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Research Article

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Designing of concrete pavement expansion joints based on climate conditions of Vietnam

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Abstract: Main objective of this paper is to present ananalysis of necessity of providing expansion joints in the plain cement concrete pavement considering the climate and weather conditions of Vietnam. This study would help in the proper designing of expansion joints of highways and airport roads and thus can improve life span of cement concrete pavements to be constructed in Vietnam.

Keywords: expansion joint, cement concrete pavement, thermal stress

1 Introduction

Average temperature in Vietnam ranges from 30°C - 35°C and it rises up to 39°C in Hanoi, and up to 38°C in Hochiminh City. Surface temperature of the cement concrete roads/ pavement rises at places upto 67-70°C during day time, due to absorption of direct sun rays falling on the pavement. Large variation of day and night temperature during summer and winter creates thermal expansion and contraction conditions in the pavement concrete causing high compressive stressinside the pavement. The value of the compressive stress depends on the expansion joints' interval. When the expansion joints' interval is large, compressive stress in the pavement may exceed allowable values, thus causing development of fracturesatthe edges of concrete slabs (Figure 1), besides development of longitudinal and transverse cracks due to warping of subgrade and also upper layers (Figure 2) [4, 10].

According to a survey [1], in the most airports in South Vietnam designed and built by the US in the war time (1960-1965), expansion joints are placed only at 150-200 m intervals. Thus in operation, fractures appeared due to thermal stresses. Cracked slabs accounted to be 80% of the total pavement slabs in the airodrome.

At present, necessity of providing expansion joints on both cement concrete airport roads and highway pavements are debatable in Vietnam. In current highway pavement design procedures [2] and airodrome pavements of Vietnam [3], there are no widely accepted guidelines to calculate expansion joint arrangements. The expansion joint layout depends on the specific project requirement. Still at number of places in pavement slab longitudinal and transverse cracks on the pavement and fractures of concrete slabs at the expansion joints, are usually seen.

In Figure 1, it is shown that cracks on the edge of the concrete slab near the expansion joint on the Bus Rapid Transit (BRT) lane on Le Van Luong Street, Hanoi city, road have expansion joint interval of 10 slabs, expansion joint of 0.02 m width. Figure 2 shows splitting off concrete slab in one of the pavement in the US [10].

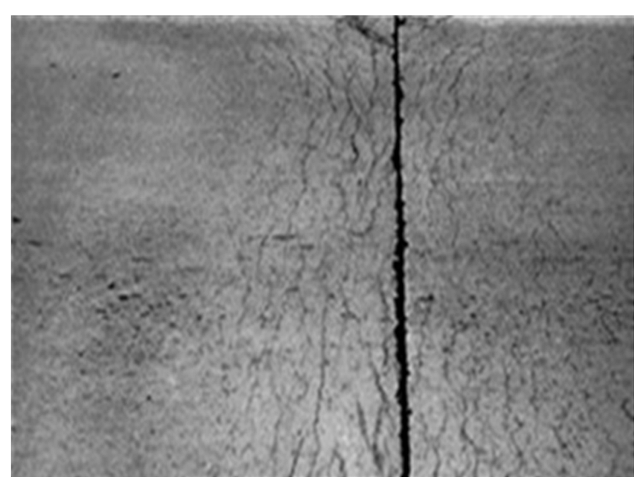

Figure 1: Fracture on the edge of concrete slab in Vietnam [4]

In this article, authors explained necessity of providing expansion joints on plain cement concrete pavements

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Figure 2: Concrete slab splitting off in the US [10]

considering weather and climatic conditions of Vietnam based on the theoretical approach.

2 Methodology of calculating spacings of expansion joints for cement concrete pavement

2.1 The necessity of expansion joints on cement concrete pavement

With the increase and decrease of temperature, the concrete slab will expand or shrink, respectively. In case of thermal expansion, if pavements or not provided expansion joints or distance and spacing between joints is not sufficient, pavement will deform and even crack. Following are some cases of concrete pavement deformation/cracks:

In the first case, lateral compression causes deformation and bending at the edges resulting fractures, when the arising shearing stress exceeds the concrete's shearing resistance. In the second case, a concrete slab is blocked from expansion, thus it would warp up and split off from the sub-base causing longitudinal instabililty.

The first case (condition 1): to avoid concrete slab edge fracture (as in Figure 1), when the slab expands due to heat, pressing the edges at the expansion joints, following condition needs to be satisfied:

$$\tau_{\max}.k \leq [\tau]\,, \tag{1}$$

where τ_{max} – shearing stress cause by heat, MPa; k – reserves factor, according to [8], it is recommended that k = 2; $[\tau]$ – shearing resistance strength of the concrete.

According to study result in [8], we have:

$$[\tau] = 0,26.\,[R_n]\,, \tag{2}$$

where $[R_n]$ – compressive strength of the concrete.

Maximum shearing stress due to temperature diffirence is determined based on plane solution according to elastic theory, concrete slab is subjected axially compression stress σ_T:

$$\tau_{\max}.k = \frac{\sigma_1 - \sigma_3}{2}.k = \sigma_T, \tag{3}$$

where σ_T – compressive stress in the concrete slab caused by heat:

$$\sigma_T = \varepsilon_{bt}.E_{bt} = \alpha.E_{bt}.\Delta T, \tag{4}$$

where σ_1, σ_3 – maximum and minimum principal stresses, respectively, MPa; E_{bt} – elastic modulus of the concrete, MPa; α – concrete thermal expansion factor, /°C; and ΔT – average temperature deviation between seasons in the concrete slab, which is temperature difference at construction time and in calculated time, it is the most disadvantageous to carry out construction in coldest weather in the year, while the calculating time is summer days.

To replace (2) and (3) into (1), we get:

$$\sigma_T \leq 0,26\,[R_n]\,. \tag{5}$$

Second case (condition 2): longitudinal stability condition of the slab series, to prevent the slab from coming up and splitting off from the base course (see Figure 2), causing longitudinal instability along the slabs. In this case compressive stress should not exceed the calculated value as per following formula:

$$\sigma_T.k \leq \sigma_T^{cp}, \tag{6}$$

where σ_T – compressive stress caused by pressing the concrete slab when the temperature increases, and the slab is unable to expand, value calculated according to (4), MPa; σ_{cp} – allowable compressive stress of the concrete, MPa, according to testing result in [9], to ensure longitudinal stability, one may take: $\sigma_T^{cp} = 0,031\sqrt{E_{bt}.\rho.h}$;; k – strength reserves factor, can be taken as 2; and h, ρ- corresponds to thickness (m) and specific density of the concrete (T/m^3).

If one or other above condition is not satisfied: either the concrete slab edge is fractured (according to condition 1), or the concrete slab series is pressed, causing longitudinal instability (according to condition 2), then expansion joints should be arranged for the concrete slab series.

2.2 Calculation expansion joint interval

Typical design of an expansion joint is presented in Figure 3.

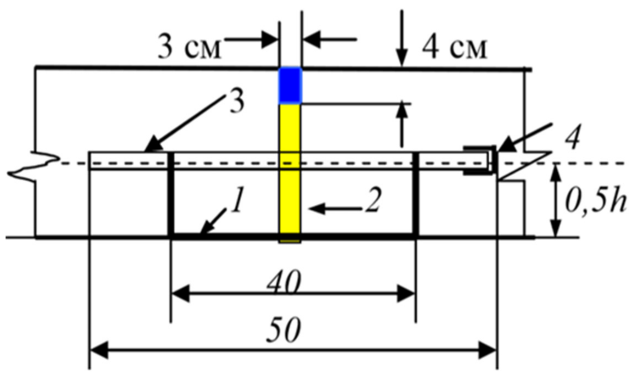

Figure 3: Expansion joint design (1 – bond transfer steel supporting rack; 2 – joint filler wood board; 3 – bond transfer steel; 4 – plastic cap)

According to elastic thermal theory, when the temperature in a concrete slab increases, the concrete slab will expand. Thermal stress in the concrete slab only appears when the concrete slab is choked, prevented from expansion. It is assumed that, because the temperature increases by a value of ΔT, the concrete slab is blocked from expansion totally, and inside the concrete slab there appears a relative deformation (virtual deformation) which is calculated as:

$$\varepsilon_{bt} = \alpha.\Delta T, \qquad (7)$$

Relative deformation ϵ_{bt} of the concrete slab series is calculated as:

$$\varepsilon_{bt} = \frac{\Delta_{bt}}{L} = \frac{\sigma_T}{E_{BT}},$$

that means:

$$\Delta_{bt} = \frac{L.\sigma_T}{E_{BT}};$$

$$L = \frac{E_{bt}.\Delta_{bt}}{\sigma_T}, \qquad (8)$$

where L – interval of the expansion joints including deformation of the slab series, m; α – thermal expansion factor BT, on average $1*10^{-5}/\ ^{\circ}C$; σ_T – concrete compressive stress caused by expansion blocking, determined by (4); Δ_{bt}- absolute expansion (blocked expansion) of the concrete; and ΔT – temperature difference in the middle of the concrete slab thickness.

For example, calculation is made for concrete pavement slab series without expansion joint. It is assumed that the concrete pavement in Hanoi city has 4.5 m size each slab, concrete elastic modulus taken as 31000 MPa, thermal stress σ_T calculated with average temperature difference in the middle of the slab's thickness in Hanoi city is $\Delta T = 36{,}7^{\circ}C$, according to (4), the result is $\sigma_T = 11.4$MPa. The concrete slab expands from its center, replace that into (8), one calculates that for each half of the slab, absolute deformation caused by expansion is $\Delta_{bt} = 0.08$ cm, concrete edge at the pressed cross joint is calculated, which comes off the base course surface at approximate height of 6cm. In Figure 4, it is shown that calculation result for the case without expansion joint of highway concrete pavement in Hanoi city climate condition.

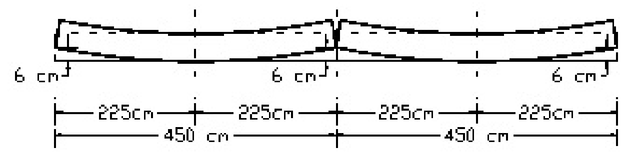

Figure 4: The model simulation of concrete slab coming up caused by thermal expansion without expansion joint

$$(H = \sqrt{225,08^2 - 225,0^2} = 6cm).$$

Similarly, calculation is made for concrete pavement slab with expansion joints made from wood having the joint width of 2.0 cm, interval spacing of 45 m. Absolute displacement of the each half concrete slab is 0.73 cm.

The allowable total displacement from two sides of the expansion joint is 1.2 cm (each side is 0.6 cm). Hence, the restrained displacement for each side is 0.83-0.6 = 0.23 cm. The restrained displacement causes the slab pushed up at the expansion joint (similar to Figure 2). The pushed up displacement can be calculated as follow:

$$H = \sqrt{2250,23^2 - 2250^2} = 32cm.$$

The calculated result indicates that the failure at the expansion jointswill still happen if the width and the interval spacing of the expandsion joints are not adequate.

In Formula (8), it is assumed that the thermal stress calculated for the case in which concrete deformation is prevented completely. In fact, at expansion joints there are filling wood boards, under pressure; the filling wood board may be compressed, thus allowing partially deformed expansion of the concrete. That means, thermal stress arises from the compressed concrete slab, may be reduced because the wood boards may absorb partially the force. That means, thermal stress value caused by compressed concrete slab, shall be reduced, because the wood boards will decrease partly, equal compression resistance strength of the wood board, then we have:

$$(\varepsilon_{bt} - \varepsilon_v).E_{bt} = \varepsilon_{tt}.E_{bt} = \sigma_{tt}, \qquad (9)$$

where ϵ_{tt} – calculating deformation considering deformation of the joint filling material; ϵ_{bt} – deformation of the concrete after totally blocking; ϵ_v – deformation of the joint blocking temerching; and σ_{tt} – calculating thermal stress caused by the concrete when expanding, less the thermal stress absorbed by the wood board. Its value equal concrete compression stress calculated with (4), less compression resistence of the joint filling wood board:

$$\sigma_{bt} = \sigma_T - \sigma_V, \tag{10}$$

Δ_V is called absolute deformation of a joint filling wood board, at that time, relative elastic deformation of the binding wood board in the middle of the expansion joint in elastic period: $\varepsilon_V = \frac{\Delta_v}{B}$, or we get:

$$\Delta_V = B.\varepsilon_V = \frac{B.\sigma_v}{E_v}. \tag{11}$$

One let 2 absolute forms of the concrete and filling wood are the same, and replace stress σ_T with press σ_{tt} theo (10), from (8) we got:

$$L = \frac{E_{bt}.\Delta_V}{\sigma_T - \sigma_v}, \tag{12}$$

In above measures: B – width of the expansion joint wood board, following the design B = 0.02-0,03 m; σ_V – compressive strength of the joint wood board, if the wood board is made of wood, on average $\sigma_V = 2-4MPa$; and E_V – elastic modulus of the joint filling wood, on average E_v = 6-8 MPa.

In case the wood board's height is smaller than the concrete slab's thickness (except mastic filling depth), combined height of the joint wood board is smaller than the concrete (thickness), degree of the stress part absorbed by the planks, this absorption disproportionate with the joint filling wood board. Then the Formula (12) is rewritten as below:

$$L = \frac{E_{BT}.\Delta_v}{\sigma_T - \sigma_v \frac{h_v}{h}}, \tag{13}$$

where h – concrete slab's thickness; h_v – height of the joint filling wood, following the design for highway, taking h_v = h-0.04,m, for any airdrome h_v = h-0,06,m; σ_v – compressive strength of the wood plank.

Thus, when one gets the concrete elastic modulus, and compression resistance strength, accoding to formula (13), concrete formula modulus, elastic modulus and compression resistance of the joint filing wood board, and compression resistance of the joint filling wood board, accoding to formula (13), it is absolutely possible to calculate the required intevals of expansion joints for pavement concrete slab series.

3 Analysis of Vietnam's climatic conditions

3.1 Evaluation ofconditions requiring expansion joints

While calculating requirements of expansion joints, temperature of both winter and summer periods should be considered, especially in Hanoi where temperature varies from 15°C to 39°C (average of 5 successive days). Heat generated from hydration of cement after spreading concrete (within 1-2 first hours after mixing), also increases temperature in the concrete on anaverage 4-6°C. Concrete selected for highway pavement is generally of has 30 MPa compressive strength, and for airo drome of 35 MPa (as per minimum strength requirement of construction regulations of Vietnam). Other parameters, concrete elastic modulus E_{bt} = 31000 MPa, thermal expansion factor $\alpha = 10^{-5}/°C$, absolute density for highway concrete ρ = 2,45 T/m^3, for airdrome concrete ρ = 2,5 T/m^3 are considered.

To calculate average temperature in the middle of the concrete slab, it is required to know temperature on the slab surface. Concrete slab surface temperature is determined by measuring by instruments. In case of no actual data available, it is possible to calculate temperature by following Formula [4]:

$$T_{bm}^{0C} = T_{kk} + T_{bx}, \tag{14}$$

with

$$T_{bx} = \frac{\rho.I.k_b}{a_{dn}},$$

where T_{kk} – air temperature, taken average of 5 hottest days in a year, °C; T_{bx} – temperature caused by solar radiation, °C;ρ – heat asorption factor, depending on colours, state of the pavement, ρ = 0,76; I – solar radiation strength, according to TCVN 2:2009, Hanoi area I = 798 kcal/m^2.h; and K_b – factor taking into account weakening solar radiation due to asorption to the amosphere, in Vietnam, it can be deemed as k_b = 0.90.

From Formula (14), temperature on concrete slab surface for Hanoi area, Vietnam, is calculated and shown in Table 1.

To calculate average temperature in the middle of a highway pavement concrete slab, apply calculating formulae in the designing procedure (QĐ 3230/2012), temperature difference along depth of the concrete slab for Hanoi city is ΔT°C = 0.86.h. In comparison to highway, for airport road pavement slab, temperature gradien factor will reduce because the concrete slab would be as thick as 40cm,

Table 1: Average temperature deviation in the middle of the slab's thickness

T°C Surface, max	T_0C		$T^{\circ C}$ – mixed Construction	Temperature deviation, ΔT, °C	
	Highway	Airdrome		Highway	Airdrome
67,4	56,7	51,8	20	36,7	31,8

in this case.In reference, temperature gradient factor is ΔT°C = 0.78.h is considered [4], where h is the slab's thickness. To calculate average temperature in the middle of the slab's thickness, depth is considered at h/2. In the calculation, depth ofhighway concrete pavement slab is 0.25 m, and airodromepavement is kept 0.4 m. Table 1 shows average temperature deviation in the middle of the slab's thickness.

3.1.1 Evaluation of requirement of expansion joints for highway pavement

According to condition (1):

$$\sigma_T \le 0,26.[R_n],$$

With compressive strength [R_n] = 35 MPa. According to (1) and (4) and from Table 1. one calculates that:

$$\sigma_T = 31000.0,00001.36,8 = 11,4MPa,$$
$$0.26.R_n = 0.26.30 = 7.8MPa.$$

This does not satisfy the conditions (1):

$$11.4 > 7.8(\text{MPa}).$$

According to condition (2):

$$\sigma_T^{cp} = 0,031\sqrt{31000.2,45.0,25} = 4,27MPa,$$
$$\sigma_T.k = 11,4.2 = 22,8MPa.$$

Not satisfying conditions (2):

$$22.8 > 4.27(MPa).$$

Both conditions are not satisfied, cement concrete highway pavement is shared in Hanoi, it is required to build expansion joints

3.1.2 Calculation of the necessity of the expansion joint for airodromepavement:

Similar calculation is applied for highway pavement, and the result is as below:

According to Condition 1:

$$\sigma_T \le 0,26.R_n$$
$$\sigma_T = 31000.0,00001.31,8 = 9,58MPa,$$
$$0.26.Rn = 0.26.35 = 9.1MPa.$$

It does not satisfy the condition (1): 9.58 > 9.1 (MPa).

According to condition (2):

$$\sigma_T^{cp} = 0,031\sqrt{31000.2,5.0,25} = 4,31MPa,$$
$$\sigma_T.k = 9,58.2 = 19,1MPa.$$

Not satisfying condition (2):

$$19.1 > 4.31(MPa).$$

Both above conditions are not satisified. Thus for Hanoi area, it is compulsory to build expansion joints for airport concrete expansion joint.

3.2 Calculation of intervals between expansion joints

For planned structure (see Figure 3), from wood board submerged in water to prevent insects, having compressive strength σ_V = 3 MPa, elastic modulus E_V = 7 MPa. Calculate for 2 types of pavement: for highway and for airport, with expansion joint's width for both case is B = 0.02 m abd B = 0.025 m, respectively.

Calculation for highway pavement: Calculate the intervals between expansion joints according to Formula (13), the result is shown in Table 2. Similarly, calculate for airdrome pavement, the results are shown in Table 3.

Conditions: As per climatic condition of the Hanoi city, it is compulsory to build expansion joints for the construction of plain cement concrete pavementfor airodromes and highways. Joints' interval depends on the expansion joint's width. When increasing width of a expansion joint from 0.02 m to 0.025 m, the interval increases from 35 up to 44 m for highway and 47-59 m for airodrome.On an average increasing interval by 10 m, help to reduce number of expansion joints on the pavement.

Table 2: Intervals between expansion joints for highway pavement

Average thicknes, m	Expansion joint width, m	Puffed -cement, m	Temperature - deviation, °C	L,m Calculate, m
0.25	0.02	0.04	36.7	35.0
0.25	0.025	0.04	36.7	44.0

Table 3: Intervals between expansion joints for airdrome pavement

Average thicknes, m	Expansion joint width, m	Puffed - cement, m	Temperature-deviation, °C	L,m Calculate m
0,4	0.02	0.06	31.8	47.0
0,4	0.025	0.06	31.8	59.0

4 Discussion and recommendations

Considering varying temperature condition of Hanoi and other region of Vietnam, it is required to ensure stability and safety of highways and airodromes pavement. To avoid development of cracks on plain concrete slabs, expansion joints are required at adequate intervals. For this, detailed analysis has been carried out and results have been evaluated.

As per analysis, the interval of expansion joints for pavement in Hanoi area should be at every 35.0 min an average (equivalent with 8 concrete slabs), with width 0.02 m; and on an average at every 44 m (that is, 10 concrete slabs), if expansion joint width is 0.025 m. For airodromes, the interval between expansion joints should be 47 m (on average 8 slabs) when the selected width of expansion joints is 0.02 m, or the interval shall be 59 m (on an average 10 concrete slabs) for 0.025m width.The above result demonstrates that on some concrete pavement in Vietnam, the expansion joint width was taken as 0.02 m. which was small therefore edge cracks and fracture were observed as shown in Figure 2.

To increase intervals between the expansion joints, it is possible to apply joint filler materials with high deformity. It wouldhelp in increasing expansion space for the concrete slab, and thus in reduction of number of expansion joints on the pavement Other measures includeselection of low expansion coarse aggregates such as Diabase with thermal expansion factor $\alpha = 0.83*10^{-5}/°C$ [10]. This will also helps in reducing the thermal stress down to 17%, and increasing intervals between the two expansion joints by 20%.

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