATED FOUNDATION ON THE PERFORMANCE OF AIRPORT RIGID PAVEMENT.

The proposed mathematical models describing the behavior of concrete pavements under the influence of aircraft wheel loads have shown that one of the most common cases that can cause pavement distress is weather conditions during the rainy season, with the appearance of sludge pump. That is, under the effect of dynamic loads, water and particles of artificial or natural foundation materials are forced onto the pavement surface through joints and cracks.

In this case, a redistribution of material beneath the pavement occurs, creating voids, damaging joints, and resulting in increased stresses and strains in the pavement with continued service. The physical mechanism of the occurrence of this phenomenon is associated with the interaction of the rigid pavement with the water-saturated foundation. The impact of aircraft dynamic loads on pavements, due to their curvature deformation, increases pore pressure in the material of natural and man-made layers of foundation. When the aircraft wheel is rolling on pavement surface, under the compression and permeability process, water from the saturated layer of foundation creates an upward osmotic flow. In natural and man-made foundations, the hydrodynamic pressure of water is capable of weakening the bond between the particles of the man-made or natural materials of base/subbase layers or subgrade, which will eventually lead to a decline in bearing capacity and damage the whole pavement structure [2].

The mathematical model describing the performance of the pavement foundation in this case is developed based on the compaction theory of the water-saturated soil layer. The model is formulated based on the following assumptions:

• The air within the voids is little or not existed, then the foundation is considered to be at fully water-saturated condition;

• The overall compressive capacity of the soil is much greater than that of the water and the mineral granular material of the soil. Therefore, they can be considered as incompressible, and accepted that the compaction of the soil only takes place by compaction of the structural mesh of the soil to reach denser state of the hard particles;

• The permeability property and the actual permeability coefficient of soil is assumed to be unchanged and independent with the change of soil stress state.

The above assumptions allow us to present the basic relations of the proposed mathematical model. The continuity equations of the liquid and solid phases of the soil in this case have the following form:

$$\frac{\partial u_z}{\partial z} + \frac{\partial n}{\partial t} = 0 \tag{1}$$

$$\frac{\partial v_z}{\partial z} + \frac{\partial m}{\partial t} = 0 \tag{2}$$

Where:

u_z- the seepage rate of water;

n- porosity of the soil;

z- verticle coordinate;

t- time;

υ_z- volume of solid particles;

m- content of solid particles per unit volume.

From equations (1), (2) when $n + m = 1$, we have:

$$\frac{\partial u_z}{\partial z} + \frac{\partial \upsilon_z}{\partial z} = 0 \tag{3}$$

This means that for a fully water saturated state, the total volume of water filled and occupied in a given soil unit volume is equal to the total volume of the solid particles of material pumped out. For the environment, we use the Darcy-Gershevanov dependency equation to consider the seepage rate:

$$u_z - \varepsilon.\upsilon_z = K_t \frac{\partial H}{\partial z} \tag{4}$$

Where:

ε- the porosity coefficient of the soil;

K_t- permeability coefficient;

H- hydraulic pressure.

The balanced equation is written in the following form:

$$q(t) = p(t) + \sigma(t) \tag{5}$$

Where:

$q(t)$- external load;

$p(t)$- water pressure;

$\sigma(t)$- stress in solid soil.

The solid soil is considered as linear deformation, the compressive equation of the soil has the form:

$$\varepsilon = a\sigma(t) + const \tag{6}$$

Where:

a- compression coefficient.

Expressions from (1) to (6) allow to obtain the equation for hydraulic function H:

$$\frac{\partial H}{\partial z} = \frac{1}{\gamma}\frac{\partial q}{\partial t} + \frac{(1+\varepsilon_{tb})}{a\gamma}\frac{\partial}{\partial z}K_t\frac{\partial H}{\partial z} \tag{7}$$

Where:

γ- density of water;

ε_{tb}- average value of the porosity coefficient over the range of stress variation under consideration.

Equation (7) in the general case is solved with the following initial and limiting boundary conditions:

$$H = f(z), t = 0;$$
$$H = \lambda(t)\frac{\partial H}{\partial z}, t > 0, z = 0; \quad (8)$$
$$H = \mu(t)\frac{\partial H}{\partial z}, t > 0, z = h;$$

In order to find the numerical solution for the above equation, Galerkin Finite Element Method (GFEM) is usually utilized. The reason for using the complicated model proposed above to study the problem of rigid pavement working on a water-saturated foundation under the effect of dynamic loads derives from the necessary to solve the problems of the contact interaction between pavement slab and foundation under water-saturated conditions in the framework represented equation (7).

It is proposed to introduce the response of the water-saturated foundation into the equations describing the performance of the rigid pavement in term of $K_s y\omega$, where - K_s is the coefficient of contact interaction of the pavement with limited stiffness and the foundation, depends on the stiffness and geometrical characteristics of the pavement, the movement speed of the load on the pavement and the parameters of the model described by equation (7); also ω- is the curvature of the pavement slab.

A demonstration to realize the above proposal by of a problem of a concrete pavement slab under dynamic loads as following:

$$EJ\frac{\partial^4\omega}{\partial x^4} + m\frac{\partial^2\omega}{\partial t^2} + \gamma\frac{\partial\omega}{\partial t} + K_s\omega = P(x,t) \quad (9)$$

Where:

EJ- flexural stiffness of the concrete slab;

ω- deflection of the concrete slab.

The equation (9) can be solve by an iteration algorithm, the initial starting value K_s being the value of the coefficient of subgrade reaction of the given soil (regardless of consolidation by permeation). The calculation of K_s is iterated until attaining the required accuracy (the gap between K_s^{i+1} and K_s^i is less than 5%). In practice, the solution of the problem can be achieved after 2-3 iterations.

Solving the problem of concrete slab pavement working on a water-saturated foundation proposed in the above model will calculate the water pressure at the depth of each foundation layer, and thus estimate the amount of material pumped on the pavement surface [2].

In application, the theoretical solution obtained from the problem in practical condition with concrete input data set of pavements will be the basis to estimate the amount of material needed to be added into the pavement foundation for improving the bearing capacity of the foundation, and also of overall pavement structure.

4. METHODS FOR INVESTIGATION AND ASSESSMENT OF THE PAVEMENT FOUNDATION.

Assessment of the condition of the layer of foundation (base, subbase, subgrade) of the pavement structure is an important stage to overly assess the technical condition of the airport pavement. Normally, the general information of physico-mechanical properties to be determined are: compaction, porosity, moisture, elastic modulus, seepage, or permeability coefficient... In addition, in many cases, it is necessary to know the particle composition of material of each layer of the foundation, the expansive property of soil, and the actual thickness of the layers.

In order to get the overall information of the concurrent condition of the pavement structure, there are many methods varying from traditional or simple to advanced technologies which have been applied to investigate and inspect material properties or performance conditions of pavement structure as the whole. The individual or combination of the methods will be properly utilized in accordance with problems rising in particular real circumstances. The ultimate objective is to clearly understand the performance conditions of pavement structure and treatment solution design also [3-5].

The following subsections introduce some relevant methods commonly applied for airport pavement investigation.

4.1. Core drill.

The common sampling method applied to take original material from the foundation layers is core drilling. The undisturbed samples will be used from the pavement structure to determine the physico-mechanical properties of pavement foundation in laboratory conditions. For surface layers, it usually consists of basic strength and deformation properties such as compression, split tensile, elastic modulus of samples. For the types of materials in the foundation (soil, sand, gravel or crushed stone…) the indicators of density, porosity, permeability coefficient, liquid limit, plastic index, and so on should be determined. If necessary for physical calculations, further appropriate values, such as coefficients of thermal conductivity, moisture conductivity, and so on.

The physical and mechanical properties of the materials, including the subgrade soil, obtained from test results can be used in the calculations of the airport pavement classification indexes (Pavement Classification Number, PCN) and (Airplane Classification Number, ACN). Based on the value of the index and the PCN/ACN ratio, conclusions and recommendations can be made about the allowable average number of landings/take-offs per day over the years.

4.2. Assessment of overall performance of pavement structure by PCN indicator.

The Heavy Weight Deflectometer (HWD) device system is commonly used to determine the pavement deflection under the impact of dynamic loads (impulse), simulation for the rolling movement of aircraft wheels. The magnitude of the applied dynamic load may vary with respect to the critical load or the equivalent single wheel design load of the aircraft. The deflection of the pavement is recorded at the location immediately below the compression plate and at typical locations 300 mm to 1,500 mm or 1,800 mm from the center of the centerline.

Currently, the Ministry of Science and Technology of Vietnam already issued the standard code TCVN 11365:2016 in 2016 for determining the number of airport pavement classifications (PCN) by measuring deflection by falling weight.

4.3. Inspecting material condition with GPR device.

Because of the limitations in detection of hidden defects or distresses of the foundation (base, subbase, subgrade) under the thick concrete slabs of the pavement in the airfield, the Ground penetrating radar (GPR) technology, a non-destructive investigation method widely used in the world, is a relevant solution to identify the distresses beneath the concrete slab. In Vietnam, this technology has also been used in mineral exploration, surveying geological defects or finding hidden works of constructions.

In 2012, the Ministry of Science and Technology of Vietnam issued the standard of investigation, assessment and exploration - georadar method, applied to research, investigation, assessment and exploration of mineral and geographical resources. hydrogeology, engineering geology, environmental geology, disaster geology and other related fields. GPR technology has also been used in mineral exploration, surveying for geological defects in river dykes and other construction works. However, the applications in pavement construction are quite limited.

5. SOLUTIONS FOR FOUNDATION DISTRESSES TREATMENT

In general, there are many countermeasures to overcome the distress of pavement foundation. It can be classified into prevention countermeasures, fast repair solutions or reconstruction, depending on the level of distress, technical availability, and time for construction process. The following subsections introduce representative solutions for handling the airport pavement foundation distress [4,6-9].

5.1. Storm water resistant and groundwater lowering.

This is a preventive solution which can be applied for long-term protection for pavement foundation in general.

The change of moisture in layers of foundation of airport pavement structures during their service life greatly affects the performance of pavement structure. The more stable the pavement components and foundations are and the less affected by moisture, the more reliable the pavement performance and the longer the service life. Many researchers have paid attention to this issue and proposed the most reasonable conditions for the operation of the airport pavement by purposefully regulating the hydrothermal regime of the artificial foundation layers. However, due to the poor operating quality of the airport facilities, especially the trench and drainage systems, it is not allowed to consider this as a decisive solution.

In real condition, water can infiltrate into the bases and subgrade of the pavement structures by many different ways: penetrate through unsealed joints, and/or through cracks; through capillary processes from the underlying soil layers; the movement of water from layers below, where it's warmer, to where it's cooler at the top; due to a rise in groundwater levels below the road surface or in adjacent areas. Therefore, the implementation of tasks such as sealing cracks and joints, repairing potholes, creating the necessary horizontal slope to ensure surface drainage, etc. should be carried out through regular maintenance work. often. In the event that water continues to penetrate and exist in the soil or foundation layers of the pavement structure, it is not possible to limit or prevent the destruction of the surface completely, it is necessary to consider measures. such as building an underground trench system to ensure the drainage capacity of the roadbed, or in some cases – lowering the groundwater level below the road surface.

5.2. Repair pavement foundation.

In case the concrete slabs are severely distressed, the solution for pavement foundation treatment can be generally grouped into 2 solutions:

(1) Replacement of damaged concrete slabs: in the circumstances where the cement concrete slab is severely damaged and cannot be used, it will be demolished and removed and the new

slab will replace the old ones. In this case, the foundation layers of base, subbase and/or subgrade will be directly treated or reconstructed. This solution can be conducted according to a large-scale upgrade or renovation plan, with long construction time. This will reduce the airfield capacity, especially for the key components such as runways, main taxiway, or even a small apron (with limited number of parking positions). Therefore, the solution is often not relevant to regular repair activity, and hardly feasible for busy airports because of continuous operation.

(2) Improve the bearing capacity of the foundation. There are advanced techniques that allow us to repair pavement foundations without demolition or removal of concrete slab. The key feature of the new methods is that a special mix of substances will be injected into the water-saturated layers of foundation. The chemical reactions will take place between substances. From here, there are two types of countermeasures, depending on stabilization mechanisms. The first kind is based on the mechanism of hardening the foundation materials. The second one is that the injected mixed substances will be expanded (about 20-30 times in volume) and hardening. It will compact the foundation material layers, and thus improve the strength or bearing capacity of foundation. These solutions have been used in many countries such as the United State, Australia, Canada, Korea…. In Vietnam, these technologies have also been initially introduced and individually applied at some airports. It would be a significant research direction for scholars.

6. POLYMER GROUT INJECTION METHOD AND EXPERIMENTAL APPLICATION FOR RIGID PAVEMENT FOUNDATION AND SUBGRADE TREATMENT AT NOI BAI INTERNATIONAL AIRPORT.

6.1. Method introduction

As mentioned above, the foundation of the rigid pavement at the water-saturated condition, its bearing capacity declines seriously, causing the distresses on PCC slabs. The injection a certain amount of 2-component polyurethane grout into the foundation by the holes drilled through the PCC slabs. After injection process of about 20-30 seconds, the two components substances of the mixture will react together and expand in volume to about 30 times, formulate a hard foam that compresses the soil and pushes water out. Foam and material of base/subbase layers and/or soil of subgrade are compacted to be a high density, which can jointly bear the stress distributed from PCC slabs, then establish a new stable foundation for the slabs.

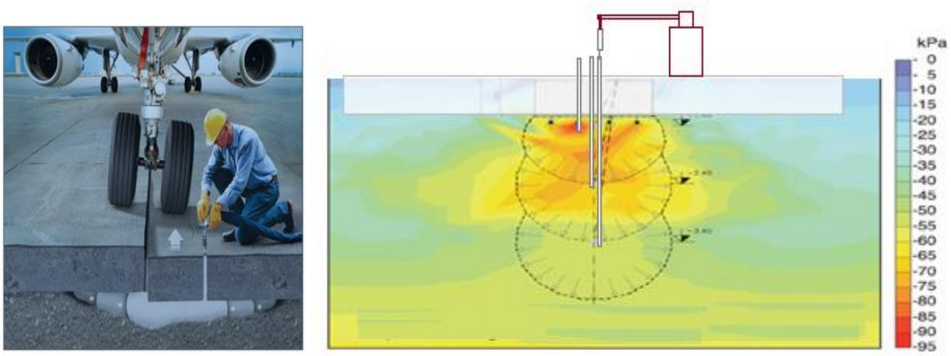

Figure 1. Principle of treatment for reinforcement of foundations and foundations with polyurethane mortar high density [6,7,9].

The urethane bond is relatively strong and stable in water conditions. Due to the diversity of synthetic materials, many products have been introduced with outstanding properties such as chemical resistance, abrasion resistance, etc. is a material with a honeycomb structure, whose properties are flexibly changed according to the original composition. Solid porous polyurethane materials are preferably used in practice. Due to the fine porous structure containing different gases, the material has very good characteristics of sound insulation and high sound absorption coefficient, durable, lightweight and waterproof. The mechanism of the method described in Figure 2. After injecting two-component liquid into the ground (common ratio of 20:1) the volume of the mixture will immediately (3-5 seconds) expand up to 30 times of original, and can create a pressure of about 50-170 tons/m2. After 15 minutes of injection, the grout can reach 90% of its design strength and the repaired area can be opened to normal traffic to flow (Figure 41) [6-9].

6.2. Experimental application at Noi Bai International Airport and results.

a. Back ground

In 2018, there was a phenomenon of silt pump out on the surface of the cement concrete surface pavement. The condition of the slab is also seriously damaged, with many structural cracks on the PCC slab dimension of 5m x 5m. At the problem, experts judged that the foundation beneath the pavement was in a state of fully water-saturation and its strength extremely declined.

Under the busy air traffic condition, the parking slots at Noi Bai should be available for aircrafts operation. The conventional demolition and replacement of slab and repair foundation and subgrade was a long time solution. Therefore, the fast repair solution by using polymer grout injection was considered as an experimental application.

b. Technical treatment solution

The general proposal to apply in practice comprise stages of diagnosis, treatment and evaluation, which are presented in Figure 2.

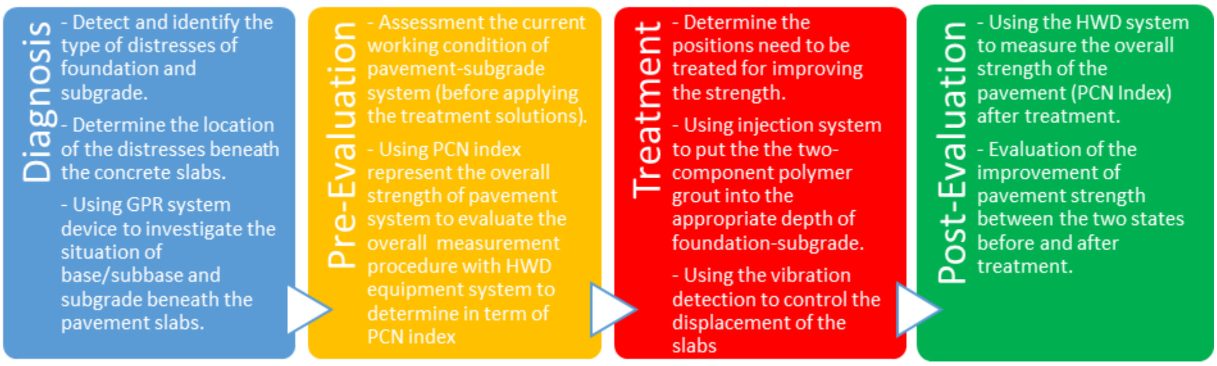

Figure 2. General of fast treatment solution for airport rigid pavement using high density polyurethane foam injection.

For the main stage of foundation treatment, the polymer grout material was injected into the foundation and subgrade through small pipes (diameter of 16 mm) installed in drilled holes through the pavement concrete slab. The low-viscosity polymer flows easily into voids and weak areas in the soil mass. As the reaction occurs, the expanding polymer capable of increasing its volume by 20-30 times its original volume will compress the surrounding soil. A controlled pressure on a limited area (0.8-1.5m) of the pavement to be repaired. The foam polymer composite material quickly becomes a high strength material together with the ground soil, and the water is pushed out through the holes and joints to formulate the stability of foundation and subgrade of pavement.

The material of polymer grout to be used (Polyurethane Foam or PU Foam) has the following characteristics: (1) Can expand 30 times compared to the original volume; (2) Insoluble and reacts even with water; (3) Able to withstand chemicals, solvents, grease; (4) Stable in environments such as: detergent solution, salt, acid, alkali; (5) No nutritional value to insects and rodents [10-12].

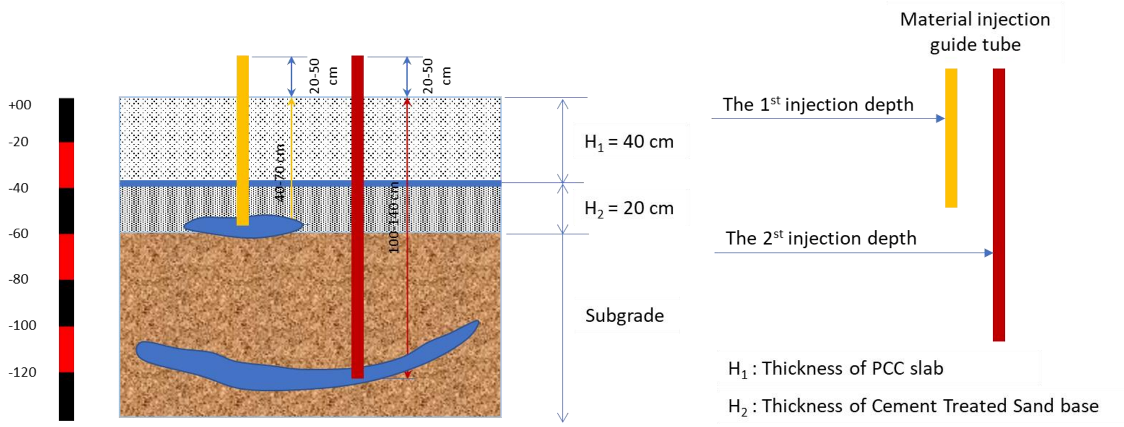

Figure 3: Polymer grouting injection applied to treat the water-saturated foundation.

In addition to the PU injection device system, the other technical supporting systems include Ground Penetrating Radar (GPR) equipment and HWD device system, which were used for investigating the condition of foundation condition and measuring the PCN index of pavement, respectively. For controlling the level of slab, a laser vibration system was used.

c. The practical implementation procedure

At first, the HWD device was used to assess the overall pavement strength of the pavement system before applying the treatment solution. The device also was used to evaluate the condition of pavement after treatment.

Figure 5. PCN index measurement at tested location of NIA’s apron.

In the next step, the location of main distresses was determined and marked on the site. The locations of the holes were marked on slab surface in order to drill and install the guide pipe (diameter of 16mm) to the right location and depth as designed.

In the next step, the two-component liquid mixture of polyurethane was injected as design dosage through the holes. After being injected into the foundation, the chemical reaction between the two substances of liquid mixture occurred, the PU foam expanded and hardened.

Figure 6. Determine the location of guide pipe for polymer grout injection.

Figure 7. Water and mud pumped out from foundation-subgrade of rigid pavement while applying treatment solution of polyurethane injection at tested location at NIA’s apron.

c. Initial experiment results

- The PCN index measure at the repair slab after applying the treatment increased by about 20%, reaching a value of 70-72 (compared to 50-60 before treatment) and was consistent with the road surface condition at the time of exploitation.

- The amount of water released under the slab (in the foundation and roadbed) has not been accurately quantified, but it has shown that the research results for the proposed solution are correct.

7. CONCLUSION

Due to the continuous operation condition, the polymer grout injection countermeasure to strengthen the foundation is a relevant solution for airport repair of rigid pavement structure. In the conditions of Vietnam, the positive results from initial results from research and experimental application at Noi Bai International Airport was proven to be feasible. The combination with other advanced methods of non-destructive investigation (GPR) and assessment (HWD) would be an promising overall treatment package, which can help to conduct airport pavement repair works promptly. For expanding the application in practice, further studies should be conducted in both the theoretical and practical sides in future.

REFERENCES

[1]. CAAV, Annual Reports, Civil Aviation Authority of Vietnam, 2021.
[2]. Pham Huy Khang, Modern Airport Pavement, Construction Publishing House, Vietnam, 2017 (In

Vietnamese).
[3]. Pham Huy Khang, Portland cement concrete pavement design for highway and airport, Transport Publishing House, Vietnam, 2010 (In Vietnamese).
[4]. Pham Huy Khang, Operation and Maintenance of airport pavement, Transport Publishing House, Vietnam, 2010 (In Vietnamese).
[5]. Nguyen Trong Hiep, Pham Huy Khang, Tran Thi Thuy, Pham Quang Thong, Ho Thanh Trung, Application of georadar method for detecting base and subgrade distresses of rigid pavement at noibai international airport, Science Journal of Transportation, 12 (2022).
[6]. URETEK, Uretek Ground Engineering, URETEK Worldwide. http://uretekworldwide.com/index.php/ground-engineering1/, accessed 22 April 2023
[7]. W. Ellis, Assessment of Uretek Deep Injection Process, Vermont Agency of Transportation, Research & Development Section, Initial Report, 2015.
[8]. Steven Soltesz, Injected Polyurethane Slab Jacking, Oregon Department of Transportation Research Group, Final Report (SPR 306-261), 2002.
[9]. URETEK, The URETEK™ Advantage for Public and Private Infrastructures, URETEK USA, Inc., 2005.
[10].O. Buzzi, S. Fityus, Y. Sasaki, S. Sloan, Structure and properties of expanding polyurethane foam in the context of foundation remediation in expansive soil, Mechanics of Materials, 40 (2008) 1012-1021. https://doi.org/10.1016/j.mechmat.2008.07.002
[11]. X. Li, J. Li, J. Wang, J. Yuan, F. Jiang, X. Yu, F. Xiao, Recent applications and developments of Polyurethane materials in pavement engineering, Construction and Building Materials, 304 (2021)124639. https://doi.org/10.1016/j.conbuildmat.2021.124639
[12]. M. M. S. Sabri, N. I. Vatin, Kifayah Abood Mohammed Alsaffar, Soil Injection Technology Using an Expandable Polyurethane Resin: A Review, Polymers, 13 (2021) 3666. https://doi.org/10.3390/polym13213666