

FINITE ELEMENT INVESTIGATION OF THE PRESTRESSED JOINTED CONCRETE PAVEMENTS

M. Foroutan Naddafi¹ and V. Sadeghi^{2,*}

¹Department of Engineering, Payame Nur University, Tehran, Iran

²Babol University of Technology, Babol, Iran

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ABSTRACT

Precast prestressed concrete pavement (PCP) technology is of recent origin, and the information on PCP performance is not available in literature. This research presents a finite-element analysis of the potential benefits of prestressing on the jointed concrete pavements (JCP). With using a 3-dimensional (3D) Finite-element modeling (FEM) the load transfer efficiency (LTE) of the prestressed pavement had been discussed. Longitudinal and transverse prestressing with various prestressing forces were analyzed. It was concluded that prestressing although increased the deflection at mid slab but the reduction in load transfer to adjacent is minor and engineers can benefit from the prestressing to reduce the slab thickness. The higher prestressing force, might affect the load transfer in the prestressed pavement, so using a prestressing for more than 400 kN should be revised carefully.

Keywords: Prestressed concrete pavement; Dowel bar; Finite element; Load transfer efficiency.

Author Correspondence, e-mail: authorC@gmail.com

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1. INTRODUCTION

Prestressing is the application of a predetermined force to a concrete member so that the combination of internal stresses within the member, from this force and any other external loads, will be confined within specific limits[1]. Prestressed concrete pavements were used for airport pavement since 1940. Most of the early European airport projects used prestressing in both directions within the pavement [2]. Although prestressed technologies were used frequently in bridge deck and girders, but the first highway applications were in France in 1945, and in the United States in military airfields in 1953[3]. Pre-compressing concrete slabs lead to a more efficient, thinner pavement resulting to material savings and improved long-term durability[4]. Other advantages are such as the ability to span voids that develop underneath the pavement because of many reasons.

The early projects mentioned were an early effort to improve and develop prestressed pavement. All of the early projects showed transverse cracking immediately after placement and longitudinal cracking few years later. Dowel bars at transverse joints in the concrete pavements are essential to transfer the loads applied on a slab to an adjacent slab. It also prevents faulting and pumping in JCPs [5,6].

Recent progresses in software programming made it simple to utilize powerful finite element analysis software packages. The use of FEM in the analysis of rigid pavement dated back to the early 1960s with Cheung and Zeinkiewics use of the method to analyze slabs on elastic foundation[7]. Now, there are FE software packages able to predict pavements under various loading regimes.

In this study, a 3D FE model was established to assess a dowel-jointed prestressed concrete pavement. Three-Dimensional Finite-Element modeling (3D-FEM) has been broadly investigated to study the dowel bars at joints in rigid pavements [8,9]. Shoukri developed a 3D-FEM to investigate the effect of moving axle loads on the response of dowel Jointed Portland Cement Concrete Pavement. He also showed that stresses increase under corner loading [10].

Recognizing the importance of knowledge gained by existing rigid pavement design, the objective of this study, is to assess the load transfer efficiency (LTE) of the dowels under static loads. It is known that prestressing reduces tensile stresses in the slab, so investigation of the stresses with the pavement is not an objective of this study.

2. MODEL DESCRIPTION

A two-slab system with a 10-mm joint width on top of supporting layers was modeled by ABAQUS software package with using the Solid 3D elements to model the concrete pavement. The model geometry is identical to the model presented by Shoukry et al[11]. The transverse joint had twelve 32 mm diameter, 470 mm long dowels, spaced at 300 mm on center. Frictional contact stress is considered between the slab and base layer. A linear elastic constitutive model was used for the concrete slab and the underneath layers with the 254 mm thick slabs were 4600 mm long and 3660 mm wide, a modulus of elasticity, $E = 29000$ MPa a Poisson's ratio, ν of 0.22 and a density of 2400 kg/m^3 . A refined mesh zone as illustrated in Fig.1 was located at the center of the joint, where wheel loads are applied. A base layer of 200 mm thick ($E = 310$ MPa and $\nu = 0.3$) was modelled on top of the subgrade with $E=30$ MPa and $\nu = 0.45$. A bonded interface action was considered between subgrade and base. Tendon with a modul elastisity of 190 GPa and 1.4 cm^2 section area was used in the model.

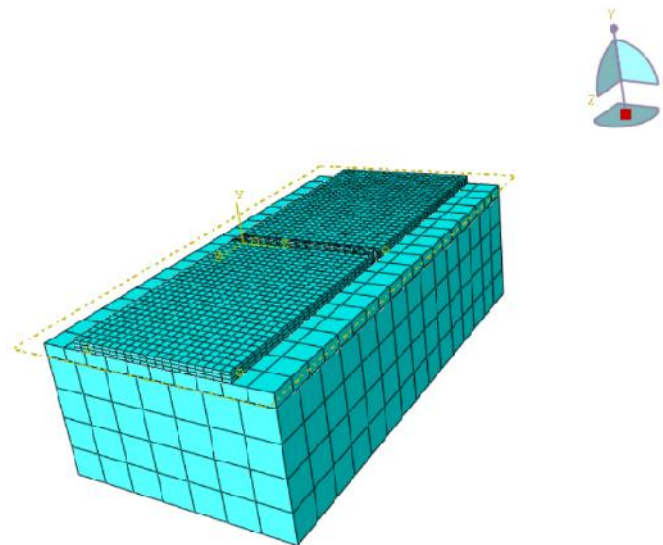


Fig.1. Finite-element mesh used for modelling

3. MODEL LOADING

Repeated loads were applied to assess pavement deflections and observe the linear-elastic response of the pavement under repetitive loads of 20 kN, 40 kN, 80 kN, and 120 kN. Loads were applied at mid slab and edge as shown in Fig 2. The loading protocol was also suggested by Alwahediah [12].

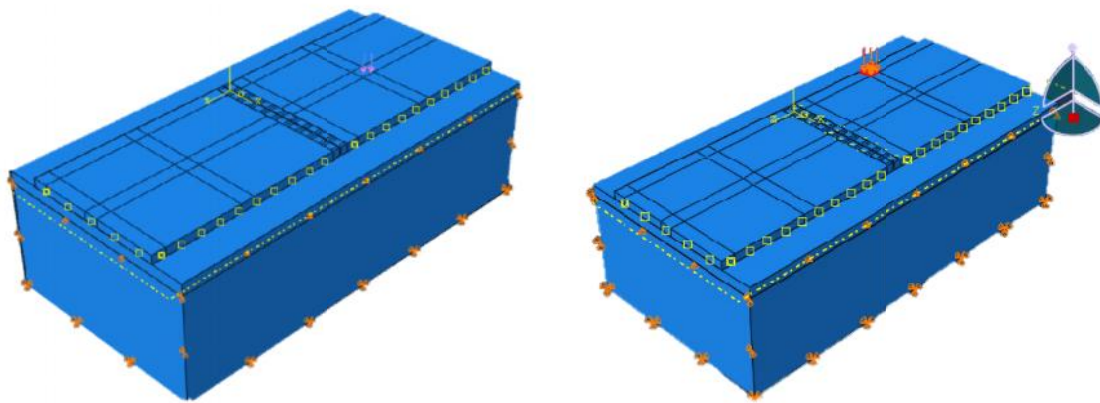


Fig.2. Loading location

4. MODEL RESULTS

The load transfer efficiency is defined by Eq. 1:

$$LTE = \frac{\Delta_u}{\Delta_l} \quad (\text{Eq.1})$$

Where Δ_u and Δ_l are deflection of the unloaded and loaded side of the slab.

Fig. 3a shows the LTE calculated from the model with mid slab loading. In this phase, no prestressing is applied. Fig 3b shows the maximum deflection of the center of the first slab. The lowest LTE is 0.8 for this situation.

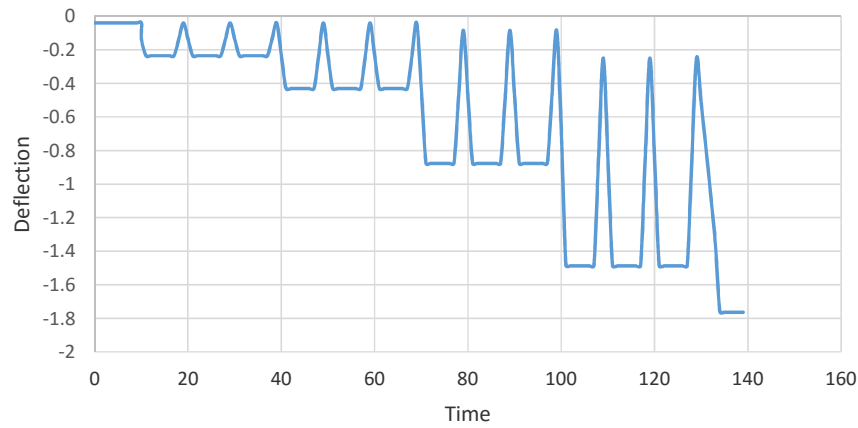


Fig.3.a. LTE Vs time when the load is applied on mid slab with no prestressing

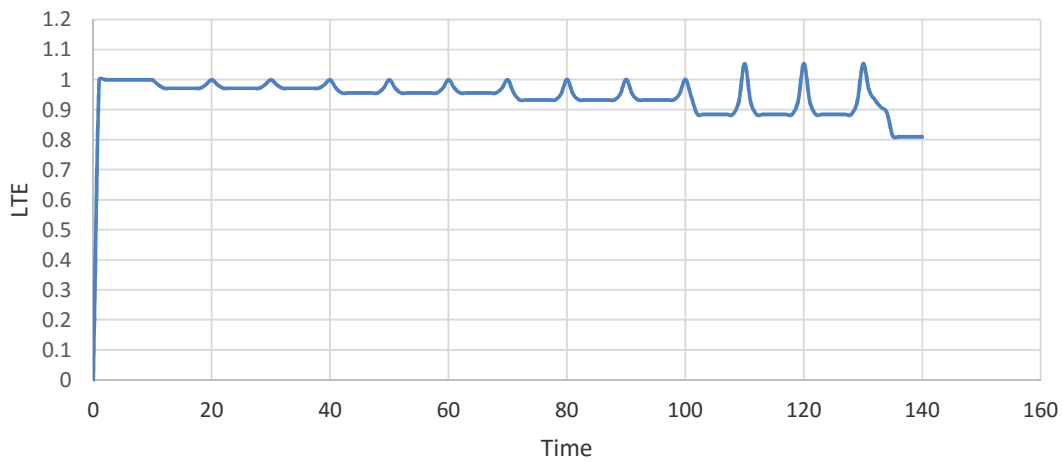


Fig.3.b. Deflection Vs time when the load is applied on mid slab with no prestressing

Fig. 4 shows the results of the loading on the mid slab when prestressing is applied on both transverse and longitudinal directions. The prestressing force is assumed to be 600 kN for the both direction. The max deflection at the center of the slab was 3.5 cm which is high and caused by high prestressing force.

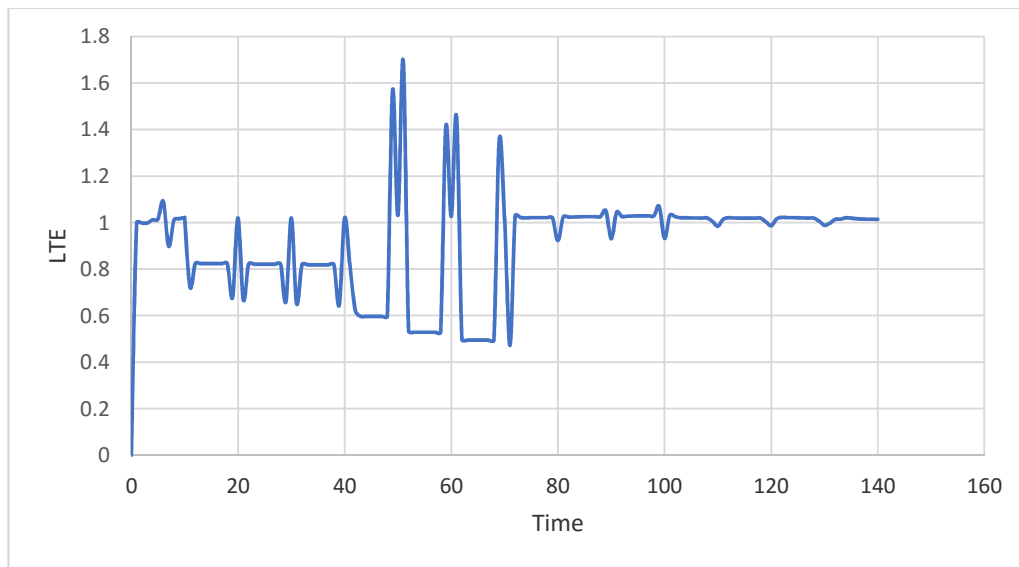


Fig.4. LTE Vs time when the load is applied on mid slab with 600 kN prestressing force on both directions

From Fig. 4 it can also be concluded that high prestressing force also has some impacts on the LTE. The maximum difference between the deflection of two edges was 5 cm, which is higher compared to non-prestressed pavement where the maximum difference was 1 cm.

Fig. 5 shows a slab with a similar prestressing (600 kN on both directions), but the loading is implied one the edge of the pavement. This type of loading affected the LTE, as it is clear in Fig. 5.

In Fig. 6, the transverse prestressing is removed. The maximum deflection is reduced compared to previous case but the ratios of the deflection of the two slabs are a bit higher. Removing transverse prestressing had some effects on load transfer, when the edge loading is implied.

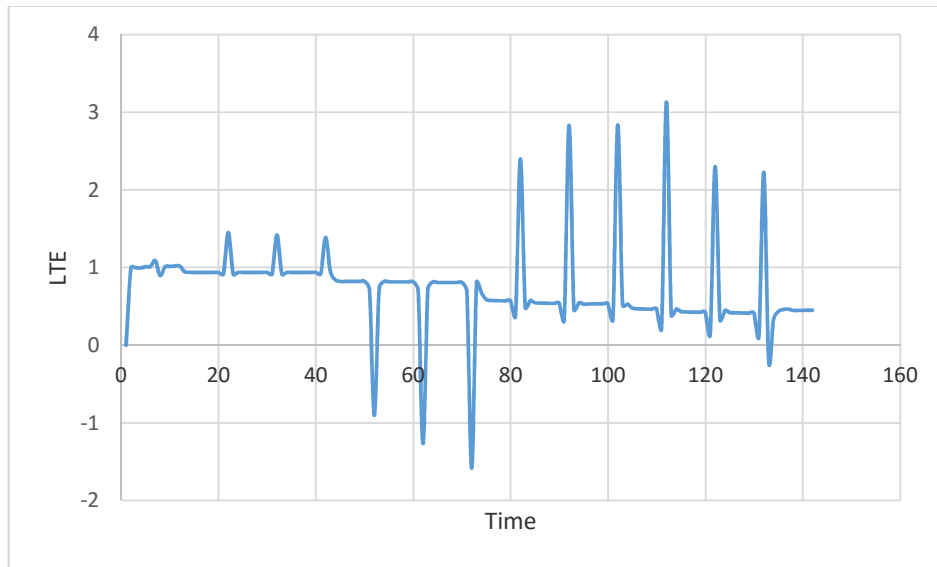


Fig.5. LTE Vs time when the load is applied on the edge with 600 kN prestressing force on both directions.

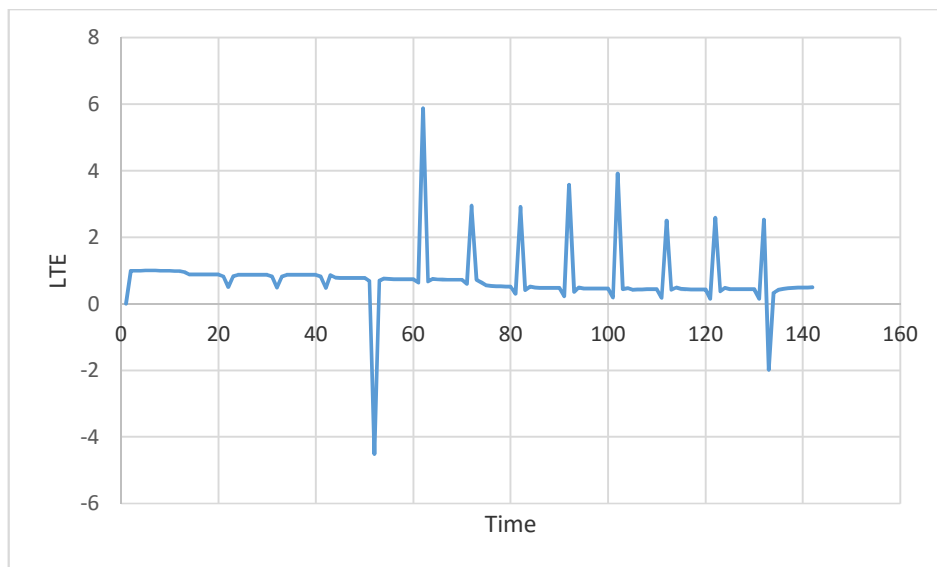


Fig.6. LTE Vs time when the load is applied on the edge with 600 kN prestressing force on longitudinal direction

When the load is implied on mid slab the difference between the deflections of the slabs is ignorable as it is shown in Fig. 7 where only longitudinal prestressing is implied, but the loading is on the mid slab. The location of the load had a clear effect on load transfer between the two slabs. The mid slab deflection is as high as 6 cm.

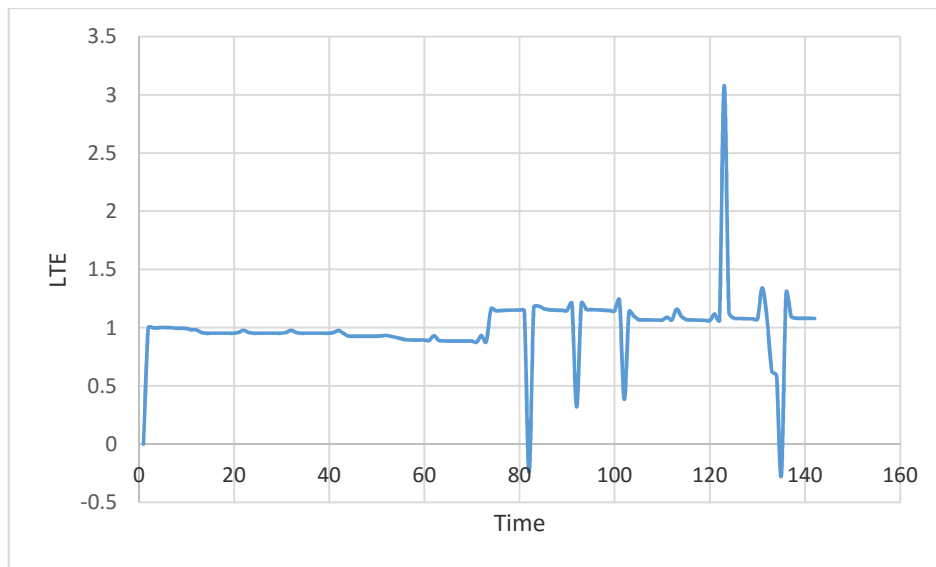


Fig.7. LTE Vs time when the load is applied on the mid slab with 600 kN prestressing force on longitudinal direction

The 600 kN prestressing force is a high prestressing force and might cause slabs move considerably against each other and it is not recommended to use such high prestressing force. Fig. 8 shows a case where prestressing is implied on both directions but with 400 kN force. The result showed that the load transfer between the two slabs is reasonable and the maximum deflection of the slab is 4 cm. 400 kN prestressing for the both direction. Compared to the higher prestressing force, for the edge loading in this case load transfer performs better. Fig. 9 shows the edge loading for the latter case. Edge loading is more critical than any other type of loading during the life of the pavement and this detrimental effect can be seen in the load transfer between the slabs.

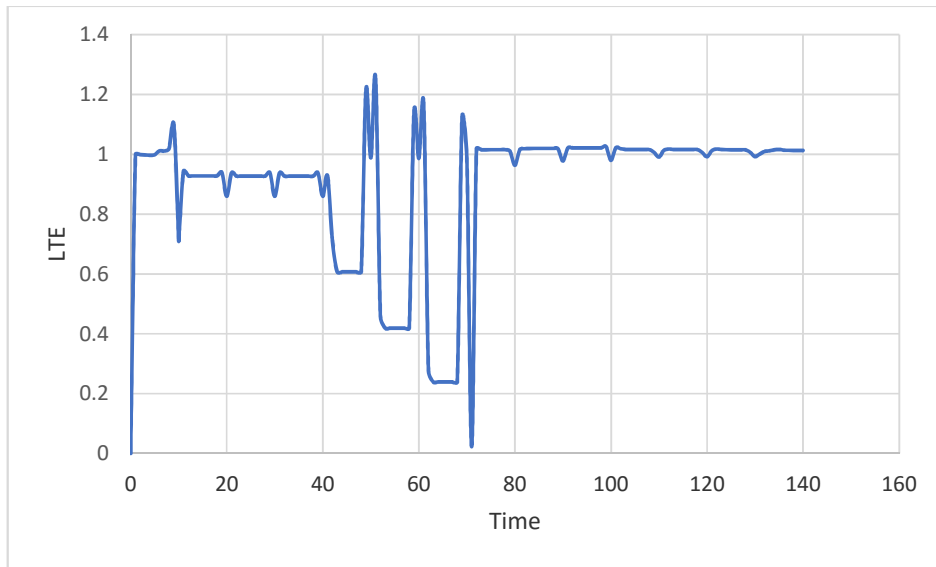


Fig.8. LTE Vs time when the load is applied on mid slab with 400 kN prestressing force on both directions

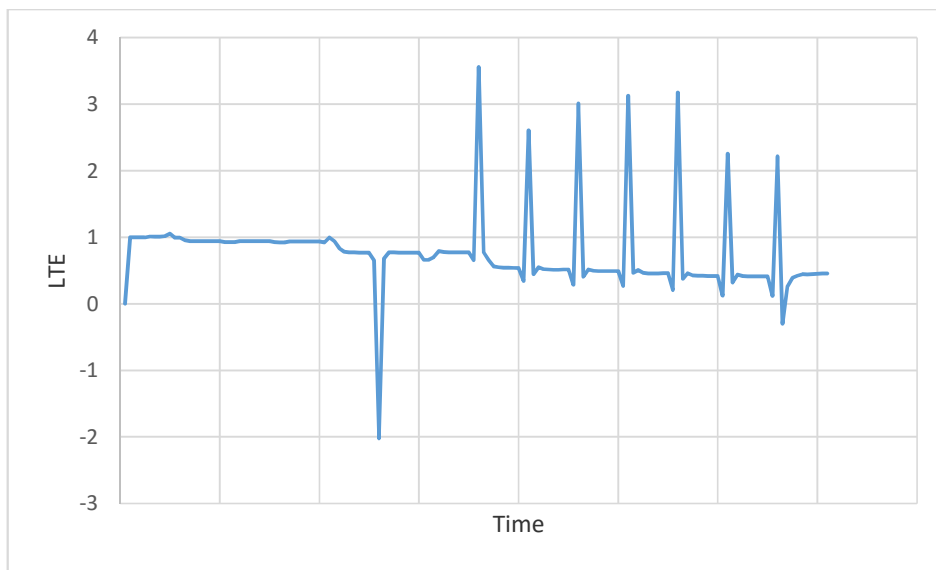


Fig.9. LTE Vs time when the load is applied on the edge with 400 kN prestressing force on both directions

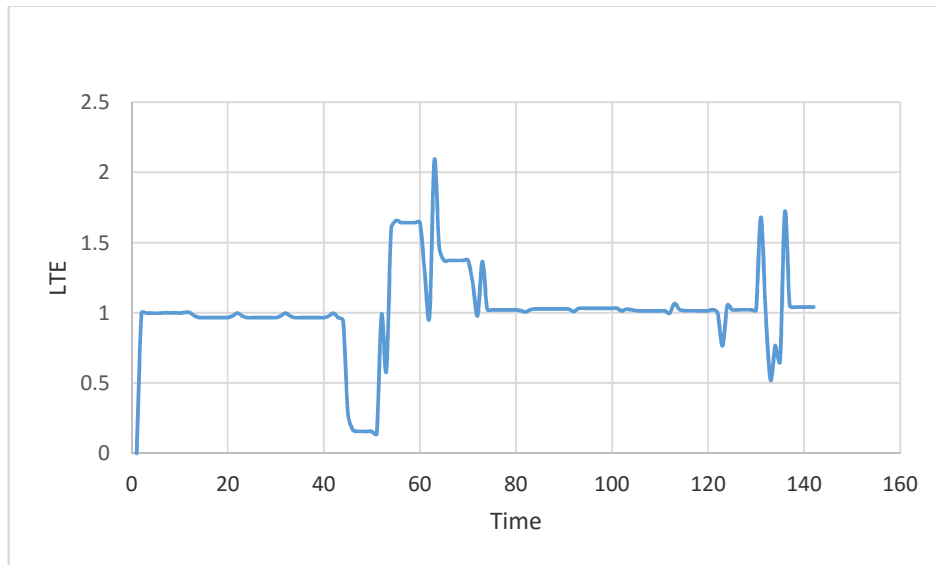


Fig.10. LTE Vs time when the load is applied on the mid slab with 400 kN prestressing force on longitudinal direction

As said before, the edge loading is the most critical form of loading, and the load transfer is also vulnerable. When the pavement is prestressed these impacts are intensified. When prestressing force passes the 400 kN, the load transfer drops considerably.

4. CONCLUSION

This paper has examined effects of prestressing and loading on the load transfer efficiency of the prestressed pavement numerically. The study employed a FEM model developed with ABAQUS. Several models with utilizing two prestressing force, 400 and 600 kN, were developed to assess the impacts of prestressing and the loading location.

The results from the study have shown that the application of prestressing had a significant effect of the load transfer between adjacent slabs. It was shown that the 600 kN prestressing force in both directions affected the load transfer and reduced it drastically. Edge loading is the most critical loading for the prestressed pavement and performs unpleasantly if combined with a high prestressing force.

The prestressing in both directions compared to single direction wasn't different and the benefits of the prestressing in the both directions can be used within the pavement considering the prestressing force.

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