

PRELIMINARY INVESTIGATION OF HAULING STRESSES
IN PRESTRESSED CONCRETE PILES

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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CHAPTER I

FIELD INVESTIGATION

Introduction

Since 1961, the staff of the Texas Transportation Institute has been engaged in piling research. A part of this research has been concerned with pile stresses during driving. It has been shown that under certain driving conditions, it is possible to introduce large tensile stresses into the pile. The magnitude of these stresses is dependent upon the soil resistance, the stiffness of the cushion block, the unit weight and elasticity of the pile, and the weight and velocity of the pile driver's ram.

The tensile strength of a prestressed concrete pile is dependent upon the final prestress and the inherent tensile strength of the pile concrete. If a pile is initially cracked, by handling or hauling, the available tensile capacity of the pile will be lowered by an amount equal to the inherent tensile strength of the pile concrete. The remaining tensile capacity of the pile will depend solely on the final prestress. It should be noted that in the case of a cracked pile, repeated passage of tensile stress waves, in excess of the available tensile capacity of the pile, could be very detrimental to the structural integrity of the pile. Repeated opening and closing of the crack (visible by dusting at the crack) will gradually disintegrate the adjacent concrete. Furthermore, there is also the danger of corrosive agents gaining entrance to the reinforcing steel by way of a crack. This possibility alone makes the use of cracked piles questionable in marine environments.

Objectives

In the course of a laboratory investigation of longitudinal strain waves in 5000 psi concrete piles, the question of pre-cracked piles arose. The investigators were concerned that the piles to be used in this investigation had been subjected to dynamic overload due to the method used in transporting the piles from the casting yard to the laboratory. The piles were transported approximately 150 miles by truck (tractor and pole trailer). It was noted upon receipt of the piles that the distance between supports was greater than that recommended by the Bridge Division of the Texas Highway Department.² It was decided, therefore, that a very limited test program would be conducted to get some qualitative and quantitative data on the behavior of piles under certain controlled hauling conditions. Field data on pile strains or stresses were also desired in order to establish the feasibility of developing a mathematical model to predict the stresses generated during hauling.

It is the object of this report to give the results of this limited test program and to explore the feasibility of using a mathematical simulation to predict dynamic stress levels induced by hauling.

Test Program

General--One solid prestressed concrete pile, 65 ft in length and 15 in. square was instrumented with strain gages at two locations and an accelerometer was placed at one location. The pile was placed on a pole trailer and hauled over a known bump at a predetermined speed. The subsequent strains and accelerations were recorded on a recording oscillograph. Figure 1 is a schematic of the pile and hauling configuration. The location of the strain gages and accelerometer are shown. The pile was hauled in the manner shown to simulate the hauling conditions used when the pile was originally received. The THD Bridge Division recommends that a 65 ft x 15 in. square pile be hauled with minimum end overhangs of 14.4 ft and 11.7 ft.³ According to these recommendations, the maximum length of pile that can be hauled safely, with the overhangs shown in Figure 1, is 53 ft. These recommendations assume that the pile will not be damaged as long as the calculated dead load static stress (no impact factor) for the support conditions, is no more than 60% of the initial prestress. This assumption is predicated on a 1.50 impact factor for hauling with zero allowable tensile stress in the concrete (assuming 90% initial prestress at hauling).

Test Site Layout--Three sets of controlled bumps were used in this program. These bumps were constructed of standard dimensioned lumber and are shown in Figure 2. The test site was located on the concrete parking apron at the Texas A&M University Research Annex (old Bryan AFB). Ample space was available for acceleration and safe deceleration of the hauling vehicle. The power supplies, strain gage amplifiers and recorder were transported in a satellite vehicle which followed to the side and rear of the hauling vehicle. Electrical connections were made through an extension cable. Appendix A gives an equipment list and Figure 3 gives a schematic of the instrumentation.

Test Procedure--The test program consisted of running the vehicle and pile over a single bump (one of the three controlled bumps). During each run the strains and accelerations were recorded continuously for the passage of the entire vehicle over the bump. A traffic radar unit recorded the speed of the hauling vehicle. After each run, the pile was inspected for cracks or other damage.

Test Results--The strain gages were located at the points of maximum positive and negative dead load movement for the pile supported as shown in Figure 1. This was done so as to be able to compare these stresses with the dynamic stresses induced by hauling.

The gages were positioned on the pile and wired as shown in Figure 3. With this arrangement, the strains measured were the average of the tensile and compressive strains. Consequently, this average strain is a direct measure of the curvature of the

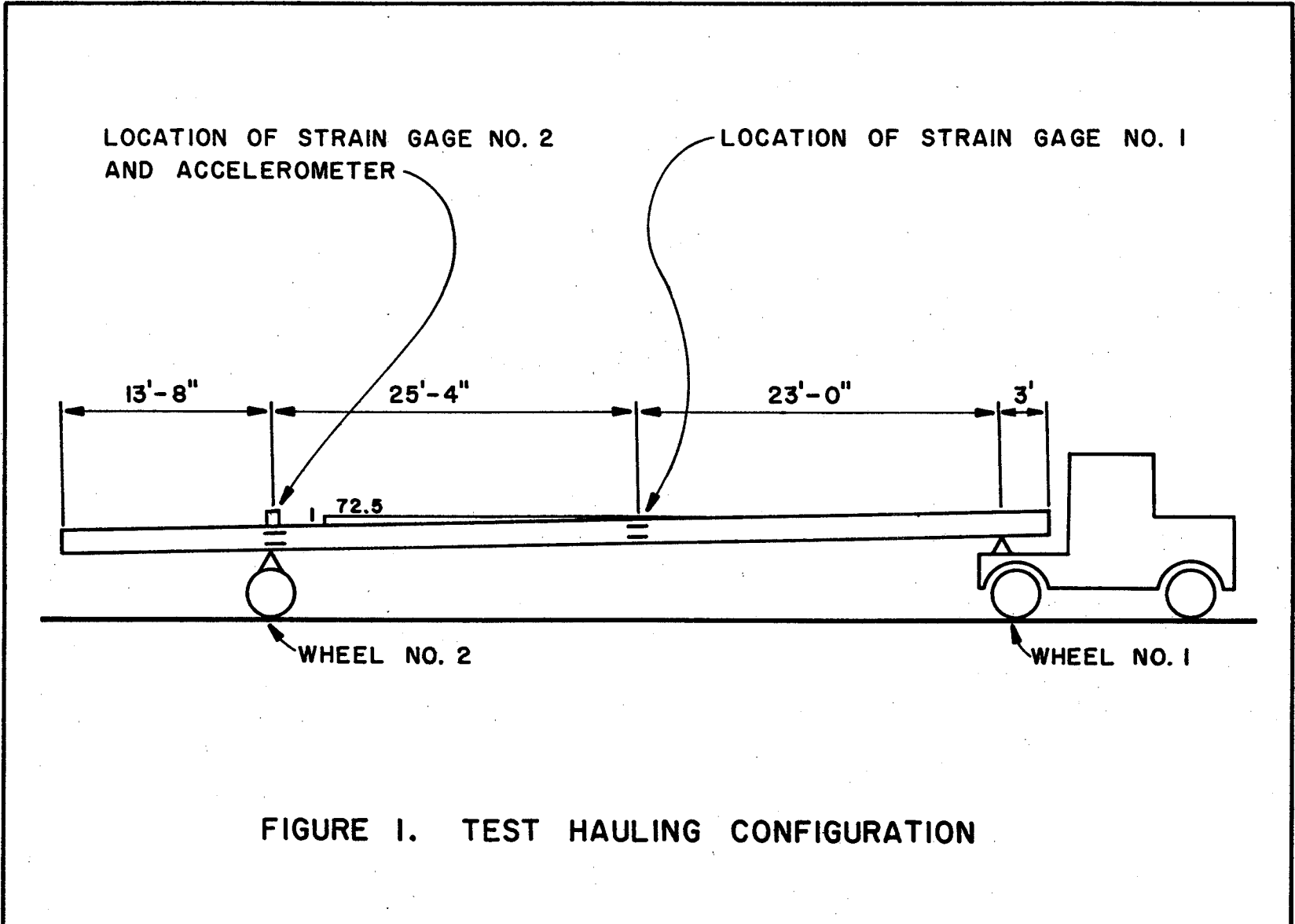
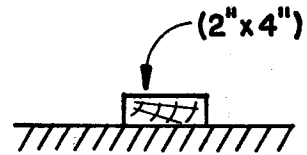
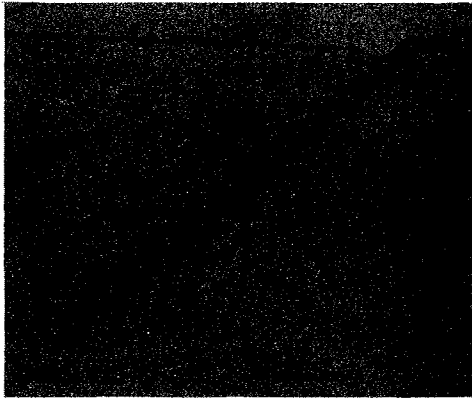
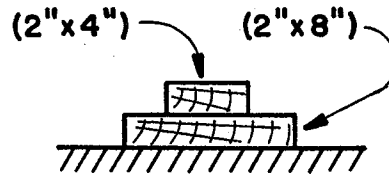
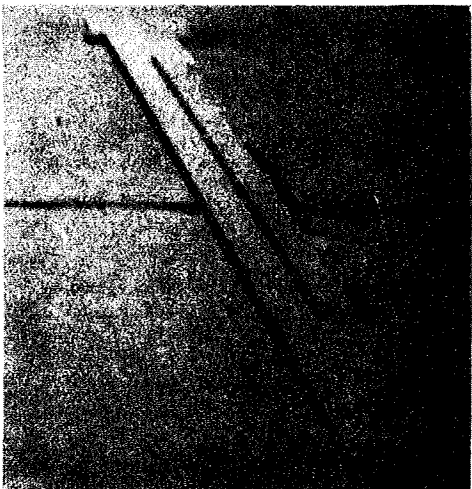


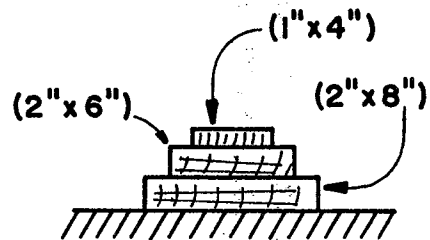
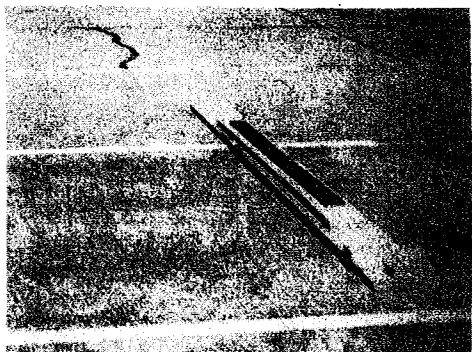
FIGURE 1. TEST HAULING CONFIGURATION



BUMP NO. 1



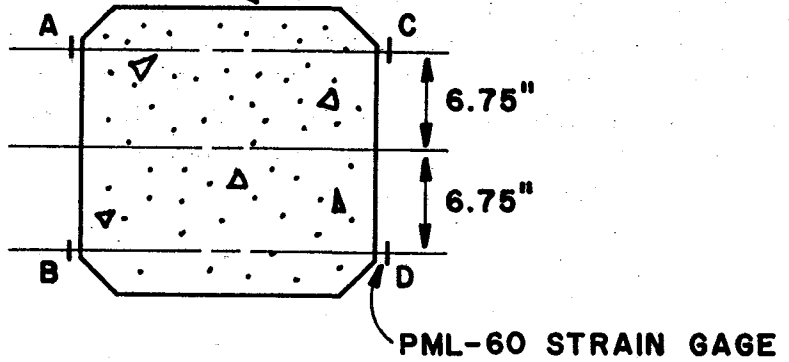
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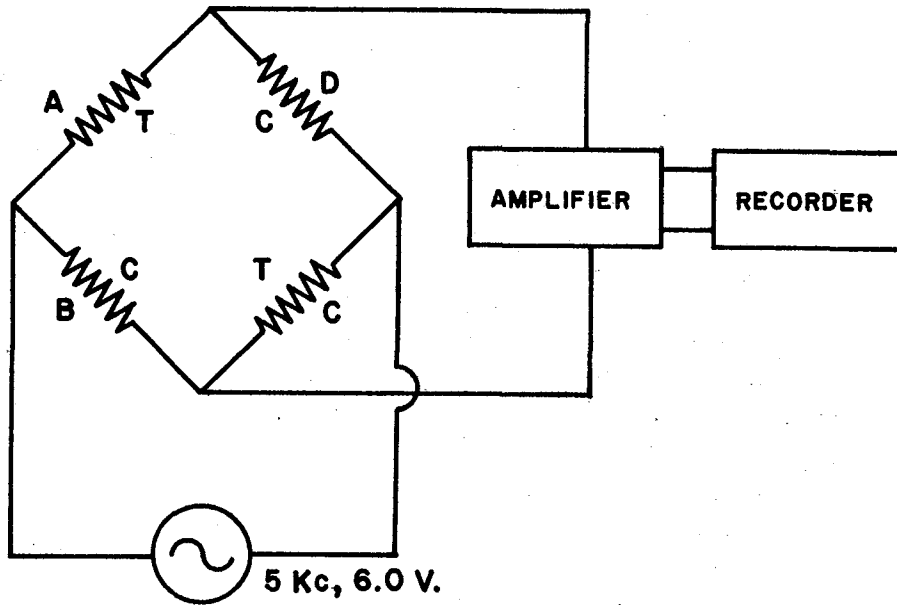
BUMP NO. 3

FIGURE 2. CONTROLLED BUMPS

TYPICAL SECTION THRU 15" SQ.
PILE AT GAGE LOCATION



GAGE LOCATION ON PILE



ELECTRICAL SCHEMATIC

FIGURE 3. STRAIN GAGE LOCATION AND ELECTRICAL
SCHEMATIC

beam and not necessarily a measure of true stress when multiplied by the modulus of elasticity of the pile concrete. The average strain was not always proportional to the stress since cracks in the pile at the gage locations were open at times and closed at times. Calculated static dead load stresses were determined using an uncracked section. Dynamic stresses were determined by multiplying the measured strain by the modulus of elasticity of the pile concrete. These stresses are fictitious in the instances when the pile cracks at the gage locations. In this case the strain gages give the average strain over the cracks.

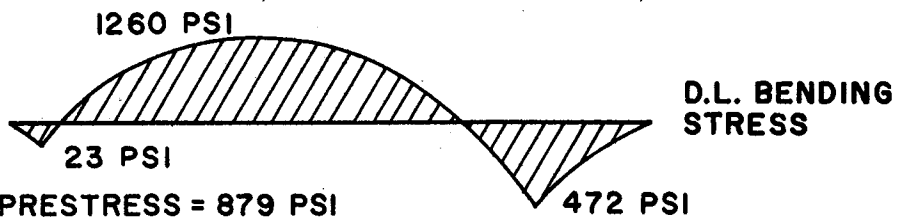
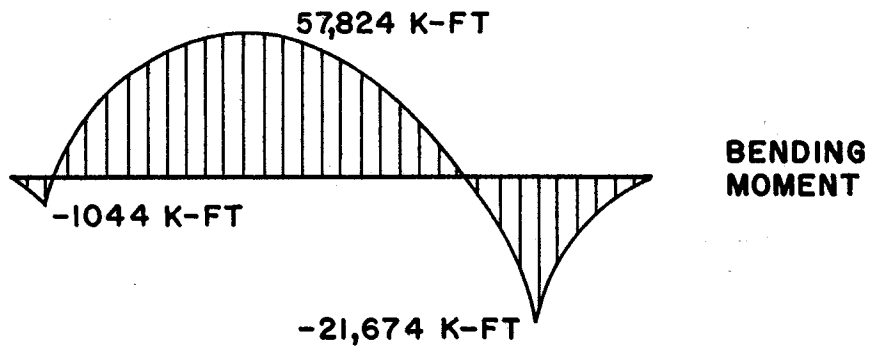
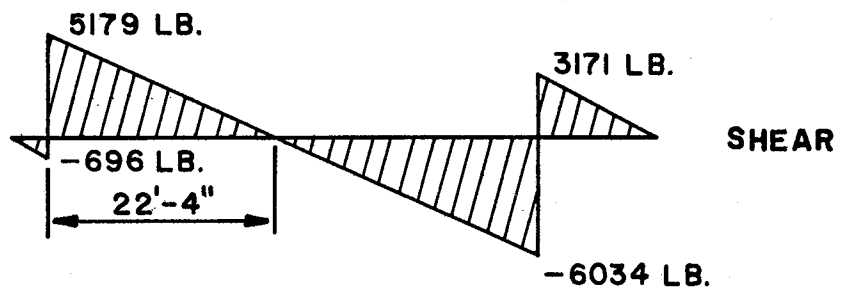
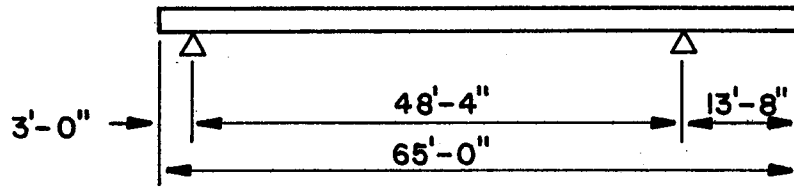
In each test the strain gage bridge was zero balanced with the pile supporting the dead load. Therefore the strains recorded reflect only the dynamic response.

Figure 4 shows the static dead load bending stress for the support condition shown. Note the maximum tensile flexure stress is 1260 psi. Allowing for the final prestress of 703 psi, the pile concrete is required to resist 557 psi. Appendix B shows that the tensile capacity of the pile concrete was 455 psi based on direct tension tests on 3 in. x 3 in. x 22 in. prisms. The modulus of rupture was 1220 psi based on flexural tests on 3 in. x 4 in. x 16 in. beams center point loaded on a 14 in. span. The true flexural tensile capacity of the pile concrete is somewhat between these two extremes. This indicates that the pile could have cracked under a dead load condition. A careful examination of the pile before the tests revealed that the pile was cracked. Hairline cracks were visible in the tensile fibers at the point of maximum moment. These cracks were observed to close when the pile was supported at the recommended pickup points.

Table I gives the values of the maximum dynamic stress during the passage of the hauling vehicle over the controlled bumps. As shown in Figure 1, wheel 1 is the drive wheel of the tractor and wheel 2 is that of the single axle pole trailer. The maximum tensile flexure stress (dead load stress plus dynamic stress) is given for the passage of each wheel over the particular bump. Also shown are the ratios of maximum dynamic stress to dead load stress at each gage location. This ratio is normally referred to as the impact factor. It should be kept in mind that the pile used in these tests had been previously cracked during hauling and, consequently the strains and stresses recorded are influenced by the presence of cracks and the reduced flexural stiffness.

The damage done to the pile during the passage over bump No. 3 is shown in Figure 5. Note that in several places the pile is cracked across the entire cross section indicating complete reversal of stress. Also note the widespread cracking throughout the length of the pile.

15 IN. SQ. SOLID PRESTRESSED CONC. PILE



INITIAL PRESTRESS = 879 PSI

FINAL PRESTRESS = 703 PSI

FIGURE 4. DEAD LOAD STRESS CONDITION

**TABLE I: MAXIMUM TENSILE FIBER STRESSES
AND IMPACT FACTORS**

		BUMP NO. 1		BUMP NO. 2		BUMP NO. 3	
		VEHICLE VELOCITY = 19 MPH		VEHICLE VELOCITY = 21 MPH		VEHICLE VELOCITY = 11 MPH	
WHEEL AT BUMP	GAGE LOCATION	f_{max} (PSI)	$\frac{f_{max}}{f_{dl}}$	f_{max} (PSI)	$\frac{f_{max}}{f_{dl}}$	f_{max} (PSI)	$\frac{f_{max}}{f_{dl}}$
1	1	1922	1.53	2938	2.33	3031	2.41
	2	673	1.43	1089	2.31	1449	3.07
2	1	1556	1.23	2184	1.73	2519	1.99
	2	1000	2.12	1833	3.88	1295	2.74

NOTE :

f_{max} = MAXIMUM FIBER STRESS (BASED ON $E=7.15 \times 10^6$ PSI)

f_{dl} = DEAD LOAD FIBER STRESS, GAGE 1 +472 PSI GAGE 2 +1260 PSI

f_i = INITIAL PRESTRESS = 879 PSI

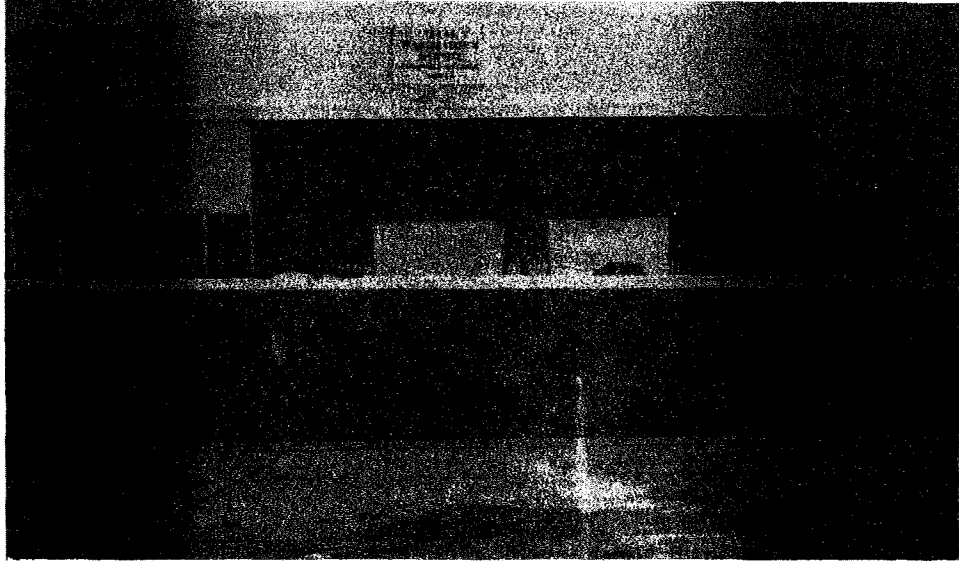


FIGURE 5. PILE DAMAGE

CHAPTER II

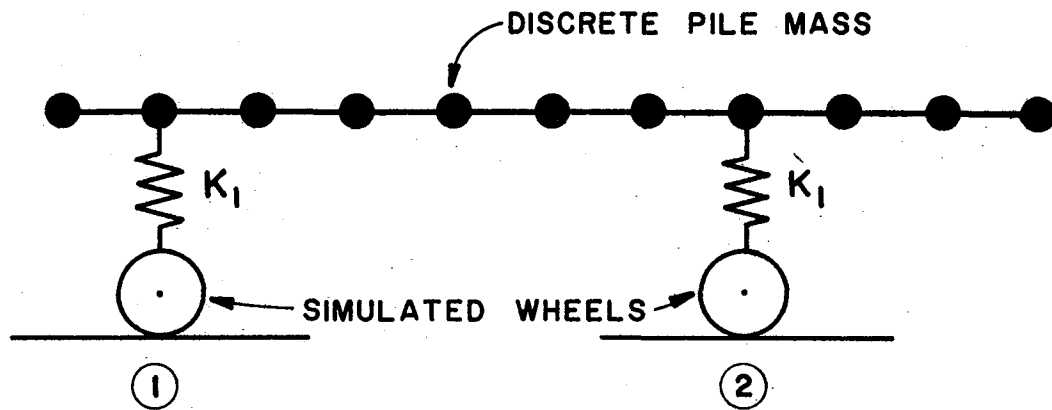
MATHEMATICAL SIMULATION

An attempt was made to simulate the behavior of the pile by using a lumped mass representation of the pile. Figure 6 (a) shows the lumped mass representation used in the simulation. Springs at the supports simulate the physical springs of the rear tractor wheels and the dolly on the pole tractor. The formulation of the dynamical equations of motion for the multidegree of freedom system assumes small deflections and neglects any shear or rotary inertia effects.⁴ Plastic effects are included by assuming elastic, perfectly plastic behavior. This assumption is in error in that a cracked concrete section does not exhibit this type behavior. However, since the simulation was intended only to be preliminary in nature, it was felt that this effort to include accurate moment curvature behavior would not be done at this stage.

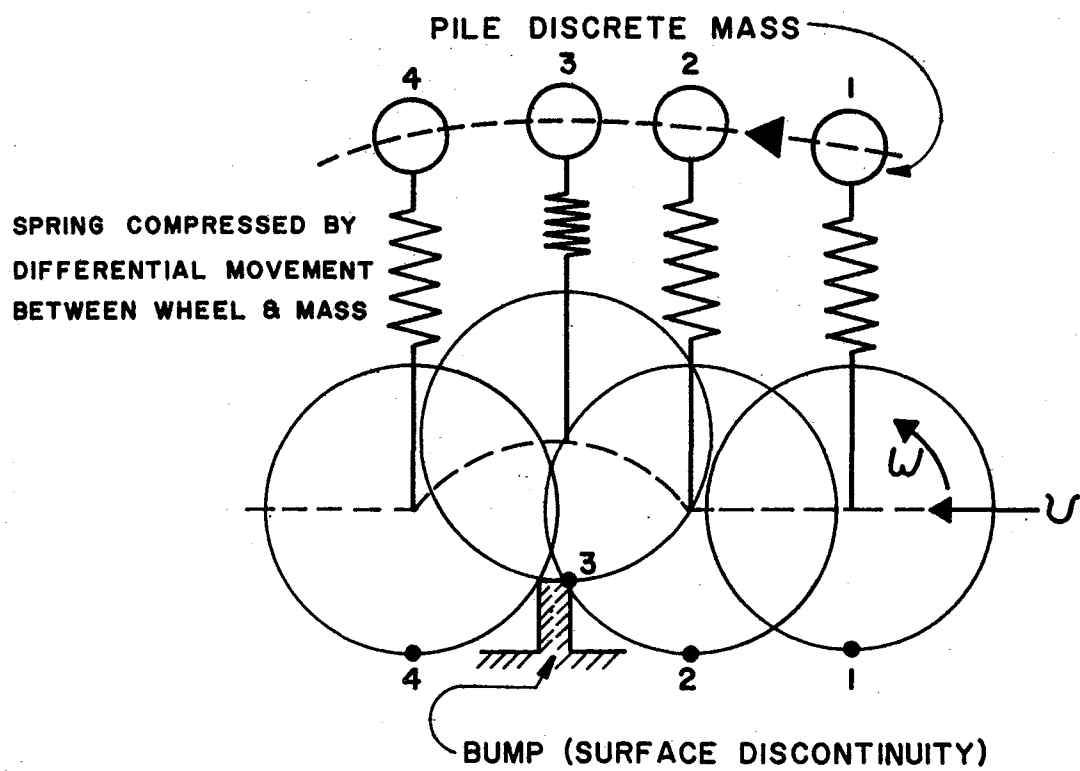
The forcing function, for a wheel passing over a bump, was simulated as a rigid disc pivoting about a surface discontinuity. This behavior is shown in Figure 6 (b). The force, which will vary with time, is dependent on the deformation of the carriage spring. The deformation is the net movement of the pile mass (at the support point) with respect to the disc or wheel. The carriage spring is a simulation of the combined spring of the dolly and tire. For the purpose of this simulation, a spring constant of 5000 lb/in. was used for springs K_1 and K_2 . Note that no dashpot (shock absorber) was included in the simulation. The inclusion of a dashpot at this stage of the investigation would introduce complications not warranted in this preliminary investigation. If a reasonable engineering correlation can be shown using a simplified model, then sophistication can only bring improvement.

Bump 2 was chosen to be correlated with the results of the mathematical simulation. Figure 7 shows a time vs. stress correlation plot for gage locations 1 and 2 for the passage of wheel Number 1 (drive wheel of tractor) over the bump. The stress values shown are plotted from the equilibrium position and hence reflect only the dynamic response. Note that the stress values of the simulation do not correlate well with the measured values. In both cases, the stress values are too large and the response is quicker. This is probably due to the fact that no dashpot (shock absorber) was included. The fact that flexural damping was ignored is of significance also. The presence of cracks would also tend to decrease the natural frequency of the real system somewhat.

Figure 8 shows the correlation for the passage of wheel Number 2 over the bump. Note that the stress values for gage location 1 are again large and not in phase. The reasoning given above applies here as well. The stress for gage 2 however is in very good agreement with the measured strain values. It should be noted that this gage was located directly over the wheel which was on the bump and hence would not be influenced as greatly by damping.

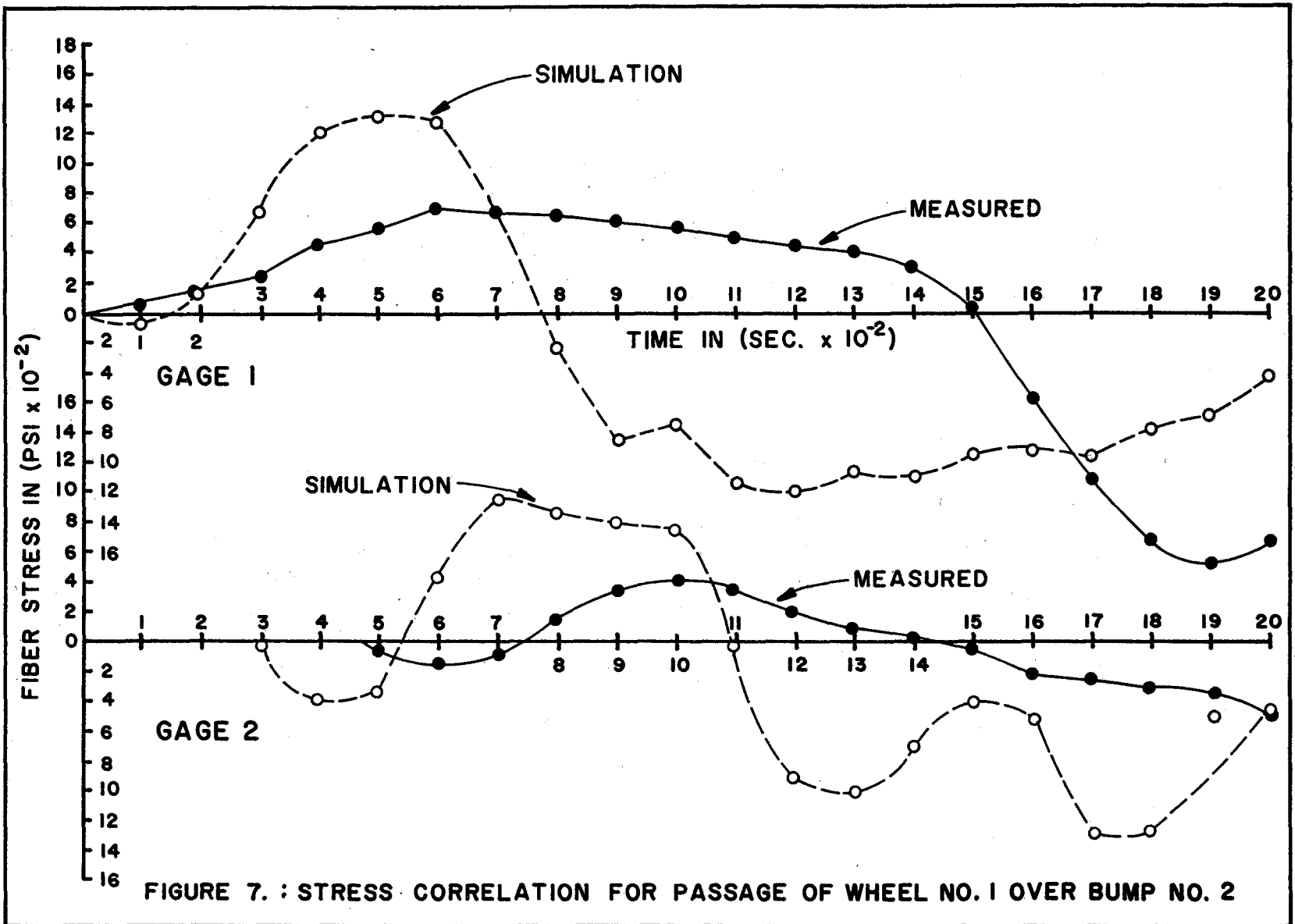


(a)



(b)

FIGURE 6. PILE AND WHEEL SIMULATION



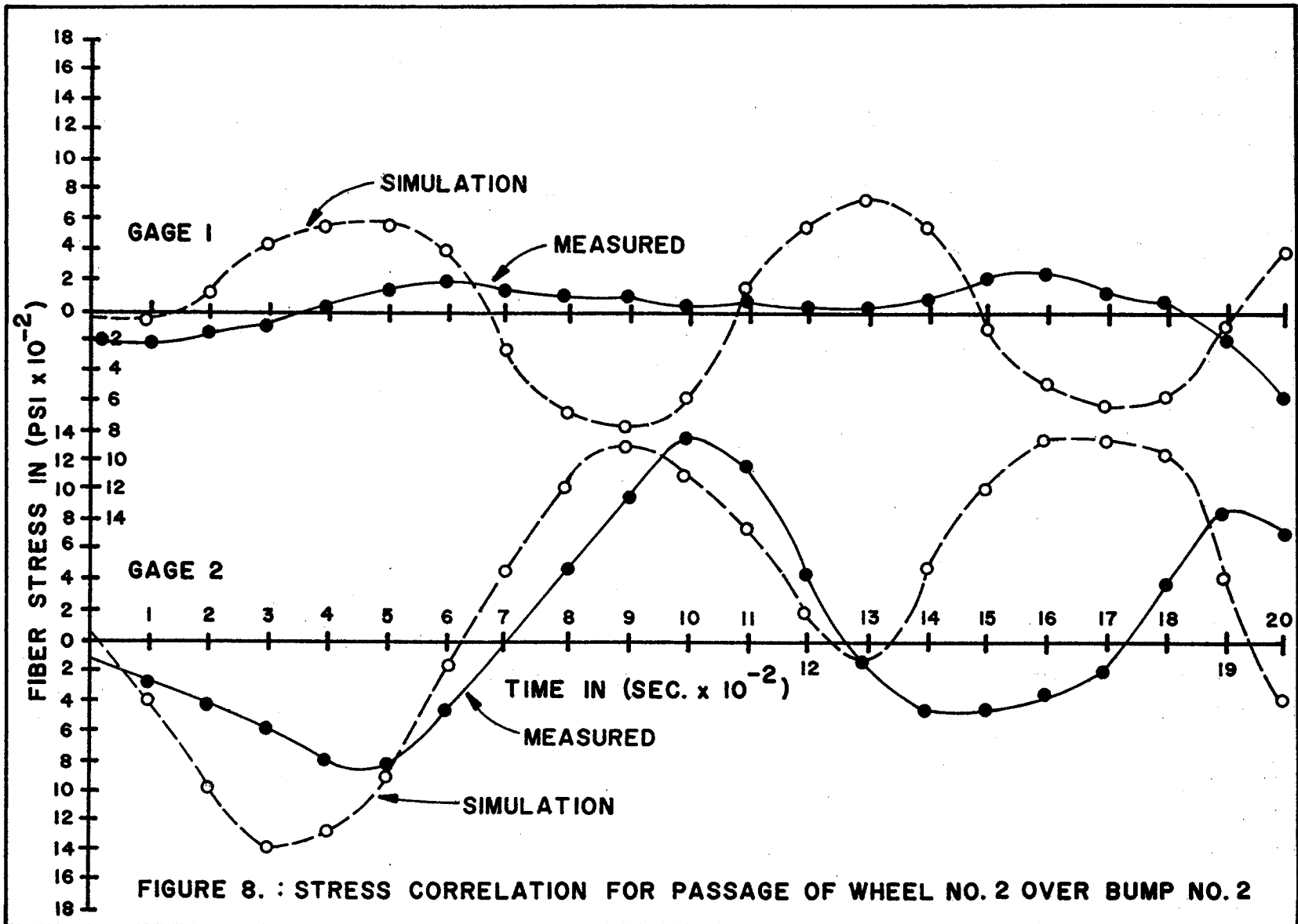


Figure 9 shows the stresses produced when the hauling vehicle traveled over a smooth pavement at 15 mph. The maximum stress is 150 psi at gage location 1 and 105 psi at gage location 2. These stresses were generated by a random forcing function (due to wheel out of balance, surface irregularities, etc.), therefore, they were present throughout the test and hence were superimposed on the stresses due to the bump. This could explain some small stress and phase variations in the correlation.

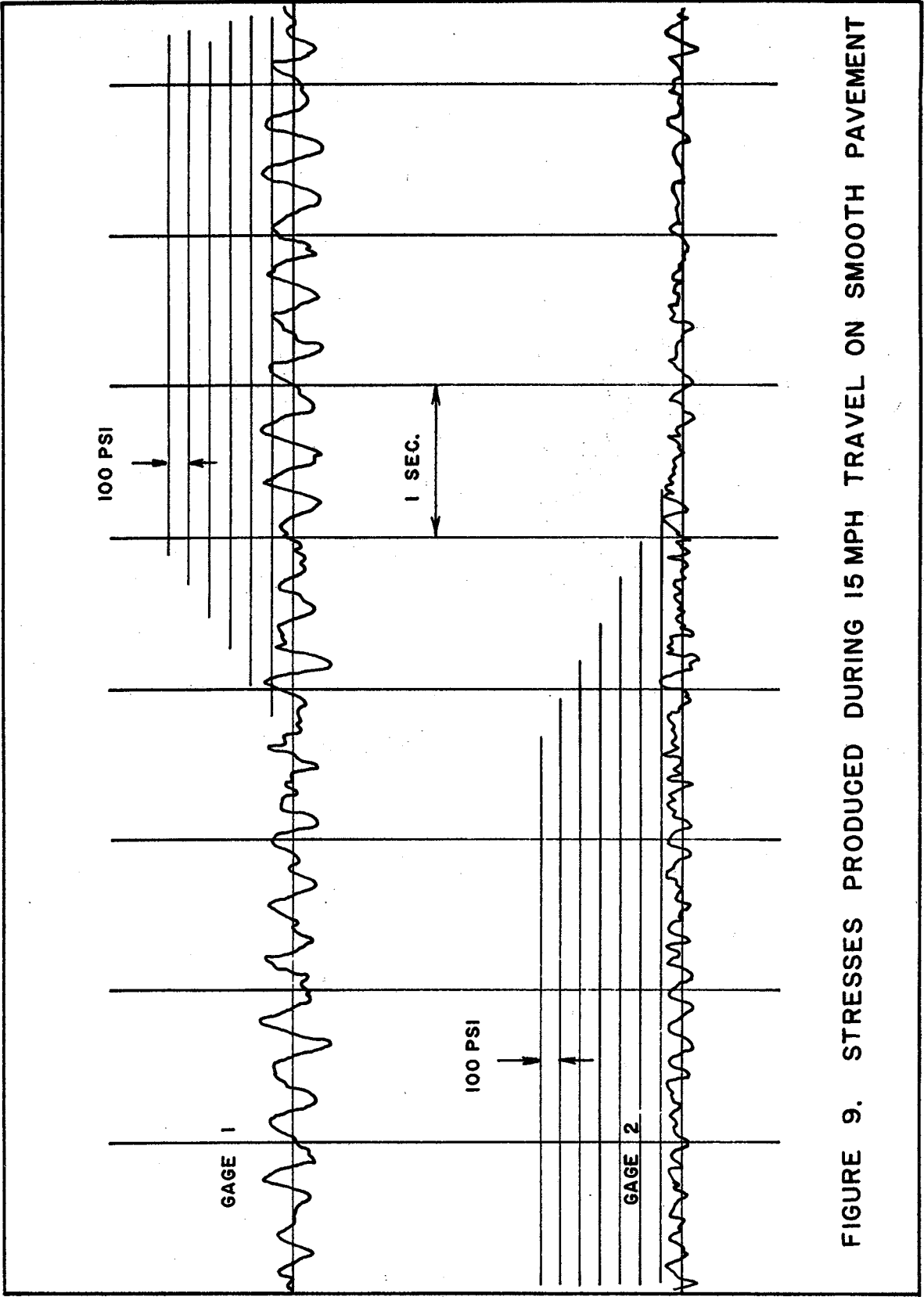


FIGURE 9. STRESSES PRODUCED DURING 15 MPH TRAVEL ON SMOOTH PAVEMENT

CHAPTER III

CONCLUSIONS

The data presented in Chapter II illustrate that the magnitude of stresses involved in hauling may be much larger than normally specified. In severe conditions, that may be encountered during hauling, dynamic impact factors for maximum stress can be as high as 2.25 (based on dead load stresses). This indicates that for piles which are supported in a critical or near critical manner, the probability of cracking during hauling is high.

The attempt to mathematically simulate pile hauling stresses was only partially successful. A good correlation was obtained for stresses in the pile at the gage location near the wheel being bumped. Very poor correlation was obtained for gage locations remote to the bumped wheel.

The simulation does give the indication however, that closer correlation can be obtained by added sophistication to the model by developing a more realistic approach to the routine used to simulate the carriage response; by including flexural and other damping factors; by using a realistic moment-curvature relation for the pile that would accurately simulate the flexural behavior of the cracked section.

A model that has been thoroughly validated is of inestimable value in setting the proper values on the behavior factors which dictate the design of a prestressed concrete member. With a tool such as this, methods of hauling and handling could be fully explored and appropriate specifications written. It could also be used in special cases where unusually long piles or beams must be handled and transported.

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2. Handling Controls for Concrete Piling. Bridge Division of the Texas Highway Department, July, 1964.
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APPENDIX A

Equipment Test

1. Strain gage:

a. Manufacturer - Tokyo Sokki Henkajujo Co., Ltd.

b. Specifications

Type - PML-60

Resistance - 120 ohm \pm 0.5%

Gage Factor - 2.19

Gage Length - 60 millimeters

2. Strain Gage Power Supply and Amplifier:

a. Power Supply - Honeywell Model 121 (5000 cps carrier frequency)

b. Amplifier - Honeywell Model 119 Carrier

3. Recorder:

a. Honeywell Model 1508 Visicorder (optical galvanometer type M 1650)

b. Recording Paper - Kodak Lineograph Direct Print, Spec. 2.

APPENDIX B

LABORATORY TEST PILES

CAST ON FEBRUARY 5, 1964

Class "F" Concrete (quantities per cy)

Cement Type III	610 lbs or 6 1/2 sacks
Gravel	1896 lbs
Sand	1360 lbs
Water	217 lbs or 26 gallons
Slump	2-3 in
Plastiment	12.8 oz
Sika Air	6.4 oz
Air Content	4%
Unit Weight	4083 lbs/cy 151.1 lbs/cy

Properties at 14 days of age

Compressive Strength 6" x 12" cyl.	6655 psi
Modulus of Rupture 3" x 4" x 16" prism	1220 psi
Tensile Strength 3" x 4" x 22" prism	455 psi
Modulus of Elasticity (static)	7.15 x 10 ⁶ psi
Modulus of Elasticity (dynamic)	7.56 x 10 ⁶ psi
Poisson's Ratio (dynamic)	0.21
Concrete Steam Cured at 145° for 14 hours	

