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Evolution of A Extensive Rupture Fatigue Destruction Model for Concrete Pavements

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Abstract: The existing mechanistic-empirical pavement design guide does not explicitly address the occurrence of longitudinal cracking in the design of concrete pavements. Nevertheless, longitudinal cracking is frequently observed in joint plain concrete pavements, sometimes surpassing the significance of transverse cracking. Such longitudinal cracking negatively impacts the performance and longevity of concrete pavements. This study aimed to identify the potential causes of longitudinal cracking in joint plain concrete pavements to facilitate effective measures in future design and construction.

A comprehensive investigation, including a field project survey of severe longitudinal cracking and numerical simulations, was conducted. The findings confirmed that construction issues, specifically inadequate longitudinal joint forming and insufficient base support, contributed to premature and localized longitudinal cracks. Additionally, field surveys revealed that the extent of longitudinal cracking increased with wider slabs and tied concrete shoulders. Numerical simulations further emphasized that the geometry of a slab plays a significant role in influencing the likelihood of longitudinal cracking, particularly with increased tandem and tridem axles in traffic. The field data informed the development of an empirical model for predicting longitudinal cracking. Since aspects of geometry such as slab length, width, and thickness are fundamental design considerations, this study underscores the necessity and feasibility of creating a mechanistic-empirical model specifically tailored for addressing longitudinal cracking in future mechanistic-empirical pavement designs.

Keywords – Longitudinal cracking; Mechanistic-empirical pavement design; Joint plain concrete pavement; Widened slab

I. INTRODUCTION

Concrete possesses a brittleness characterized by a relatively modest tensile strength. If the tensile stress caused by either traffic, environmental loading, or a combination of both surpasses the tensile strength of concrete, the concrete slab is prone to developing cracks, manifesting as transverse, longitudinal, or corner cracking. The orientation of these cracks typically aligns closely with the perpendicular direction of the critical tensile stress induced by loads. However, it's crucial to note that the direction of the critical tensile stress can be significantly influenced by the geometric characteristics of the slab, encompassing factors such as slab length, width, and thickness

The predominant distress issues identified for jointed plain concrete pavements (JPCP) in the recently developed AASHTO Mechanistic Empirical Pavement Design Guide (Pavement ME) include joint faulting and transverse cracking in the mid-slab region. When it comes to structural cracking induced by external loads, mid-slab transverse cracking is recognized as the primary form of distress for JPCP pavements [1]. Conversely, longitudinal cracking is frequently encountered or perceived as an outcome resulting from suboptimal construction quality and non-load-related factors, such as insufficient procedures for forming longitudinal joints [2, 3] or inadequate support beneath the concrete.

The forecasting of longitudinal cracking in jointed plain concrete pavements (JPCP) is not included in the AASHTO Pavement ME because of factors like inadequate slab design [2–4] or excessive drying shrinkage [1,5]. In spite of this, longitudinal breaking is regularly seen in genuine situations on jointed substantial asphalts, sometimes awe-inspiring the meaning of cross over breaking [5, 6]. This event unfavorably influences the presentation and life span of substantial asphalts.

Through limited component examination, Hiller and Roesler [5] led a correlation of the basic pliable pressure close to the cross over joint with that at the mid-piece edge for California-type jointed plain substantial asphalts (JPCP). Their discoveries demonstrated that leftover negative angles coming about because of temperature-actuated twisting and differential drying shrinkage, joined with traffic stacking, can possibly prompt longitudinal, cross over, or corner weakness breaks. The particular kind of weariness break framed relies upon elements like the calculation of the section and the sort of shoulder. One more concentrate by Ruiz et al. delved deeper into this phenomenon.

In Louisiana, the event of noticeable longitudinal breaks on the asphalt surface is a continuous concern. These breaks act as pathways for water and residue answers for penetrate the asphalt, possibly causing siphoning and voids underneath a substantial chunk. Under the load of traffic, this, in turn, accelerates the pavement's deterioration. On jointed plain concrete pavements (JPCP), longitudinal cracking is more common than transverse cracking, according to a recent survey conducted in Louisiana. To proficiently moderate the gamble of longitudinal breaking, it is pivotal to play it safe in the mix of asphalt foundational layout, material determination and extents, and development rehearses.

The point of this examination was to recognize the potential variables adding to the issue of longitudinal breaking in Louisiana. The objective is to pinpoint these causes to work with the execution of compelling measures in future asphalt plan and development attempts.

II. PROJECT SELECTION AND FIELD INVESTIGATION

A total of 43 projects were chosen from the current joint substantial asphalt. These ventures were painstakingly decided to address different thruway classifications (Interstate, arterial, and collector), different traffic volumes, and different geological areas (Fig. 1). Likewise, country roadways were favored in light of the fact that metropolitan sections generally have crossing points and conflicting traffic pat-terns. It ought to be noticed that, in any case, there was no goal to choose projects with a particular sort or level of pain as it were. It is accepted that the chose test could be a fair delegate of the substantial asphalts in Louisiana.
Generally, piece thickness goes from 8 to 12 in. (10 and 11 in. (203–305 mm) 254 and 280 mm) as the larger part (65%). These ventures were developed somewhere in the range of 1974 and 2010, with a typical time of 20.3 years toward the finish of 2014. Introductory average annual daily traffic (AADT) ranges somewhere in the range of 3000 and 30,000 vehicles each day, and beginning affirm age yearly AADTT ranges between 400 and 4500 vehicles each day. Truck rates are somewhere in the range of 5% and 32%. As far as path width and shoulder types, segments in metropolitan regions are regularly 13 ft. (with monolithic curbs and a width of 4.0 m. Others are basically extended to 15 ft. (4.6 m) with tied substantial shoulder or black-top shoulder, particularly those built as of late. Segments are somewhere in the range of 0.2 and 3 miles (0.3 and 4.8 km) long with a normal of 1.0 mile (1.6 km). A sum of 67.5 miles (108.6 km) substantial asphalts were reviewed in this review. Asphalt pictures and option to proceed photographs in the primary traffic path of the chose 43 undertakings were gathered utilizing a multi-capability computerized parkway information vehicle worked by the Transportation Research Center (LTRC). AASHTO PP 68-14 [10] was firmly followed to gather great asphalt pictures. On a workstation, a manual distress survey based on the images was then conducted.

Figure 1: Location of selected concrete projects

During the manual study, mid-piece cross over breaking, longitudinal breaking, corner breaking, and fixing were classified. For each 0.1 mile (161 m) subsection, the complete length of each kind of breaks, and the number of pieces with each sort of breaks were recorded. In addition, longitudinal profiles were collected by the vehicle, and ProVAL software was used to estimate joint faulting and calculate pavement smoothness (IRI) [11].

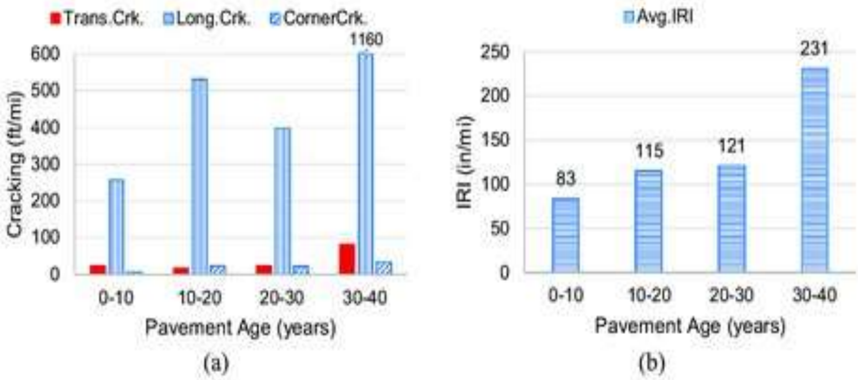

Figure 2: Cracking length and average IRI in all selected projects

Fig. 2 presents the general exhibition with regards to breaking and IRI for the chose projects. It is demonstrated that (1) mid-slab cracking does not appear to be a problem for Louisiana's JPCP pavements, and (2) longitudinal cracking is not.
As indicated by Fig. 2a, regardless of their age, pavements are clearly experiencing longitudinal rather than transverse cracking. Regarding ride ability as displayed in Fig. 2b, it appears to be that IRI decisively expanded for streets more seasoned than 30 years. Further investigation was conducted on sections with extremely significant longitudinal cracking. Project data, for example, plan documents, development records, and verifiable executions were recovered from various information base at Louisiana Department of Transportation and Development (LADOTD). Site visits were additionally directed when required.

III. DISCUSSION ON POSSIBLE CAUSES FOR LONGITUDINAL CRACKING

Fig. 3 shows typical examples of longitudinal cracks observed in this study. In many cases these cracks were located at the right wheel path. The adverse effect of construction problems such as inadequate longitudinal joint forming and inadequate base support on concrete pavement performance has been widely acknowledged in the literature [1, 12]. This study also confirmed this finding. In addition, during performance analysis and field investigation, it was noticed that more longitudinal cracking occurred on projects with widened slabs and tied concrete shoulders.

Figure 3: Cracking in Jointed Plain Concrete Pavements

3.1 Discussion on possible causes for longitudinal cracking

Fig. 4 shows typical examples of longitudinal cracks observed in this study. In many cases these cracks were located at the right wheel path. The adverse effect of construction problems such as inadequate longitudinal joint forming and inadequate base support on concrete pavement performance has been widely acknowledged in the literature [1, 12]. This study also confirmed this finding. In addition, during performance analysis and field investigation, it was noticed that more longitudinal crackingoccurred on projects with widened slabs and tied concreteshoulders.

Figure 4: Typical examples of longitudinal cracking of JPCP pavements

3.2 Widened slab with inadequate longitudinal joint forming

Project 817-08-0021 is a four path street with a two-way-left-turn path on LA 946 interfacing Stick Rouge and Focal. The substantial asphalt was worked in 1994 with 8 in. (203 mm) a slab made of Portland cement concrete (PCC) on top of a 2 in. 51 mm) hot-blended black-top (HMA) cover layer and 6 in. (152 mm) treated subgrade. 1 1 in. (30 mm) dowel bars were utilized. 15 feet of width was added to the outside lane. 4.6 m) with a 7 ft. (tied PCC shoulder (2.1 m). The undertaking has extremely serious longitudinal breaking, 4163 ft/mi (788 m/km), or 86% sections with longitudinal breaks (Fig. 4a). No siphoning from any joints, breaks or shoulder; therefore, it is unlikely to be the result of inadequate base support or subgrade settlement. As suggested by Government Expressway Administration (FHWA), ill-advised position of plastic supplements has been identified as a reason for irregular longitudinal breaking [13]. This procedure has been supplanted with saw cut and seal beginning around 2000 s in Louisiana. Albeit the development record of this task isn't accessible, authentic performance information from asphalt the board framework shows that serious longitudinal breaking has been existed as soon as in 2000. Almost certainly, these breaks happened not long after the development to ease the pressure in substantial chunks because the intended longitudinal joints were not formed.

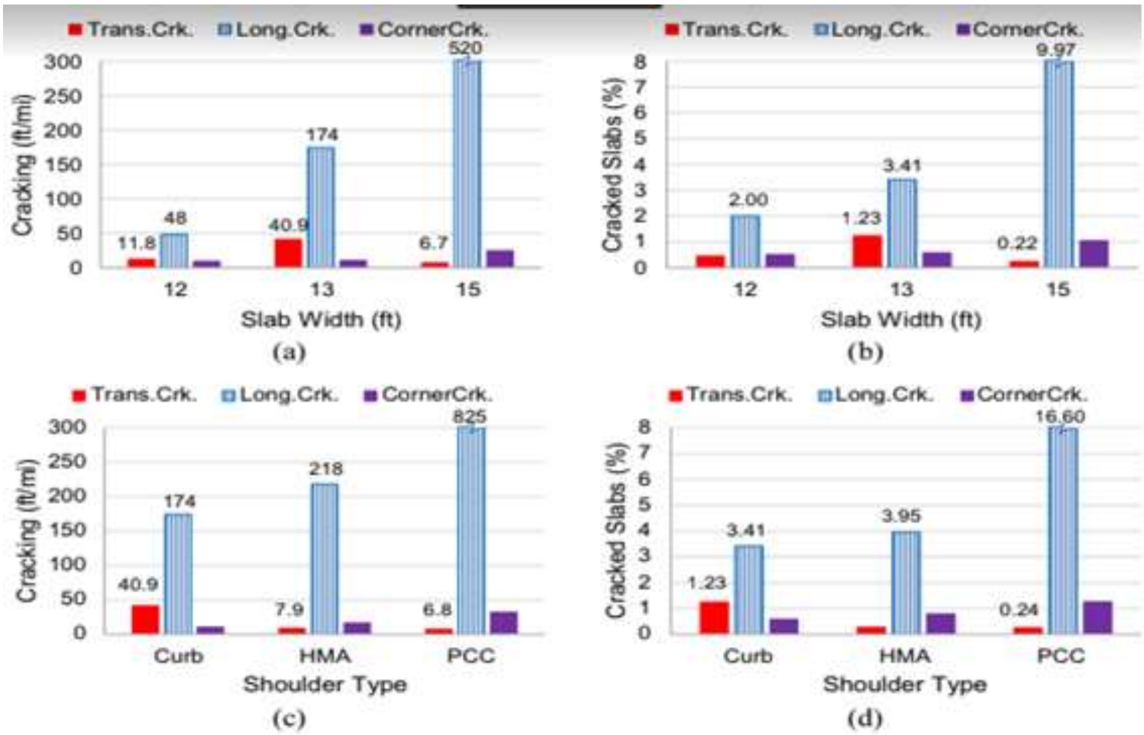

Figure 5: Observed cracking grouped by slab width and shoulder type

Some other projects experienced longitudinal cracking were found having very shallow saw-cut, similar to the casereported in Texas [2] and Colorado [3]. Therefore, in designof a widened slab, an appropriate longitudinal joint is as critical as the transverse joint in order to control the potential of longitudinal cracking.

3.3 Widened slab with inadequate base support

In another venture 455-07-0009, a constant longitudinal break was seen in the entire length from log mile 16.3 to 16.4. This venture had 15-ft (4.6 m) augmented travel path and 7-ft (2.1 m) black-top shoulder. The right wheel path appeared to have the crack. Every transverse joint showed pumping at the shoulder. The road was constructed in 1987 using 10 in. 254 mm) PCC chunk on top of 2 in. (51 mm) HMA cover layer and 6 in. (152 mm) cement treatment base, 5 inches 127 mm) chose material. The dowel bar breadth was 1.25 in (32 mm) since neighboring segments are in great or fair condition and the traffic on I-49 is relative low contrasting with other between state (for example I-10 and I-20), it is assumed that deficient base help is the justification behind this part. This could be ascribed to the nature of chosen material or deficient compaction during development that could prompt lopsided settlement. It might likewise on the grounds that the HMA material was inclined to stripping [14], brought about the siphoning of concrete and fines from the concrete treated base layer when water went into the asphalt from joint openings [15]. Historical performance data indicate that longitudinal cracks were minimal (270 ft/mi, or 51 m/km) in the year 2000; however, cracks have grown rapidly in recent years, reaching 4640 ft/mi, or 879 m/km, in 2012. By and by, this model shows that extended pieces might have magnified the unfavorable effect of deficient base help which prompted more longitudinal breaking.

3.4 Widened slabs and tied concrete shoulders

There are two possible explanations for the causes of longitudinal cracking on JPCP pavements that have been discussed previously. To start with, augmented path and tied substantial shoulder changed the chunk math (for example the length/width proportion), and subsequently changed the pressure/strain appropriation in the piece. As shown by Hiller and Roesler [9], the basic weariness harm area under an enlarged piece could be transformed from the center along the longitudinal edge to the lower part of the section at the external wheel way along cross over joint, which might prompt a longitudinal break. Second, since the presentation of inflexible asphalt incredibly depend on the uniformity as opposed to the strength of the help, more extensive chunk might amplify the inconvenient effect from lopsided help. Such magnification might appear as the improvement of longitudinal breaking in broadened JPCP asphalt.

IV. NUMERICAL SIMULATION

Dowel bars in transverse joints and tie bars in longitudinal joints were modeled with beam elements. All loadingwas applied in the wheel paths. That is, the right side of an8.5-ft (2.6-m) wide axle is located at one feet (30.5 cm) away from the right edge or the white marking for widenedslabs. Traffic loads from different axles were modeled withpressures over rectangular areas to facilitate the rectangular shape of mesh [18]. Major inputs used in the FE model construction are listed in Table 1 and the following design factors were considered in FE analysis for the determination of critical tensile stresses in JPCP slabs:

- Slab thickness (*h*): 8 and 12 in. (203 and 305 mm)
- Dowel bar diameter (U): 1 and 1.5 in. (25 and 38 mm)
- Tie bar diameter: ½ and 5/8 in. (13 and 16 mm)
- Equivalent elastic modulus of base and subgrade (E):20,000 psi and 40,000 psi (138 and 276 MPa)
- Linear equivalent temperature difference (DT): 20, 0, +20 °F (11, 0 + 11 °C)
- Slab width (ft.) and shoulder support: 12 + 0; 15 + 0; and 15 + 7 (3.7 + 0 m, 4.6 + 0 m, 4.6 + 2.1 m)
- Axle type: Single, tandem and tridem
- Load location: at mid-slab, and at transverse joint

A total of 288 cases were executed following a partial factorial design. For each case, the critical tensile stressat the top and the bottom of the slab was recorded at boththe transverse (*x*) direction and the longitudinal (*y*) direction. If the tensile stress at the transverse direction (r_x) was found greater than the tensile stress at the longitudinaldirection (r_y), it would indicate that the slab would crack longitudinally; and vice versa.

Table 1: Major inputs used in the numerical simulation

Input	Property	Value (SI units)	Value (US units)
PCC slab	Joint spacing (slab length)	6.1 m	20 ft.
	Elastic modulus	29.0 GPa	4,200,000 psi
	Poisson's ratio Coefficient of Thermal Expansion (CTE)	0.15 9.0 * 10^{-6} mm/mm/°C	0.15 5.0 * 10^{-6} in/in/°F
Dowel bar	Length	457 mm	18 in.
	Spacing	305 mm	12 in.
	Poisson's ratio	0.10	0.10
	Elastic modulus	200.0 GPa	29,000,000 psi
Traffic loading	Single axle load	8165 kg	18,000 lb
	Tandem axle load	15422 kg	34,000 lb
	Tridem axle load	19051 kg	42,000 lb
	Tire pressure	0.83 MPa	120 psi
	Axle width (edge to edge)	2.6 m	8.5 ft.
	Tandem axle spacing	1311 mm	51.6 in.
	Tridem axle spacing	1250 mm	49.2 in.

For instance, the slab is unlikely to crack longitudinally if LCR is less than 0.8; at the point when LCR is somewhere in the range of 0.8 and 1.0, breaks might start either in the longitudinal course or in the cross over heading; at the point when LCR is somewhere in the range of 1.0 and 1.2, longitudinal breaks are probably going to happen; assuming that LCR is over 1.2, the chunk will definitely break longitudinally. Following these rules, sums of 127 cases in the FE examination were found to have longitudinal breaking potential. Among these 127 instances of longitudinal breaking, different influence factors were examined and the outcomes are introduced in Fig. 6. From Figure, the following considerations can be derived: 6.

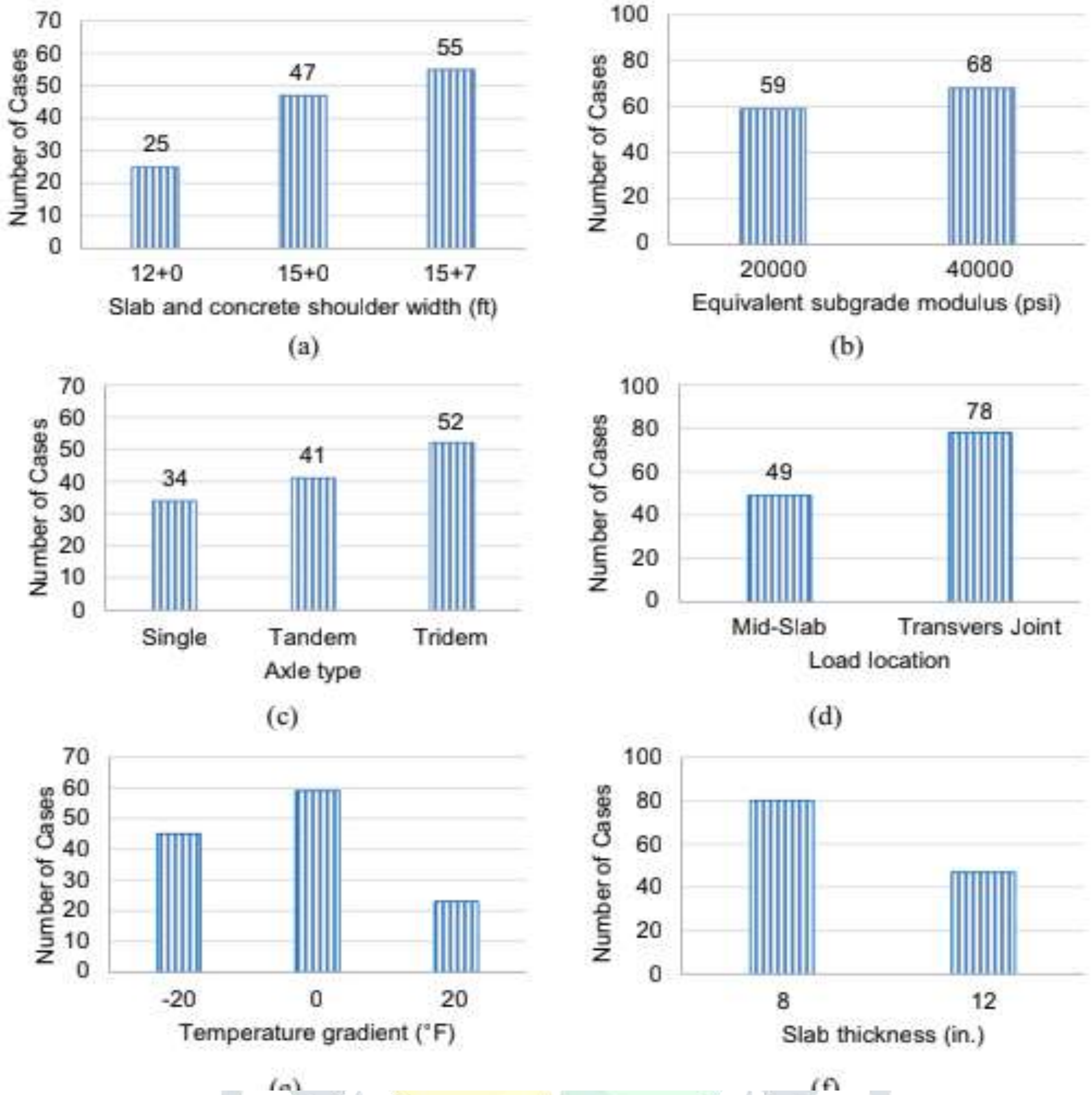

Figure 6: Potential of longitudinal cracking

The significance of piece math to chunk breaking has been broadly acknowledged [19]. Hiller and Roesler [9] saw that as, when sections are broadened, the basic harm loca-tion moves from the longitudinal edge to the cross over edge, which prompts potential longitudinal or corner breaking. Substantial shoulders which are generally attached to the traffic path further change the length/width proportion, coming about basic pliable pressure at the right wheel way and 55 cases with the probability of longitudinal breaking.

Fig. 6b shows that the capability of longitudinal breaking is somewhat expanded as the expanding of identical sub-grade modulus. The expanded breaking over a stiffer backing could be made sense of by the expanding of twisting burdens, expanded comparable subgrade modulus, or ran-

dom breaking when the substantial piece and it are completely attached to basic layer. According to Moody [20], slabs built over cement-treated bases with high in-situ modulus values were more likely to crack than slabs built over any other type of base. Sim-ilarly, longitudinal breaking was found as the significant trouble for substantial segments with concrete subbase or concrete treated base in North Carolina [20].

Fig. 6c and d shows that couple and tridem hub stacking at cross over joints additionally expands the capability of longi-tudinal breaking.

Fig. 6e shows that both positive and negative gum based paint ture inclinations don't expand the capability of longitudi-nal breaking. The FE results (not displayed in Fig. 6e) confirmed that a greater temperature gradient—positive or negative—greatly increases the likelihood of transverse cracking because transverse cracking is brought on by critical stress ry in the center of the slab [1]. Then again, Fig. 6e likewise demonstrates that a less temperature gra-dient would cause more longitudinal breaking on JPCP asphalts. A concrete slab may have a smaller temperature gradient than a cold slab in a warm region like Louisiana.

V. CONCLUSION

Currently longitudinal cracking is not considered in pavement design. However, experience in Louisiana foundthat longitudinal cracking was more prominent than trans-verse cracking for jointed concrete pavements. Hence, a research effort was made to understand the possible reasons for these cracks. Both field investigation and numerical simulations were conducted. Analysis of results led to the following conclusions.

- Overall performance revealed that Louisiana's JPCP pavements had more longitudinal cracking than transverse cracking. Field examination confirmed that development issues, for example, insufficient longitudinal joint shaping technique and lacking base help are among the potential explanations behind longitudinal breaking.
- Field examination and mathematical reenactment further showed that piece augmented to 15ft (4.6 m) and tied con-crete shoulder would improve the probability of longitudinal breaking. Chunk math ought to be painstakingly intended to limit the capability of longitudinal breaking.
- The research's longitudinal cracking model showed that standard-width pavements had more transverse cracking and widened slab pavements had more longitudinal damage. These patterns fit well still up in the air by past analysts. This was shown utilizing contextual analysis models and matches field perceptions and old style asphalt hypothesis forecasts.
- An experimental model was created to make sense of the noticed longitudinal breaking in this concentrate quantitatively.
- The standards of similitude ended up being an entirely significant device both for characterizing a decreased factorial. In addition to stress analysis, the characteristics of pavements that are susceptible to longitudinal versus transverse cracking were identified using this reduced factorial.

Essentially augmented chunk and tied shoulder have been demonstrated to effectively lessen cross over and corner breaking, however the negative effect on longitudinal breaking likely should be painstakingly examined and tended to. As the calculation including chunk length, width and thickness is for the most part a plan issue, this study upholds the need and plausibility of fostering a robotic exact model for longitudinal breaking. Since breaks happen because of exhaustion harm, longitudinal models that incorporate weariness investigation are suggested for future examination.

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