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A Study on Numerical Modelling of Rigid Pavement: Temperature and Thickness Effect

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***Abstract*—**Pavement engineering plays a significant role to develop cost effective and efficient highway and road networks. In general, pavement regarding structure is categorized in two core group namely flexible and rigid pavements. There are various benefits in application of rigid pavement. For instance, they have a longer life and lower maintenance costs in compare with the flexible pavement. In rigid pavement designs, temperature and thickness are two effective parameters that could widely affect the total cost of the project. In this study, a numerical modeling using Kenpave-Kenslab was performed to investigate the effect of these two important parameters in the rigid pavement.

***Keywords*—**Rigid pavement, Kenpave, Kenslab, thickness, temperature.

I. Introduction

PAVEMENT is a broad field of geotechnical engineering that has drawn the attention of the researchers due to its contribution to the development of the transportation and accordingly developments in economic. Up to now, many types of researches have been carried out on the application of the flexible pavement [1]-[10] but the rigid pavement less considered by the researchers. The rigid pavement usually made of concrete reinforced with steel and has a low cost of maintenance.

Recently, a considerable literature has grown up around the theme of pavement engineering. For instance, in a rigid pavement study using high-performance concrete and steel, the authors recommended that these materials could fulfill the design criteria of the bus lanes and they could be applied in the bus lanes instead of the flexible pavements [11]. In another case, cost factor was reported as a deficiency in the design process of rigid pavements, and a formulation based on genetic algorithm was recommended in optimum design a rigid pavement [12]. Based on a series of experimental studies on a composite of tire and cement, an analytical model was recommended to determine the thickness of this material for subgrade layer in rigid pavement design [13]. In another case, the vulnerability of the rigid and flexible pavement under a combination of thermal and temperature stresses was compared and concluded that both has a same potential vulnerability [14]. In another study, the dynamic behavior of a rigid pavement under stresses of an airplane was figured out. The results showed that temperature gradient increased [15]. In another study, a series of reviews carried out on crucial parameters in selecting sealant for a rigid joint pavement [16]. In another case, the effect of temperature on the rigid and flexible pavement was performed. The results for rigid pavement showed that the maximum value for temperature differential was 15ºC at 2 cm underneath from the results of [17]. A study performed to figure out the minimal impact of the thermal expansion ratio of optimized thickness in a rigid concrete pavement [18]. In another study, the effect of ordinary concrete pavement on the environment was compared with the effect of concrete mixed with alternative materials such as fly ash and concluded that application of fly ash is very beneficial [19]. In a study of shrinkage behavior of the concrete pavements, optimized contents of the rubber mix with concrete to control shrinkage of a rigid concrete pavement mixed with rubber were revealed [20]. In another pavement study in airport areas, the effect of temperature changes in deflection of concrete pavement joints was investigated [21]. An experimental investigation after six-month monitoring showed that application of the fiber reinforced concrete is a cost-effective and useful technique in road construction [22]. In another case using marble waste in concrete pavement construction, it was reported that increasing marble content of the concrete leads to decrease the strength of the content while it increases the durability of the concrete [23]. In a comparative study of concrete reinforced fiber, it was reported that application fiber reduces self-shrinkage cracks of a concrete pavement in compared with unreinforced concrete [24]. A design method was proposed to construct a concrete pavement using fiber in another similar study [25]. In another case, the effect of air temperature on the rigid pavement was investigated [26].

II. Rigid Pavement

A rigid pavement structure made of three layers namely surface layer, base course, and sub-base course. The terminology of the concrete pavement is another common name that is used instead of rigid pavement.

The surface layer or slab is the firmest layer that absorbs the primary part of the stresses. The base and sub-base course layers have a lesser firmness in comparison with surface layer but have a major effect on draining of the pavement and freezing protection.

The higher rate of the modulus of elasticity is the main reason that the rigid pavements are crucially firmer than flexible pavements. This factor leads to lower deflection for

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rigid pavements under severe stresses. Reinforcing steel is applicable in the rigid pavement to transfer heat stresses and to reduce joints and keep cracks tightly. Fig. 1 shows a typical section of a rigid pavement [27].

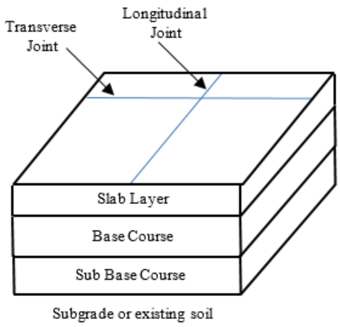

Fig. 1 A typical section of the rigid pavement

In Section II A-C, we present different types of the rigid pavement have been introduced.

A. Continuously Reinforced Concrete Pavement

In this kind of rigid reinforcement, steel reinforcing bars located along with the length of the pavement to firmly transverse the stresses by transverse cracks. Fig. 2 illustrates a schematic plan and profile section of this technique [27].

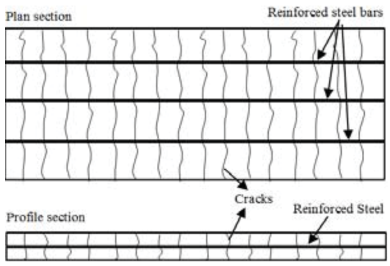

Fig. 2 A typical section of the continuously reinforced concrete pavement

B. Concrete Pavement Contraction Design

In this technique, application contraction joints prevent any crack appears on the slab instead of a steel reinforcing bar. The spaces between transverse joints help to prevent any crack produce on the surface concrete due to moisture and temperature stresses. The dowel bars in transverse joints and tie bars at longitudinal joints apply to transfer the loads. Fig. 3 illustrates a schematic view of this pavement design method [27].

C. Jointed Reinforced Concrete Pavement

In the Jointed Reinforced Concrete Pavement technique, a combination of joints and steel reinforcements control the cracks and transfer the stresses. The transverse joints place with more offset in compares with concrete pavement contraction design method. Fig. 4 illustrates a schematic plan and profile of this technique [27].

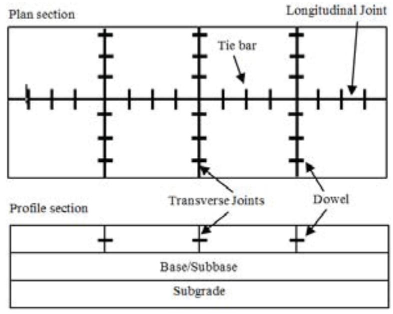

Fig. 3 A typical section of the concrete pavement contraction design

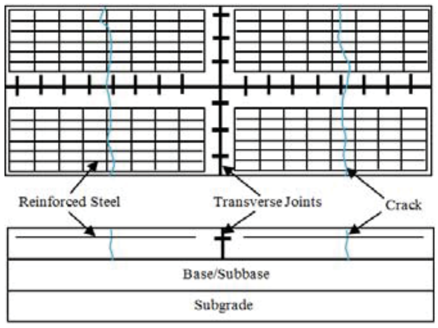

Fig. 4 A typical section of the concrete pavement contraction design

III. Methodology

In this study, to investigate the effect of temperature and thickness as two crucial factors in rigid pavement a series of numerical analysis have been performed. Fig. 5 illustrates the flow chart of this study.

In this study, to investigate the effect of temperature, three degrees of temperature were namely compared 40^0C, 25^0C and 10^0C. The thickness of each slab under mentioned temperature was supposed as 10 cm constantly. To compare the effect of the thickness, two slabs with 5 cm and 10 cm thickness under 10^0C was compared.

Only one layer was considered to perform the modeling. Besides, one nodal number was used to check the convergence. To check the contacts, one cycle number were deemed. Seven points in the x-axis and seven points in y-axis were considered to perform the modeling. A tolerance of 0.001 envisaged in each iteration to perform an accurate modeling. Also, the coefficient of thermal considered as 0.000005. The finite element coordinate of the studied slab was shown in Table I.

TABLE I
Finite Element Grid Coordinate for Studied Slab

X-Axis	Y-Axis
0	0
15	15
30	30
50	50
80	80
120	120
180	180

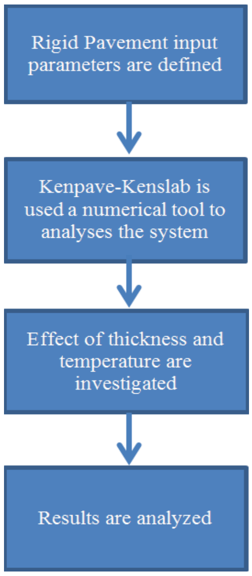

Fig. 5 Flowchart of this study

IV. Results and Discussion

A. *Effect of Temperature (40^{0}C)*

The deflection values of modeled slab under 40^{0}C temperature and 10 cm thickness could be seen in Table II. The lowest deflection value for point No. 1 and No. 29 was about -0.00005 cm and the maximum value for deflection was at point No. 21 about -0.00235.

B. *Effect of Temperature (25^{0}C)*

Table III shows the effect of the 25^{0}C temperature and 10 cm thickness for modeled slab. The maximum value for the deflection is No. 41 is about 0.00242. The acquired minimum deflection value for slab was gained at point No. 1, No. 5 and No. 29 with -0.00004 cm.

C. *Effect of Temperature (10^{0}C)*

Table IV shows the effect of the 10^{0}C temperature and 10 cm thickness to the slab. The acquired minimum value for deflection under 10^0 C was gained at point No. 1, No. 2, No. 5, No. 8, No. 9 and No. 12, No. 29 and No. 30 which was about -0.00002. The measured maximum deflection value was at the point of 49 with -0.00140 cm.

D. *Effect of Thickness (5 cm)*

In this section, a slab with 5 cm thickness under 10^0 C temperature was modeled, and the results were compared with the outcome of the slab with 10 cm thickness and under 10^{0}C.

Table V shows the effect of the 5 cm thickness on deflections of the slab. As could be seen, from point number 1 to 3 and 8 to 9 no deflection points could be seen. The lowest deflection value belongs to point No.10, No. 11, No. 16, No. 17 and No. 22 and No. 23 with 0.00001 cm deflection. The acquired maximum deflection value belongs to point number 41 with 0.00035 cm deflection.

TABLE II
Deflection of the Slab under 40 ^{0}C Temperature and 10 cm Thickness

No.	Deflection (cm)	No.	Deflection (cm)
1	-0.00005	26	-0.00015
2	-0.00006	27	0.00136
3	-0.00010	28	-0.00241
4	-0.00015	29	-0.00005
5	-0.00005	30	-0.00006
6	0.00146	31	-0.00009
7	-0.00230	32	-0.00015
8	-0.00006	33	-0.00004
9	-0.00007	34	0.00146
10	-0.00011	35	-0.00231
11	-0.00017	36	0.00146
12	-0.00006	37	0.00145
13	0.00145	38	0.00142
14	-0.00231	39	0.00136
15	-0.00010	40	0.00146
16	-0.00011	41	0.00291
17	-0.00014	42	-0.00085
18	-0.00020	43	-0.00230
19	-0.00009	44	-0.00231
20	0.00142	45	-0.00235
21	-0.00235	46	-0.00241
22	-0.00015	47	-0.00231
23	-0.00017	48	-0.00085
24	-0.00020	49	-0.00419
25	-0.00026	50	-

TABLE III
Deflection of the Slab under 25 ^{0}C Temperature and 10 cm Thickness

No.	Deflection (cm)	No.	Deflection (cm)
1	-0.00004	26	-0.00012
2	-0.00005	27	0.00114
3	-0.00008	28	-0.00201
4	-0.00013	29	-0.00004
5	-0.00004	30	-0.00005
6	0.00122	31	-0.00008
7	-0.00192	32	-0.00012
8	-0.00005	33	-0.00003
9	-0.00006	34	0.00122
10	-0.00009	35	-0.00192
11	-0.00014	36	0.00122
12	-0.00005	37	0.00121
13	0.00121	38	0.00118
14	-0.00193	39	0.00114
15	-0.00008	40	0.00122
16	-0.00009	41	0.00242
17	-0.00012	42	-0.00071
18	-0.00017	43	-0.00192
19	-0.00008	44	-0.00193
20	0.00118	45	-0.00196
21	-0.00196	46	-0.00201
22	-0.00013	47	-0.00192
23	-0.00014	48	-0.00071
24	-0.00017	49	-0.00350
25	-0.00021	50	-

TABLE IV
DEFLECTION OF THE SLAB UNDER 10 ^{0}C TEMPERATURE AND 10 CM THICKNESS

No.	Deflection (cm)	No.	Deflection (cm)
1	-0.00002	26	-0.00005
2	-0.00002	27	0.00045
3	-0.00003	28	-0.00080
4	-0.00005	29	-0.00002
5	-0.00002	30	-0.00002
6	0.00049	31	-0.00003
7	-0.00077	32	-0.00005
8	-0.00002	33	-0.00001
9	-0.00002	34	0.00049
10	-0.00004	35	-0.00077
11	-0.00006	36	0.00049
12	-0.00002	37	0.00048
13	0.00048	38	0.00047
14	-0.00077	39	0.00045
15	-0.00003	40	0.00049
16	-0.00004	41	0.00097
17	-0.00005	42	-0.00028
18	-0.00007	43	-0.00077
19	-0.00003	44	-0.00077
20	0.00047	45	-0.00078
21	-0.00078	46	-0.00080
22	-0.00005	47	-0.00077
23	-0.00006	48	-0.00028
24	-0.00007	49	-0.00140
25	-0.00009	50	-

TABLE V
DEFLECTION OF THE SLAB WITH 5 CM THICKNESS UNDER 10 ^{0}C TEMPERATURE

No.	Deflection (cm)	No.	Deflection (cm)
1	0.00	26	-0.00007
2	0.00	27	0.00019
3	0.00	28	-0.00021
4	0.00001	29	-0.00008
5	-0.00008	30	-0.00008
6	0.00018	31	-0.00007
7	-0.00022	32	-0.00007
8	0.00000	33	-0.00016
9	0.00000	34	0.00010
10	0.00001	35	-0.00029
11	0.00001	36	0.00018
12	-0.00008	37	0.00018
13	0.00018	38	0.00018
14	-0.00022	39	0.00019
15	0.00000	40	0.00010
16	0.00001	41	0.00035
17	0.00001	42	-0.00005
18	0.00002	43	-0.00022
19	-0.00007	44	-0.00022
20	0.00018	45	-0.00021
21	-0.00021	46	-0.00021
22	0.00001	47	-0.00029
23	0.00001	48	-0.00005
24	0.00002	49	-0.00040
25	0.00002	50	-

V. CONCLUSION

Recently pavement engineering has drawn attentions of many researchers due to its role in economic development of each country. In this study, two effective parameters of the rigid pavement namely temperature and thickness were investigated using Kenpave [28]. According to the acquired results, it could be concluded that the differences between the maximum and minimum of the slab in higher temperatures are more than the differences in lower temperatures. Regarding thickness effect, it could be concluded that the slab with 5 cm thickness has lower values of the deflection in most of the point.

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