

The Second Generation of Minnesota Accelerated Loading Facility - Minne-ALF-2

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Abstract

This paper presents the second generation of Minnesota Accelerated Loading Facility (Minne-ALF-2), a laboratory-based loading pavement test stand that simulates the passage of heavy wheel loads moving over a small full-scale pavement test strip. It is shown that Minne-ALF-2 can provide important information related to long-term performance of dowel joints of concrete pavements, as well as useful information which may lead to a better understanding of the mechanics of joints in concrete pavements.

The first results of the ongoing test program are also presented in the paper. This initial study of joint behavior during loading and unloading of a joint with hollow dowels reveals an interesting pattern: deflections in the unloading path are different from the deflections at the loading path. It was also found that the residual differential deflections remain after the first loading and unloading cycle. Available finite element models for rigid pavements do not explain these effects. Hence, advanced models of PCC joints explaining the observed above phenomenon are needed for a better understanding of the joint behavior and joint design optimization.

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Introduction

Transverse joint faulting is one of the main types of distresses in jointed concrete pavements (JCP) that affect serviceability (Khazanovich et al. 1997). Significant joint faulting has a major impact on the life-cycle cost of the pavement in terms of early rehabilitation and vehicle operating costs. The rate of progression of JCP faulting is increased significantly when a given pavement exhibits a combination of poor load transfer across a joint or crack and high corner deflections.

Many transportation agencies use round steel dowel bars to ensure that adequate load transfer is provided across transverse joints in rigid pavements. Several major pavement performance studies (Yu et al. 1997, Khazanovich et al. 1998, Hoerner et al. 2000, Khazanovich et al 2005) demonstrate that properly placed dowels significantly reduce transverse joint faulting and corner cracking. However, since dowels substantially increase the initial construction cost, it is important to optimize their design. In addition to structural design considerations, one of the major challenges affecting dowel performance is dowel corrosion and reduction in useful dowel life due to use of de-icing salts in cold climates. This threat of corrosion prompts the industry to search for alternatives to traditional steel dowels, like plastic or stainless steel dowels. The effective use of these non-traditional dowels requires a better understanding of dowel-concrete interaction. Full-scale accelerated joint testing is a very effective tool for acquiring this information.

This paper presents the second generation of Minnesota Accelerated Loading Facility (Minne-ALF-2), a laboratory-based loading pavement test stand that simulates the passage of heavy wheel loads moving over a small full-scale pavement test strip. It is shown that Minne-ALF-2 can provide important information related to long-term performance of doweled joints of concrete pavements, as well as useful information which may lead to a better understanding of the mechanics of dowel-concrete interaction in jointed pavements.

Minne-ALF

The Minne-ALF test facility is the result of more than 10 years of cooperation between the Minnesota Department of Transportation and the University of Minnesota. In 1994, the Minnesota Department of Transportation commissioned the University of Minnesota to develop a laboratory facility that could efficiently and accurately evaluate the long-term performance of new and experimental highway pavement designs. The main focus of that facility was to evaluate both design methodologies and rehabilitation techniques of joints in concrete pavements.

The research team, lead by Prof. Mark Snyder, evaluated twenty-two existing accelerated-load facilities and designed a unique testing system. The Minne-ALF test stand comprised a steel foundation, a specimen enclosure, a vertical support structure, and two hydraulic actuators. As a full description of the design, construction and modification of the Minne-ALF testing facility can be found elsewhere (Beer, 1997; Mauritz, 1997; Embacher and Snyder, 1999), a fairly brief

description is provided below.

The Minne-ALF covers a horizontal area of 400 square feet, and has an overall height of 16 ft. The foundation consists of a grillage of eleven W27 x 84 steel beams. Four HP12 x 74 steel columns support overhead beams, to which the actuators are mounted. An 8 x 16-ft rectangular enclosure containing the slab specimens is created by four 15-in. deep steel channels. The specimen enclosure rests on $\frac{3}{8}$ -in. thick steel plates, which in turn rest on a $\frac{1}{4}$ inch layer of neoprene to provide vibration reduction during testing. The neoprene is placed on each of the eleven W27 x 84 foundation grillage beams.

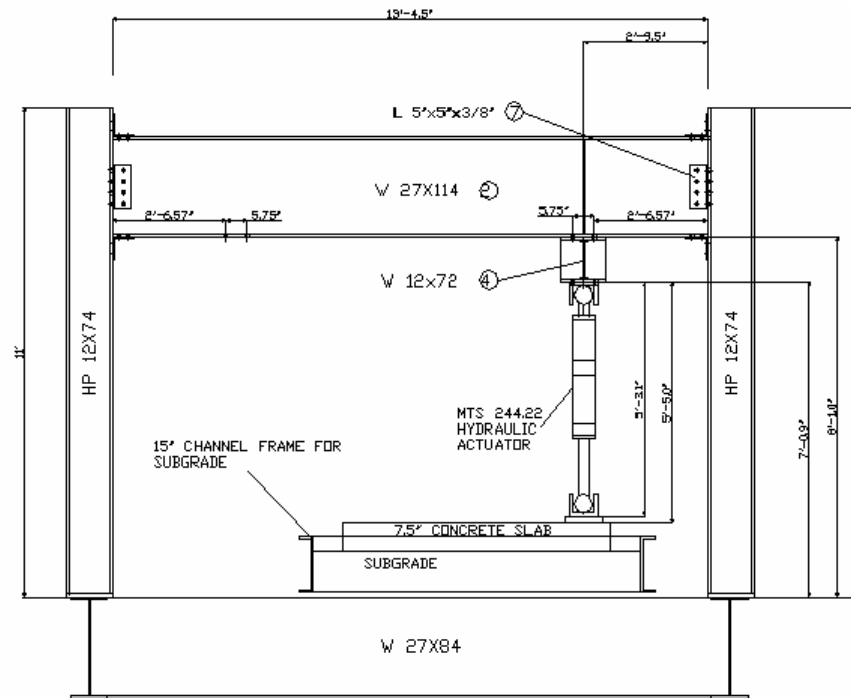
In the past Minne-ALF projects, a foundation comprising a $\frac{1}{4}$ inch layer of neoprene, a nine-inch layer of clay loam, and a 3-inch layer of Mn/DOT class 5 material replicated a foundation of one of the test sections at the Minnesota Road Research Facility (Mn/ROAD). Pavement specimens were cast on top of this foundation. The traffic flow was simulated by a W10 x 68 steel rocker beam loaded by two hydraulic actuators. The transverse movement of the rocker beam was set at 1.5 hertz, or 1.5 cycles per second, to simulate a vehicle speed of 30 mph.

The first version of Minne-ALF was used to test 14 jointed concrete pavement slabs that received a combined loading of more than 100 million load cycles (Embacher et al., 2001; Popehn, 2002). This loading has induced cumulative damage in many of the Minne-ALF parts, in some cases driving the components to the limit of their useful life. For example, the repeated loading of certain steel members, such as the stub column in the rocker beam, has produced fatigue cracks that have been repaired several times in the past. This component and other components in the loading frame had to be replaced for the reliable future operation of the Minne-ALF.

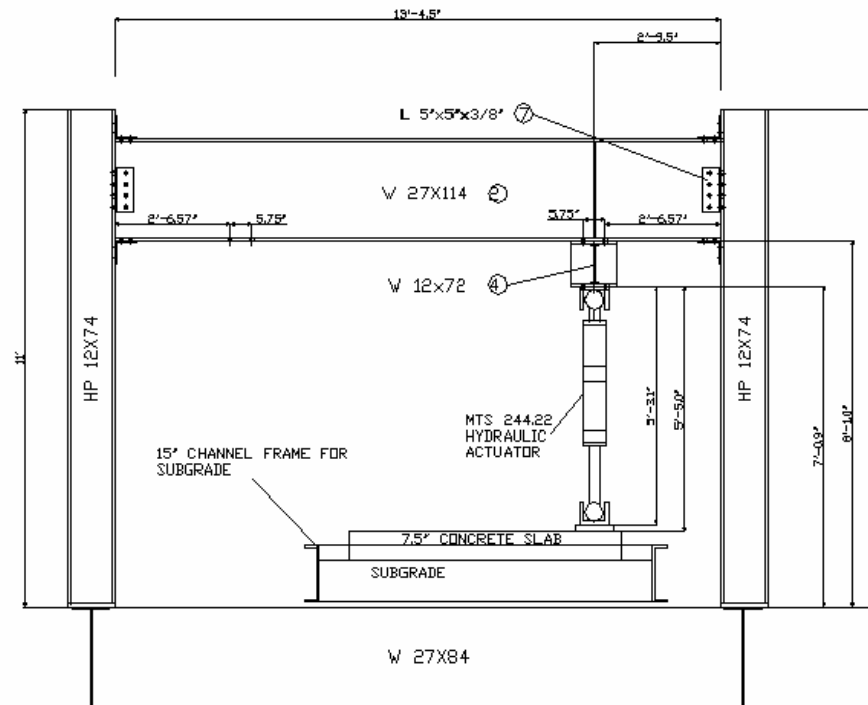
To speed up the process of reconstruction of the Minne-ALF and to simplify the testing procedure, a decision was made to modify its structure and adapt a simpler experimental setting. Instead of a rocking beam, two vertical actuators would simulate the passage of heavy wheel loads moving over a pavement joint. (This setting was used in the early 1990s by Dr. Snyder in a few research projects at Michigan State University.) The replacement of the rocking beam required significant re-designing of the current Minne-ALF.

The test stand of the modified version of Minne-ALF, Minne-ALF-2, has the same foundation as the original Minne-ALF, but the vertical support structure of the update significantly differs from that of the original. Minne-ALF-2 contains two vertical frames placed 8 feet apart. Each frame consists of two HP12x74 11-foot long columns supporting the overhead beams. The overhead beams are connected by the transitional beam, to which two vertical force actuators are mounted. The distance between the axes of the actuators is 13 in to simulate the loading of both sides of a joint in the concrete slab by wheel loads with the centers located 6.5-in away from the joint. Figures 1 and 2 present a drawing and a photo of the

Minne-ALF-2, respectively.



LONGITUDINAL ELEVATION



LONGITUDINAL ELEVATION

Figure 1. Configuration of Minne-ALF-2.



Figure 2. Minne-ALF-2.

Moving Load Simulation

Minne-ALF-2 simulates vehicle loads traveling across pavement joints at highway speeds by means of two hydraulic actuators. These actuators act vertically on the loading plates that are placed 6.5-inches away from the concrete pavement joint. In the ongoing study, a simulated vehicle load crossing a joint of a pavement specimen is a unidirectional 9,000-lbs load. This load pattern is selected because the maximum allowable single axle load in Minnesota is 18,000 lbs, and the size of the test specimen is one half the size of a standard lane. The load acts only in one direction, because it is the most common load type on highway pavements. Furthermore, the jointed slabs are designated according to their orientation relative to the direction of traffic: there is an “approach” slab (which is on the side of the joint against the flow of traffic) and there is a “leave” slab (on the side of the joint as you move with the traffic flow).

In order to create a proper loading sequence, command signals are first sent to the actuators from a text file. The text file contains the desired waveform described by a 1,024-point sequence. The waveform for each actuator is combined from haversine segments varying between 0.5 Kip and 9.5 Kip load and ramp segments with constant 1 Kip load. There is a 90 degree phase lag between two waveforms.

This lag is selected to keep the total load applied to the slab close to the constant values for the period between the time when the approach slab and the leave slab actuator loads have reached their maximum values (see figure 3). The time lag between the load peaks of the leave and approach actuators is correlated with the simulated vehicle speed using the following equation:

$$v = \frac{L}{T} \quad (1)$$

where

v = vehicle speed

L = distance between the actuators. In this study, this distance is equal to 13 in.

T = time lag between the actuator load picks.

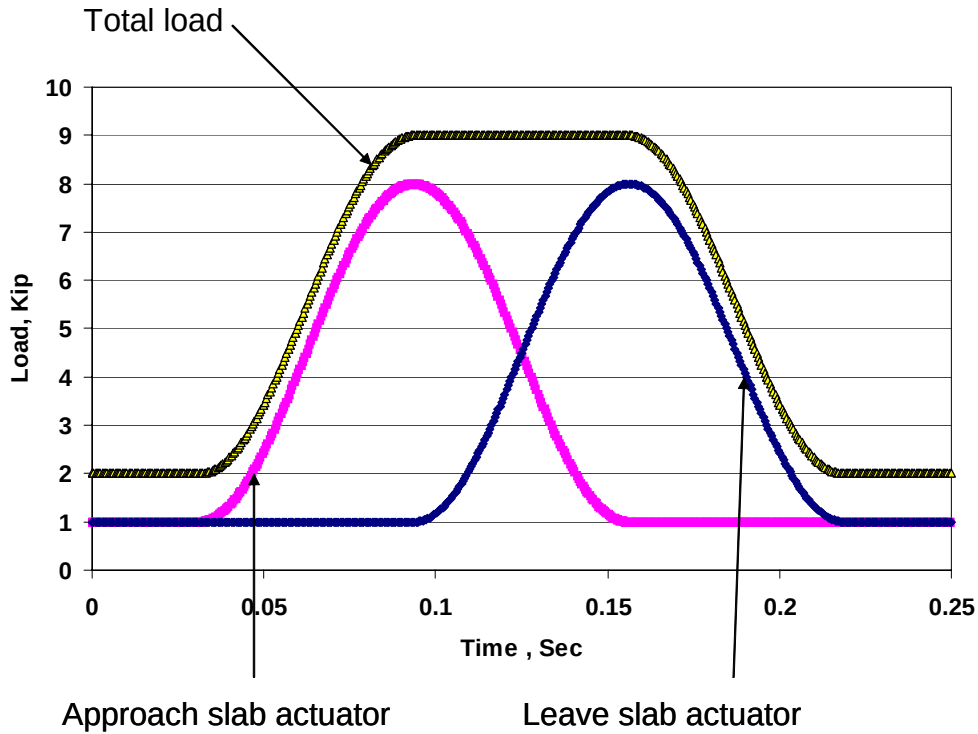


Figure 3. Design load pattern.

If the loading and unloading of an individual actuator accounts for one half of the entire loading cycle (i.e., another half of the cycle is dedicated to the rest time), then the vehicle speed is related to the frequency of the loading cycle as follows:

$$v = 4 f L \quad (2)$$

where

f = frequency of the loading cycle.

Figure 4 shows the calculated vehicle speed for different load frequencies.

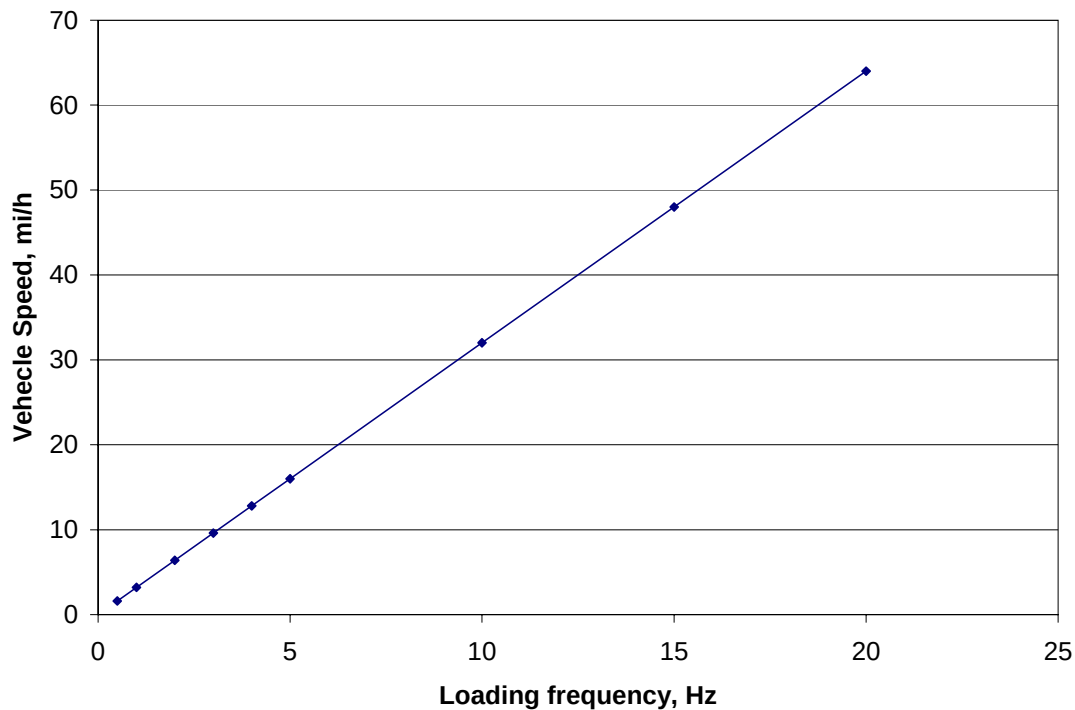


Figure 4. Simulated vehicle speed vs loading frequency.

Current Testing Program

The Minnesota Department of Transportation (MnDOT) has selected a new dowel bar to be used as a bid alternative for its high-performance portland cement concrete (PCC) pavements. This dowel bar is a 316L stainless steel schedule 40 pipe, with a finished (polished) surface, conforming to ASTM A312. The dowel bar has a minimal nominal size of 32 mm (1.25 inches), a length of 381 mm (15 inches), and a wall thickness of 3.5 mm (0.14 inches). The Mn/DOT special provisions indicate that this dowel bar is filled with a durable material or have snug-fitting end caps to prohibit any intrusion of concrete or other materials. Although this dowel bar should provide sufficient shear transfer capacity and low concrete bearing stresses, there is a concern that if only the snug-fitting end caps are used, then the lack of a solid core may not provide sufficient resistance of the cross-section to distortion under a heavy axle loading. These distortions may cause horizontal cracking in PCC slabs resulting in a loss of dowel effectiveness (load transfer) and eventual joint spalling.

To investigate the long-term performance of the 316L stainless steel schedule 40 pipe, the Federal Highway Administration and MnDOT sponsored a study in which doweled joints should be subjected to accelerated repeated loads through the use of the Minne-ALF-2. Two types of joints will be evaluated:

- A doweled joint with schedule 40 pipe with the snug-fitting end caps

- A dowel joint with solid 1.5-in diameter epoxy coated dowels

An assessment of the long-term effectiveness of schedule 40 pipe dowels will be made based on the test results by comparing the performance of these dowels with the performance of solid dowels. Two specimens (one with hollow dowels and another with solid dowels) should be tested in this study. Each test specimen consists of two slabs 6-ft. wide and 7.5-in. thick. The combined length of these slabs is 15 feet. The slabs are cast in place using MnDOT 3A41 concrete mix supplied by a local ready mix producer. The doweled joints are located in the mid-length of the specimen and contain three dowels installed in dowel baskets. The 12-in. spaced dowels are positioned to provide a 3-in. PCC cover, and the outer dowel is located 6 inches away from the edge of the slab (see figure 5). The joint is formed by a 1/4-in thick, 7.5-in. wide, and 6-ft. long plywood sheet installed prior to slab casting. The plywood sheet should provide proper joint formation, as well as ensure that transfer from one slab to another is provided mostly by the dowel bars.

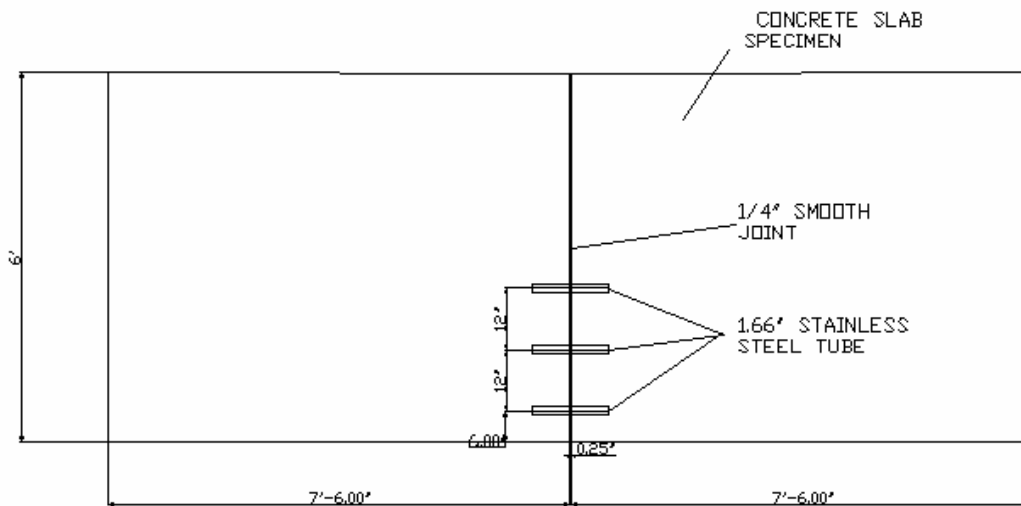


Figure 5. Location of dowels in the joint.

Each of the slabs is loaded using the load pattern described above. The approach slab corner deflections and the differential corner deflections are monitored using two LVDTs. Measurement of the approach slab corner deflection is conducted using a LVDT mounted on a cantilever attached to the test frame. The LVDT touches a contact plate glued to the top surface of the approach slab approximately 1 inch away from the joint and 3/4 inches away from the longitudinal edge of the slab. The differential deflection is measured by the LVDT fixed on the steel angle, which is bolted to the approach slab. The LVDT touches another angle, which is bolted to the leave slab (see figure 6). This LVDT measures the difference between the vertical displacements of these steel angles, which is equal to the difference between corner deflections of leave and approach slabs.



Figure 6. External LVDTs for measurement of corner and differential deflections.

The deflection load transfer efficiency calculated can be easily calculated if the corner and differential deflections are known. Each specimen should be loaded until one of two conditions are met: 1) the application of 10 million load cycles or 2) the LTE drops below 70 percent. In addition, periodically the load cycling is interrupted, and the static LTE is measured by slowing loading and unloading both sides of the joint.

This study is still under way. At the time of the paper submission, only the slab with the doweled joint with schedule 40 pipe has been tested. However, interesting data from this initial loading have been collected and analyzed. Some of the results are presented below.

“Moving” Loading Test

Approximately every 100,000 cycles, the following information is collected over a 2-second time increment:

- Time of measurement
- Load applied to the approach slab
- Load applied to the leave side
- Approach actuator displacements
- Approach slab loaded corner displacements
- Differential deflection defined as a difference between the deflection of the approach and leave slab deflections.

Figure 7 presents measured approach slab corner deflections along with actual

applied loads to the approach and leave slabs and calculated total load on the joint. The load frequency is 2 Hz. As expected, the deflections increase when the MinneALF-2 simulates passing a wheel across the joint and are small during the rest periods.

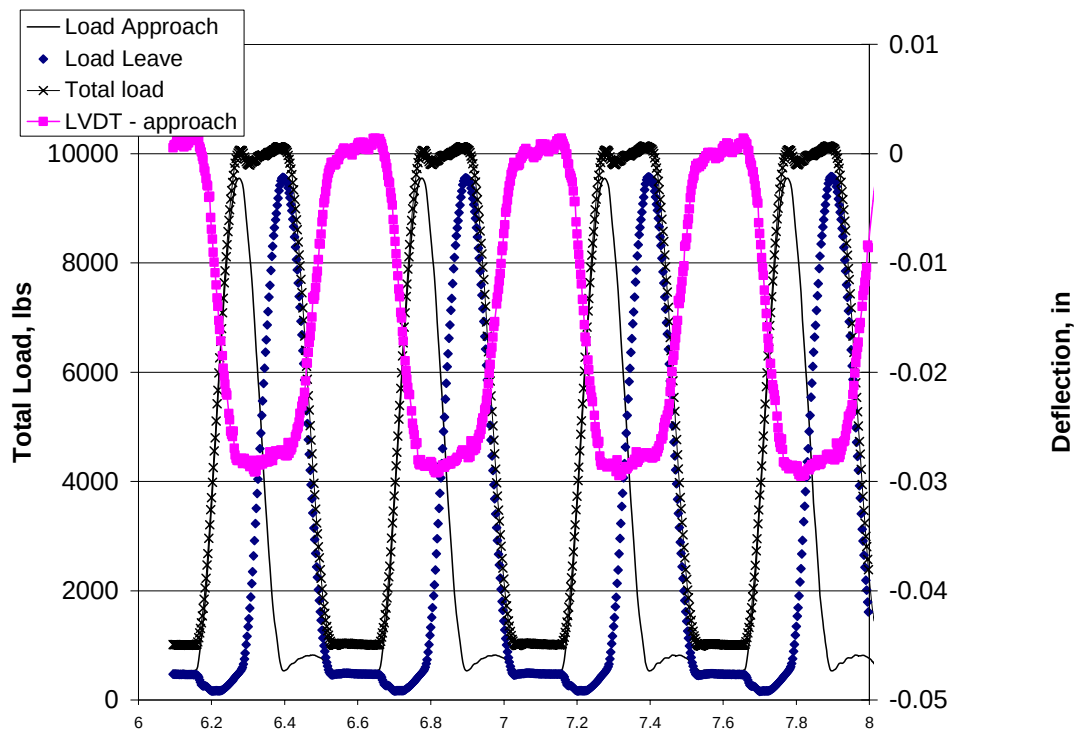


Figure 7. Approach slab corner deflections for the “moving” load test.

To evaluate if the magnitude of measured deflection is reasonable, the measured deflections were compared with the deflections obtained using the finite-element program ISLAB2000 (Khazanovich et al. 2000). Figure 8 shows the finite element mesh and the footprint of the applied load. Since it is difficult to estimate the coefficient of subgrade reaction, a series of runs was performed with the coefficient of subgrade reaction varying from 100 to 500 psi/in. The load transfer efficiency of the doweled joint was estimated to be 90 percent. The slab modulus of elasticity was assigned to be equal to 3,980,000 psi, which corresponds to the PCC modulus of elasticity measured after 28 days from the test slab casting.

As can be observed from figure 9, ISLAB2000 predicts that for the specified ranges of subgrade reaction, the maximum corner deflection varies from 0.020 to 0.080 in. The measured maximum corner deflection is approximately 0.030 in, which is thus within reasonable limits. According to ISLAB2000, the corresponding coefficient of subgrade reaction for this maximum corner deflection is 300 psi, which seems to be reasonable for the MinneALF-2 foundation.

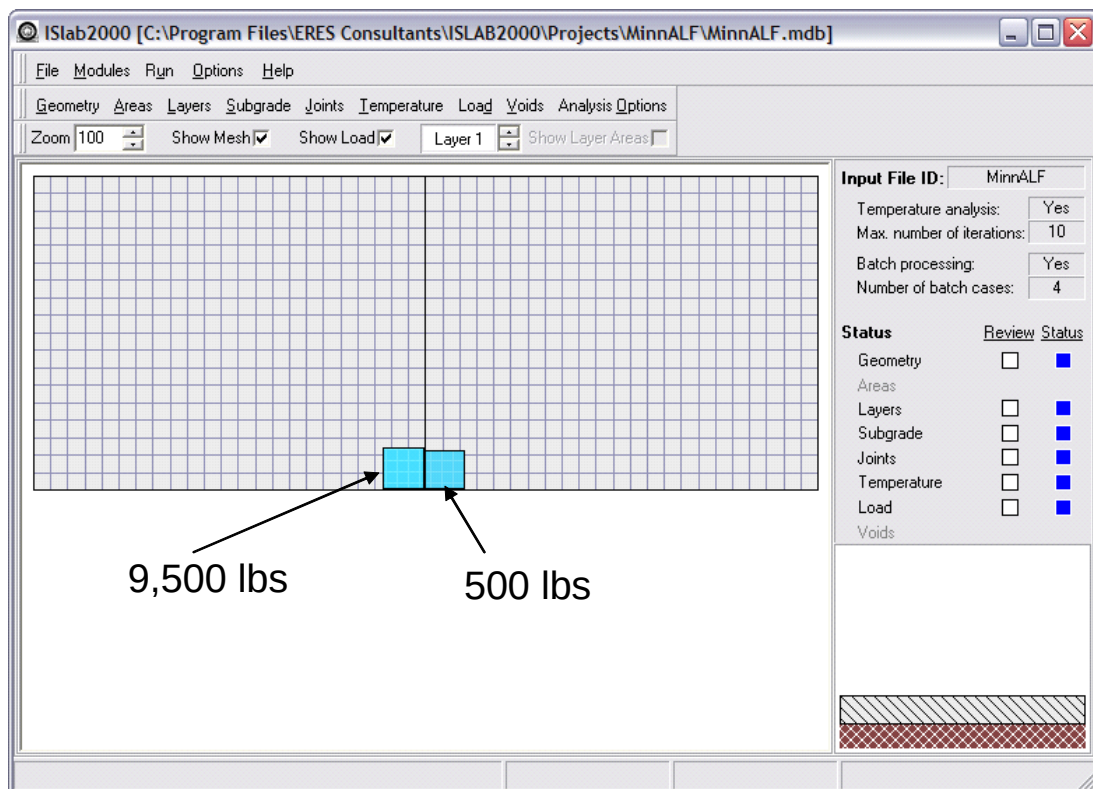


Figure 8. ISLAB2000 finite element model of the Minne-ALF-2 test slab.

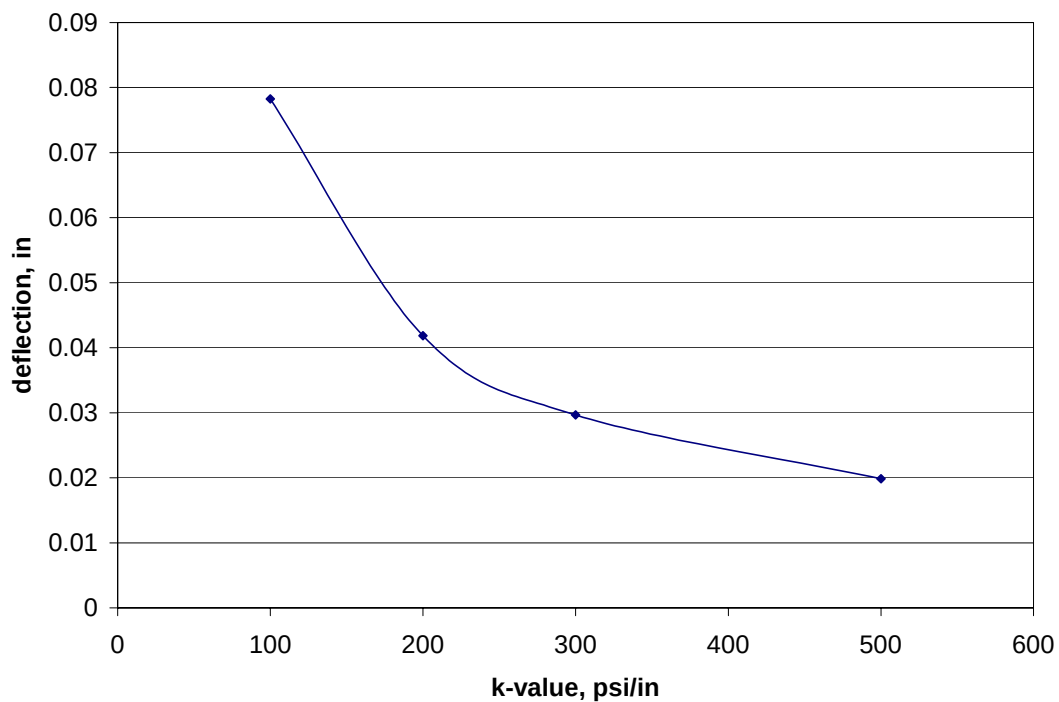


Figure 9. ISLAB2000 maximum corner deflections.

At the same time, a more complicated picture is observed from the differential deflection measurements. Figure 10 shows the measured differential corner deflections along with both the actual applied loads to the approach and leave slabs and the calculated total load on the joint. One can observe that the differential deflections are positive when the load on approach slab is greater than the load on the leave slab. When the load on the leave slab is greater than the load on the approach slab, the differential deflections are negative. Although the overall trend of the differential deflections is reasonable, significant fluctuations in measurements are observed. A first impression is that this fluctuation is a measurement noise. However, the measurements are remarkably repeatable. Figure 11 presents the same differential deflections plotted against the total load on the slab for four consequent cycles. One can observe that although the deflections oscillate when the load increases or decreases, the deflection paths almost coincide. The reason for this behavior will be investigated in the near future.

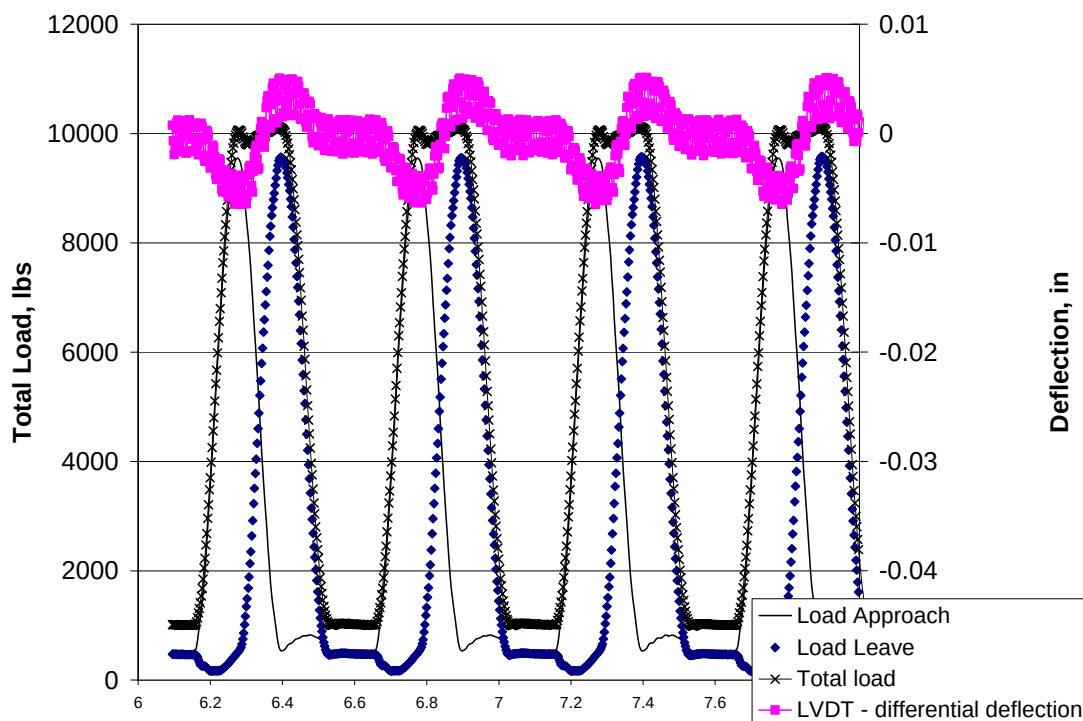


Figure 10. Differential corner deflections for the “moving” load test.

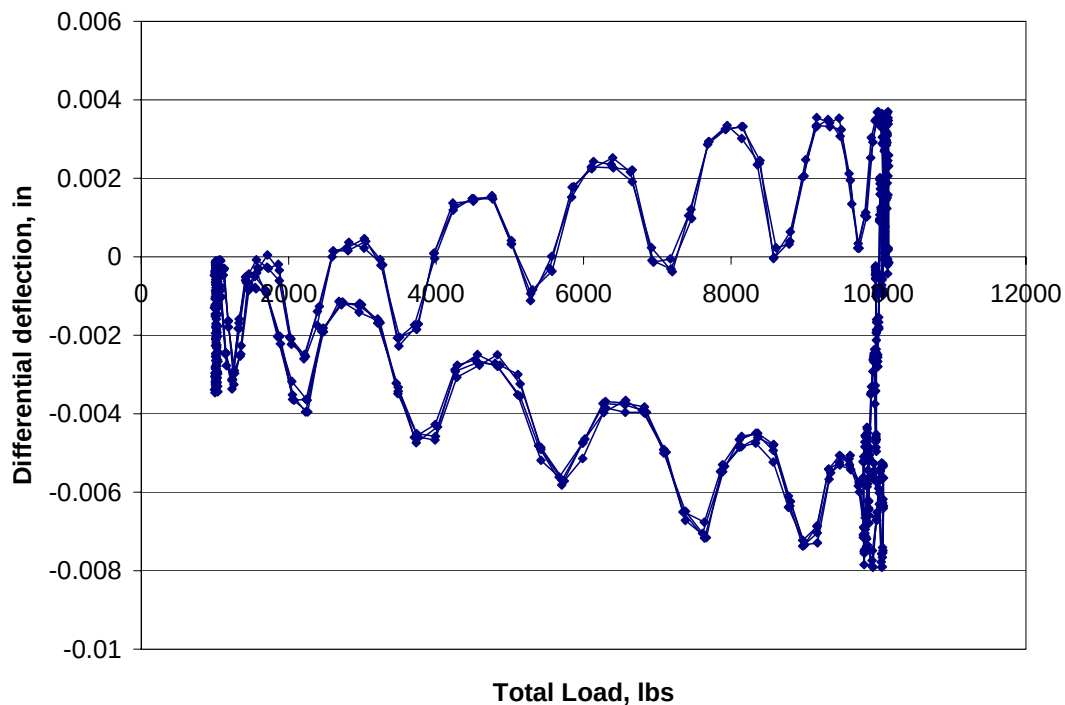


Figure 11. Differential corner deflections vs total load.

Static Loading Test

As it was stated above, slab deflections are monitored during the moving loading of the slab specimen. In addition to these measurements, static measurements with the load applied only either on the approach or leave side of the joint are conducted. In this test, the approach slab is loaded and unloaded three times. Then the same test is repeated for the leave slab. The deflections for each cycle of loading are calculated by subtracting from the LVDT reading at the given load level the reading of the LVDT at the beginning of the first loading cycle.

Figure 12 presents the calculated approach slab corner deflections from the static loading test conducted after the slab received 200,000 moving load application. One can observe that loading on either side of the joint results in deflection paths that are consistent for each loading cycle. In all loading cycles the approach slab corner deflections were the same when the load reached 9000 lbs. As expected, the maximum approach slab corner deflection is higher when the approach slab is loaded.

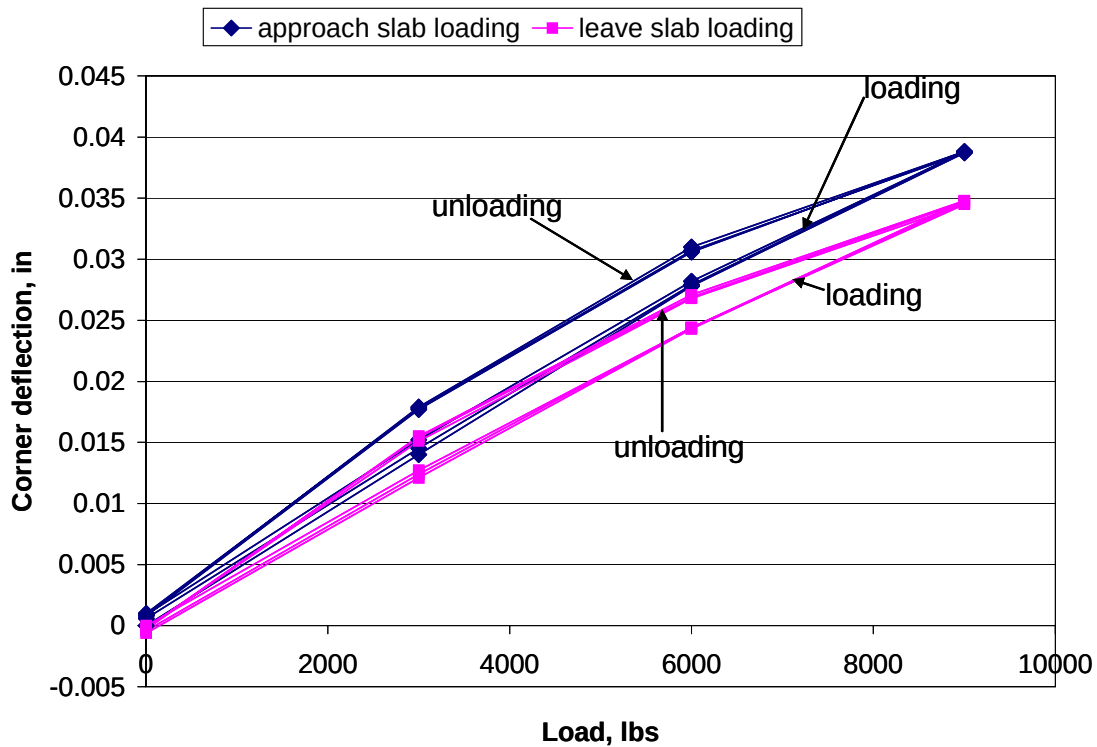


Figure 12. Approach slab corner deflections from static loadings of approach and leave slabs.

It is interesting to note, however, that the unloading paths are different from the loading paths. The deflections during loading are proportional to the magnitude of the applied load, whereas the deflections during unloading exhibit non-linear behavior with respect to the applied load. If the approach slab is loaded, with loads equal to 3000 and 6000 lbs, the deflections during unloading are greater than the deflections for the same load level during loading. On the other hand, if the leave slab is loaded with loads equal to 3000 and 6000 lbs., the deflections during unloading are greater than the deflections for the same load level during loading.

Interesting trends are also observed for the differential deflection (see figure 13). Although all three loading cycles of each slab resulted in the same differential deflections for the maximum load, the differential deflection paths from the first loading cycle are different from the corresponding deflection paths from the second and third loading cycles for the loading of both the approach and leave slabs. At the same time, the unloading paths were practically identical. Unloading from 9000 to 6000 lbs. did not lead to an appreciable reduction in the differential deflection. Every time the slabs were unloaded, the differential deflections returned to the same non-zero level, i.e. the position prior to the first loading.

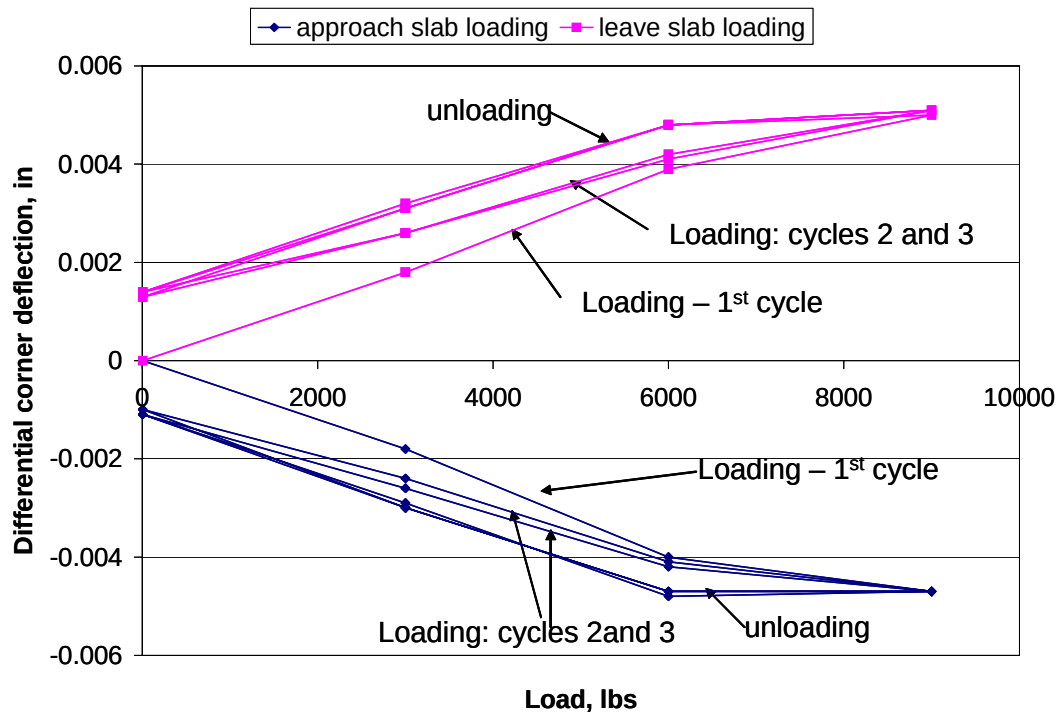


Figure 13. Approach slab corner deflections from static loadings of approach and leave slabs.

The static loading of the joint was conducted after 300, 450, 600, 900, and 1,200 thousand load cycles, and every time a similar behavior was observed. Although these effects can be ignored in a simplified routine analysis using ILLISLAB or ISLAB2000 models for an analysis of pavement responses, current models of PCC joints should be modified to explain the observed phenomenon from these preliminary results.

Conclusions

The paper presented the second generation of Minnesota Accelerated Loading Facility (Minne-ALF-2). It was shown that the system allows realistic simulation of repeated truck loading of concrete pavement joints.

In addition to testing of long-term performance of concrete pavement joints, Minne-ALF-2 can be used for an investigation of the fundamentals of concrete joint behavior. This information may be later used for the development of improved mechanistic-empirical models of pavement joints.

For example, the first series of experiments on a concrete joint with hollow stainless steel dowels showed that deflections in the unloading path are different from the deflections at the loading path. It was also found that the residual differential deflections remain after the first loading and unloading cycle. Available

finite-element models for rigid pavements do not explain these effects. Advancements in the modeling of PCC joints are required to explain the observed above phenomenon and develop a better understanding of joint behavior and design.

The observed trends were found to be repeatable for this test specimen. It is important to verify the results for other specimens with different joint designs. Several other slabs will be tested in the near future, which will allow us to verify if these trends are independent of the joint design.

Acknowledgment

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