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EVALUATION OF INNOVATIVE CONCEPTS RELATING TO PRESTRESSED CONCRETE PAVEMENTS

by

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16. Abstract

This report presents an evaluation of three methods for post-tensioning concrete pavements without embedded steel tendons. All methods permit joint movement while maintaining slab prestress at the pavement joint. One method consists of thin-wall hydraulically presurized bellows as stressing elements. The second uses a pnuematically charged rubber bladder. The third method makes use of stacked Belleville springs.

Three prototypes were constructed and tested in the laboratory. Test conditions included joint movement and simulated traffic loading.

The Belleville spring system was selected as most promising for use in prestressed pavement overlays on the basis of performance and cost.

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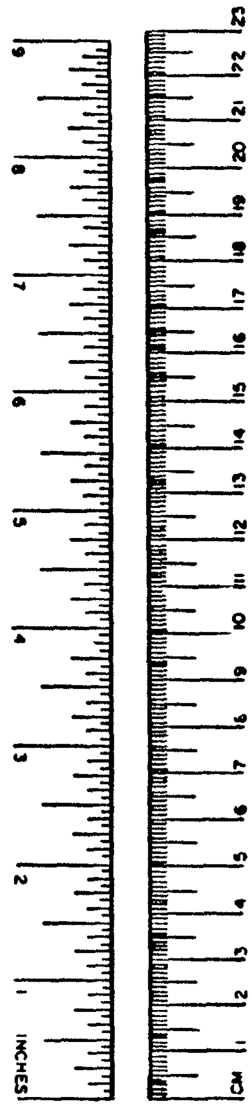
METRIC CONVERSION FACTORS

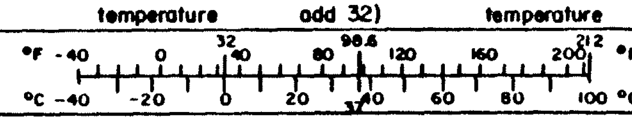
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons(2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares(10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report has been prepared as part of a contract between FHWA and the Construction Technology Laboratories, a Division of the Portland Cement Association. It is the fifth of a five-volume series concerning design of prestressed concrete pavements. The series consists of the following reports:

(1) Prestressed Pavement Joint Designs

(2) Prestressed Pavement Thickness Design

(3) Prestressed Pavement Construction Manual

(4) Prestressed Pavement Accelerated Testing Program

(5) Evaluation of Innovative Concepts Relating to Prestressed Concrete Pavements

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INTRODUCTION

The objective of Federal Highway Administration's Research Project 5E, Premium Pavements for "Zero Maintenance" is to exploit modern materials and technology in developing "Zero Maintenance" pavements for warranted use.

As a portion of this research project, an investigation has been conducted by the Construction Technology Laboratories, a Division of the Portland Cement Association, to develop design and construction techniques for prestressed concrete pavements. This work will be co-presented in reports covering the following:

(1) Transverse joint design
(2) Thickness design procedure
(3) Construction techniques
(4) Accelerated testing program
(5) Laboratory studies

This report presents work done to evaluate a confidential idea presented by Gene R. Morris, Arizona Department of Transportation entitled "Self-Compensating Hydraulically Precompressed Pavements" (SCHPP). Work was conducted by the Construction Technology Laboratories (CTL) in accordance with Task J, Enclosure 1 of Contract No. DOT-FH-8894, Modification 6.

Evaluation of the concept entailed the design, manufacture, assembly, and laboratory trial of a workable self-compensating hydraulic pressure unit. Laboratory testing included observation of performance under simulated in-service conditions.

In addition, a rubber bladder and a spring system were developed and performance was observed in laboratory trials. The spring system was selected as suitable for use in prestressed portland cement concrete overlays.

DESIGN CONCEPT I

The intent of the Arizona self-compensating hydraulic precompressing system was to provide a zero-maintenance, low cost, modular pavement prestressing system to be installed in concrete pavement joints using uncomplicated field techniques. The proposed hydraulic system used a series of corrosion resistant thin wall metal bellows as stressing elements installed at active joints. Pavement thermal movement would be compensated for at these joints. This was to be accomplished using an edgewelded flat plate accumulator operating exclusively in the elastic region of the plate material. The accumulator would compensate for pressure changes caused by bellows oil displacement resulting from joint movements. Design assumptions and details of the proposed Arizona system are presented in Appendix A. The following sections present the CTL design, construction, and laboratory evaluation.

Design

Bellows were designed for the following conditions:

(a) Pavement thickness of 8 in. (203 mm)

(b) End of slab prestress of at least 200 psi (1.38 MPa).

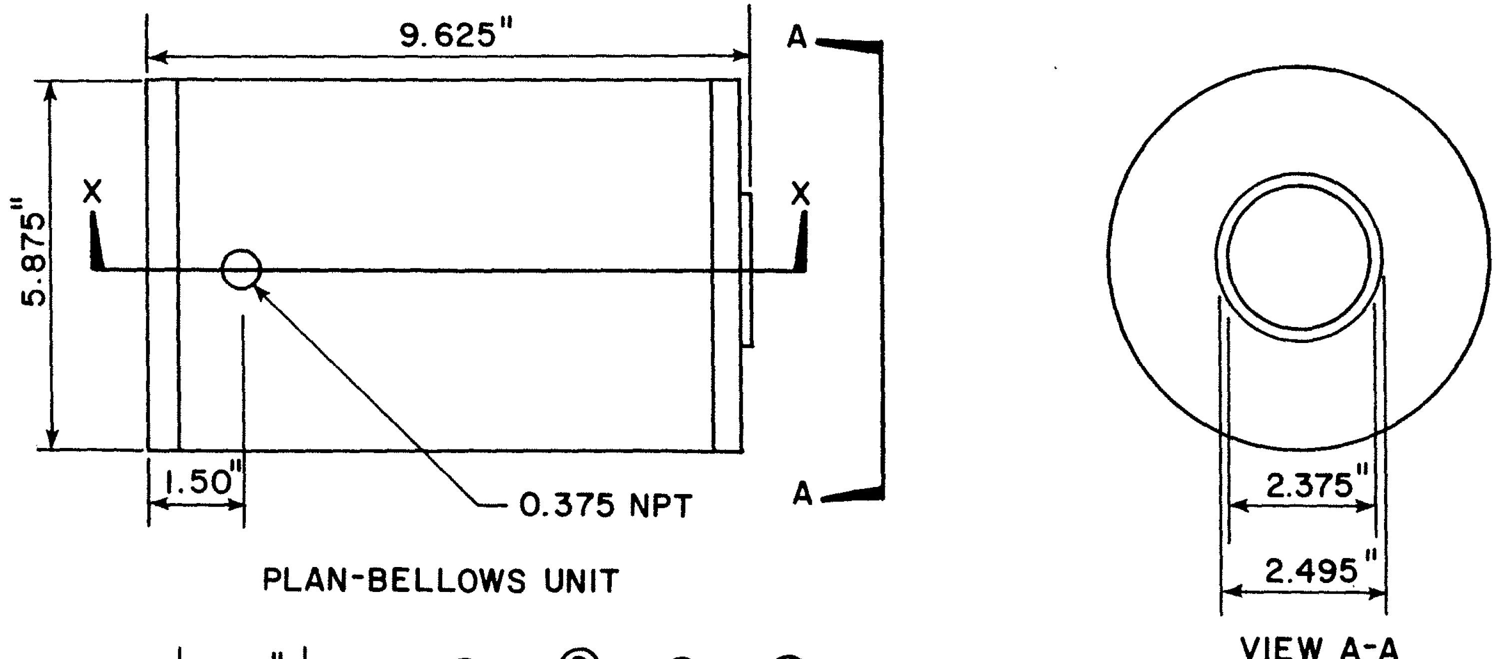
(c) Thermal slab length variation of 2 in. (51 mm)

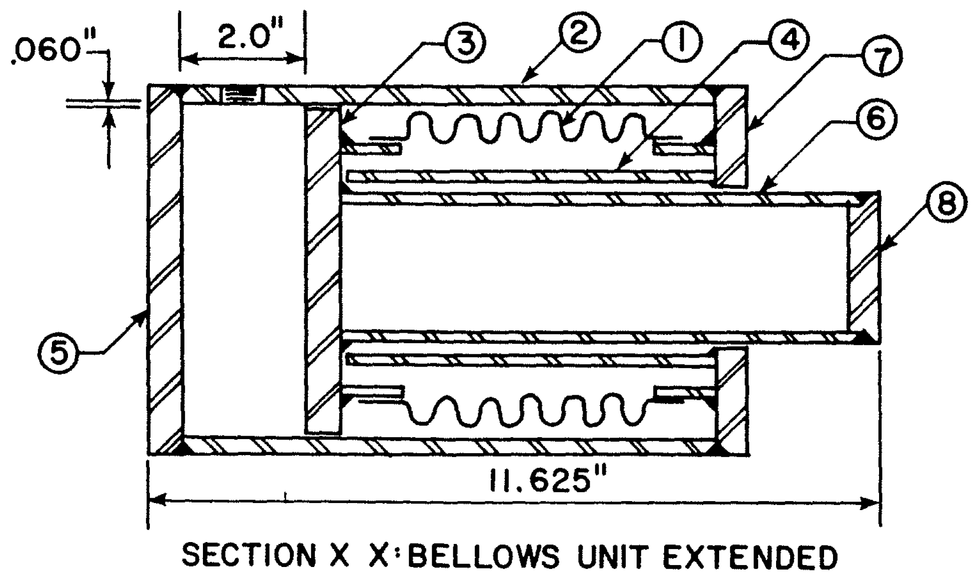
(d) Compensation for slab elastic shortening, shrinkage, and creep.

Bellows Design

Due to the complex nature of thin wall metal bellows design, it was decided that the most efficient method of obtaining a workable design was by solicitation of manufacturers. Twenty-seven bellows manufacturers were requested to submit internally pressurized bellows designs capable of applying at least 200 psi (1.38 MPa) pressure over a 24x8-in. (610x203 mm) area with a 2-in. (51 mm) stroke requirement. Instructions also specified corrosion resistant materials and an endurance rating of 10,000 full strokes and 30,000 half strokes at operating pressure.

None of the manufacturers could supply an internally pressurized bellows as proposed by the Arizona DOT. The design shown in Figure 1 was selected from five designs received. The





Item	Description	Mat'l
1	Bellows, 4.0 ID, 5.0 OD, 4 Ply, 0.012 Th.	Inconel
	6.5 Convolutions	625
2	Tube, 5.875 OD, 5.375 ID	Stain-
3	Plate, 0.5 Th.	less
4	Tube, 3.0 OD	Ty. 304
5	Plate, 0.5 Th.	↓
6	Pipe, 2 IPS, Schedule 40	
7	Plate, 0.5 Th.	
8	Plate, 0.5 Th.	

Figure 1 - Bellows Design

bellows unit is externally pressurized to prevent buckling, totally enclosed, and corrosion resistant.

An operating bellows pressure of 680 psi (4.69 MPa) with four bellows required per 2 ft (0.61 m) of joint width supplies a prestress of 225 psi (1.55 MPa). A 2-in. (51 mm) joint movement causes a hydraulic fluid volume change of 46 cu in. (0.75 l) per bellows unit.

Accumulator Design

To compensate for the hydraulic fluid volume change, an accumulator, a device that uses stored energy to develop pressure on a fluid, was designed. The most reliable accumulator was found to be a bladder type. It utilizes the stored energy of a nitrogen gas charge contained in a rubber bladder to force hydraulic fluid into the bellows system when a pressure loss occurs due to pavement thermal movement. This accumulator is an "off the shelf" item.

A 10-gallon (37.9 l) nominal capacity accumulator was selected as most suitable for maintaining prestress level near 200 psi (1.38 MPa) as practicable. This accumulator size controls the prestress variation from 225 to 206 psi (1.55 to 1.42 MPa) as system pressure is reduced from 680 to 623 psi (4.69 to 4.30 MPa) when the joint opening increases 2 in. (51 mm). A schematic diagram of the self-compensating hydraulic precompressing system is shown in Figure 2.

Joint Hardware

After design of the bellows unit, consideration was given to the following:

(a) Protection of precompression assembly
(b) Correct alignment of bellows units across pavement section
(c) Providing roadway continuity over a relatively wide joint.

Figure 3 shows the joint hardware. The 0.75-in. (19 mm) thick coverplate protects the bellows units and provides a

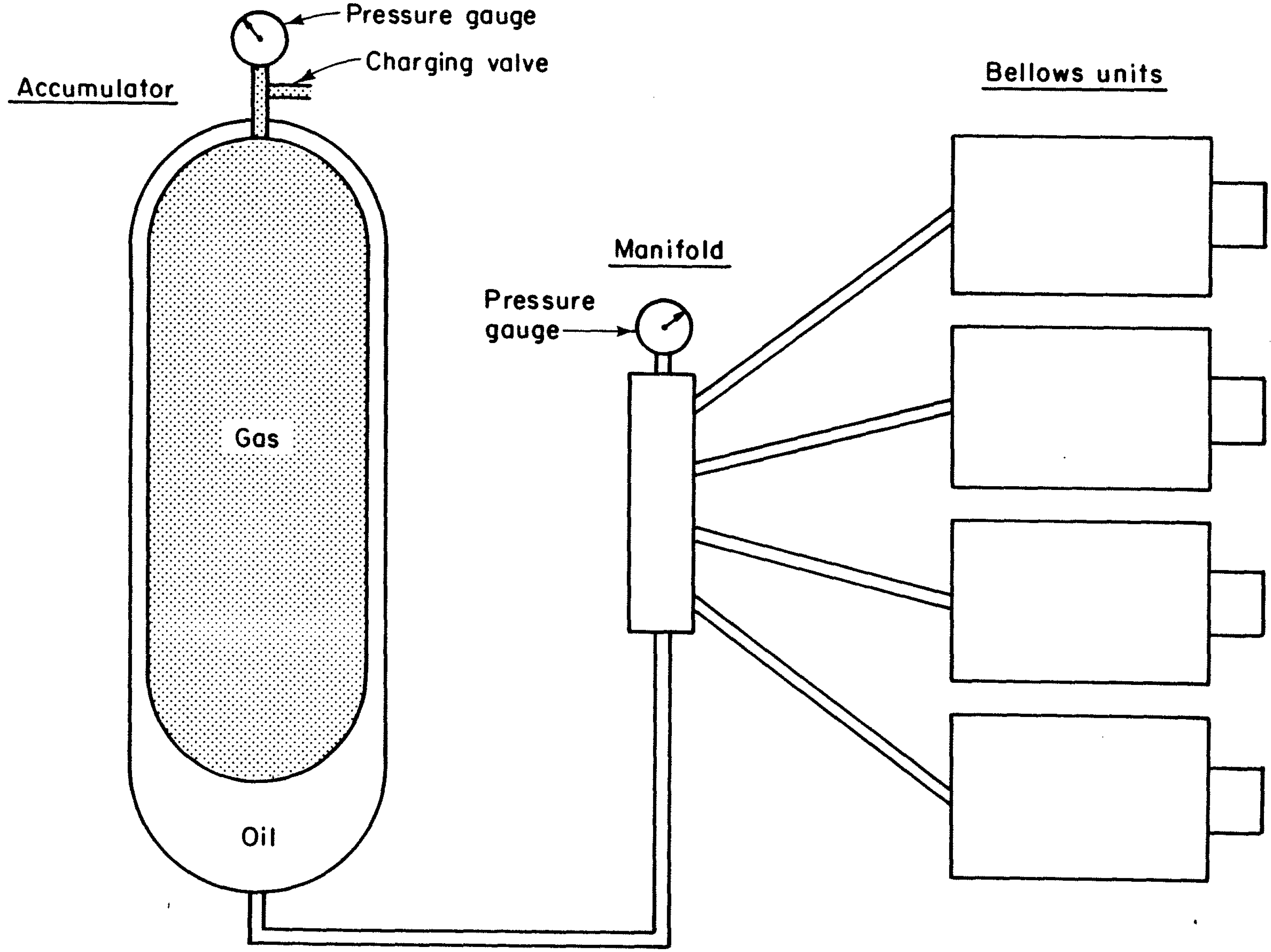


Figure 2 - Schematic Diagram of System

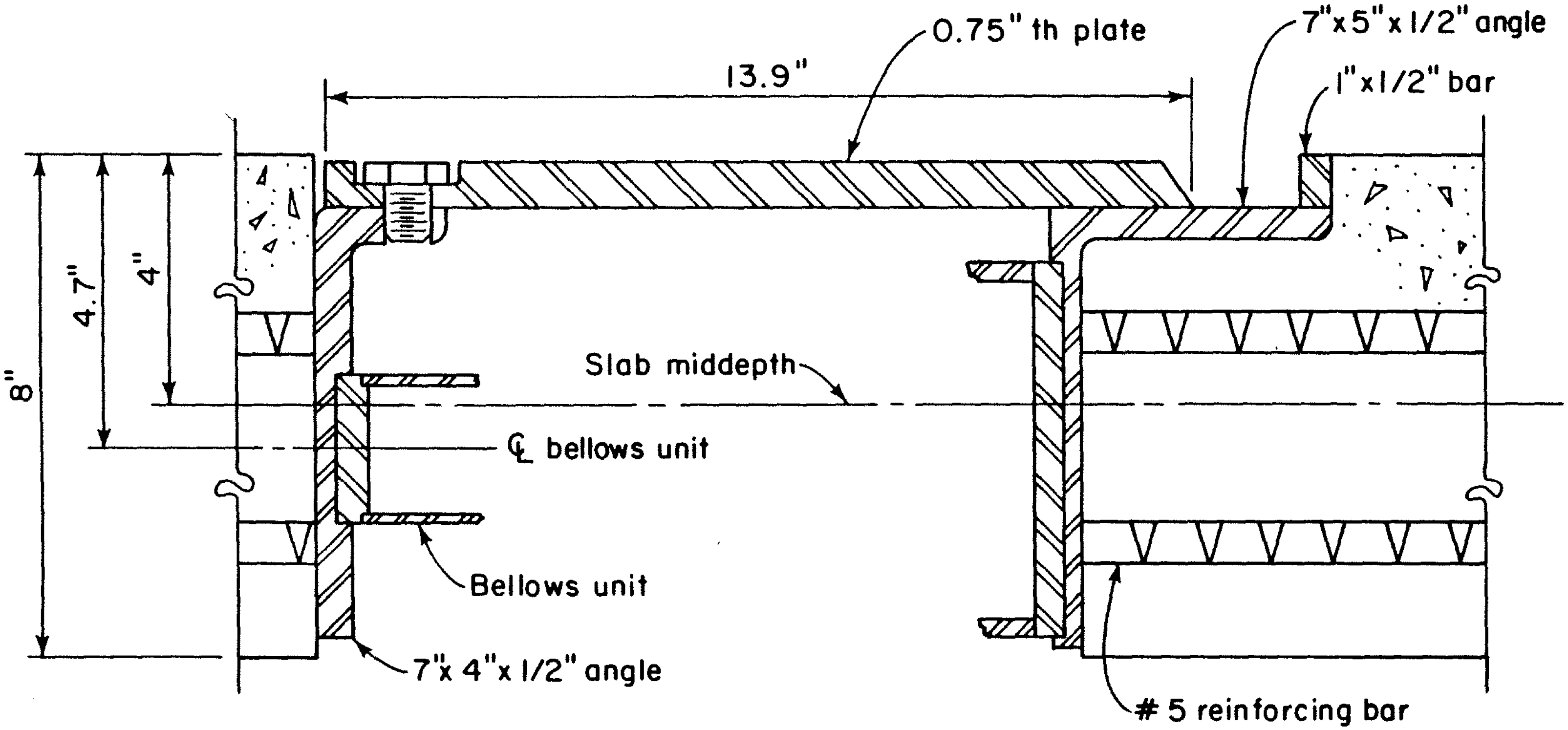


Figure 3 - Joint Design

smooth ride over the joint. The two structural steel angles were milled to hold ends of bellows units below pavement mid-depth, thereby reducing upward warping at pavement ends. Angles are anchored in the concrete using steel reinforcing bars. For servicing of the joint, the coverplate is removed. Figures 4 and 5 show joint components. An additional steel element may be inserted between bellows units and steel angles to compensate for slab elastic shortening, shrinkage, and creep.

Laboratory Evaluation

A 3-phase accelerated test program was developed to investigate:

(a) Joint movement/system pressure response

(b) Performance of the precompression joint under simulated traffic and environmental conditions

(c) Durability of a single bellows unit.

This section describes specimen construction, test methods and test results.

Specimen Construction and Preparation

For the first and second phases of testing, a slab 14x2 ft (4.3x0.61 m) in plan was cast. A transverse joint located at slab mid-length contained the precompression joint. The joint was formed as shown in Figure 6. The slab was cast on an artifical subgrade consisting of four layers of 0.75-in. (19 mm) thick cellotex. A double layer of 0.004-in. (0.1 mm) thick polyethylene was placed over the subgrade to break bond.

A paving mix was used with an average 14 day compressive strength of 5,900 psi (40.7 MPa). Load testing started 14 days after casting.

Joint opening was monitored using gage plugs attached to the slab and a vernier caliper. Four deflection dial gages were used for measuring static load-associated deflections on both sides of the joint.

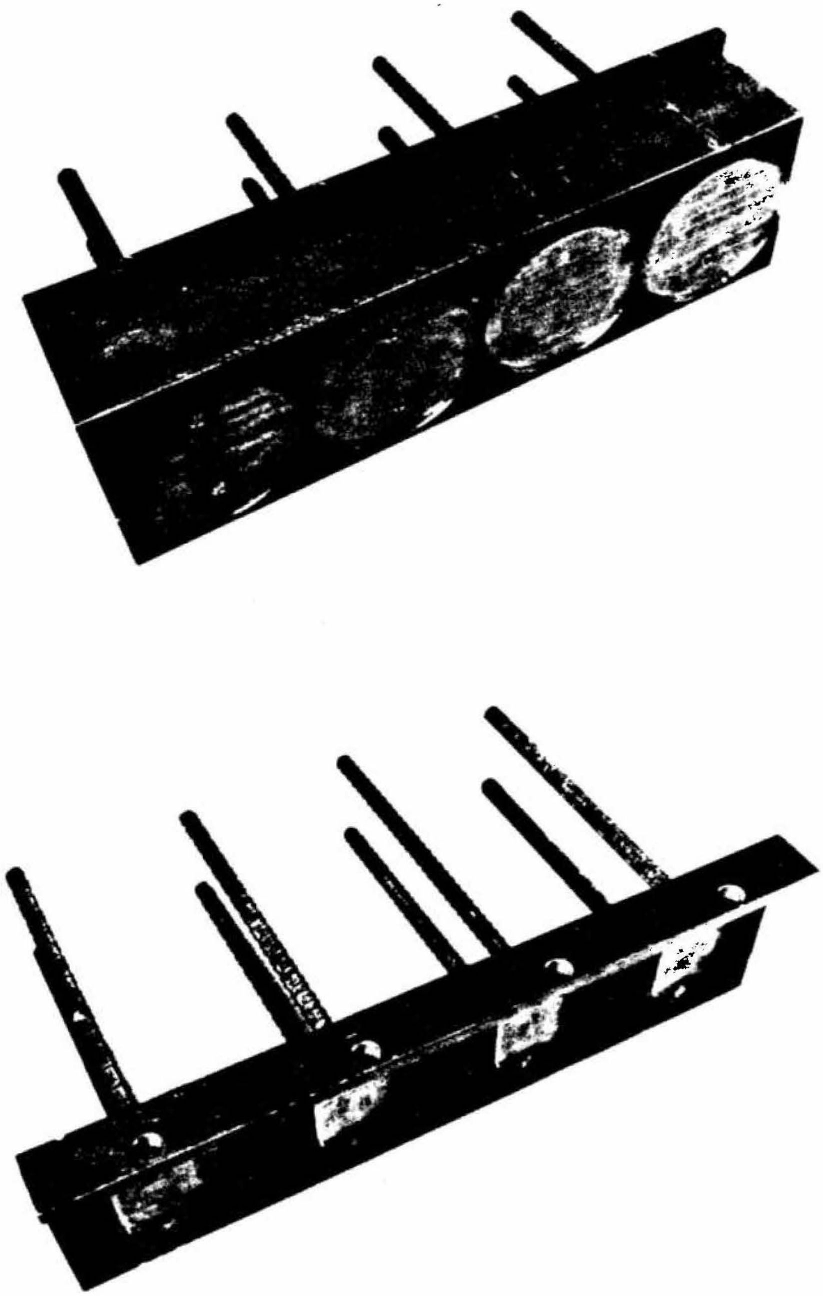


Figure 4 - Joint Components

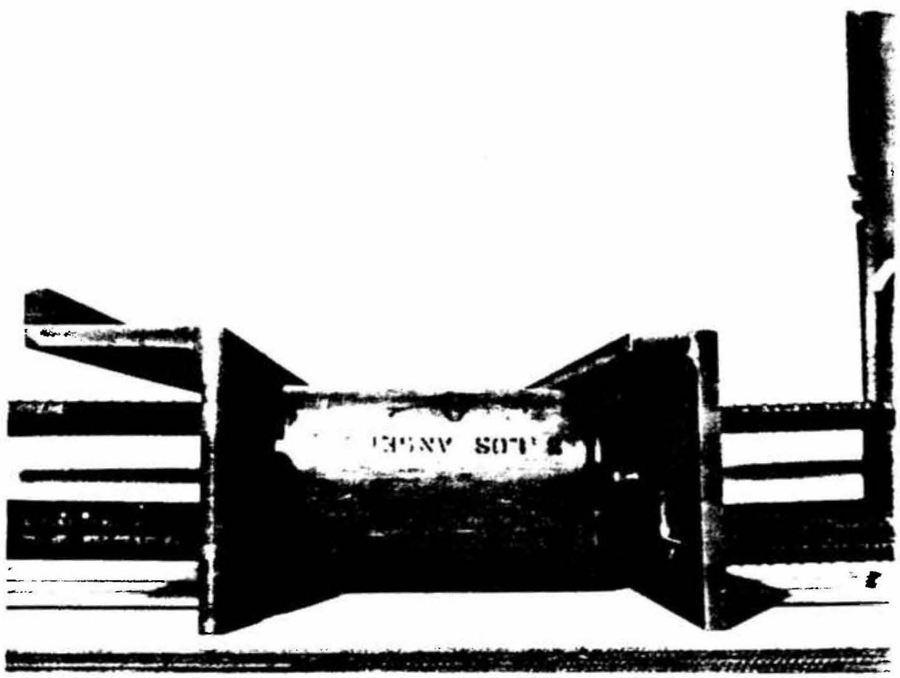


Figure 5 - Joint Components Assembled

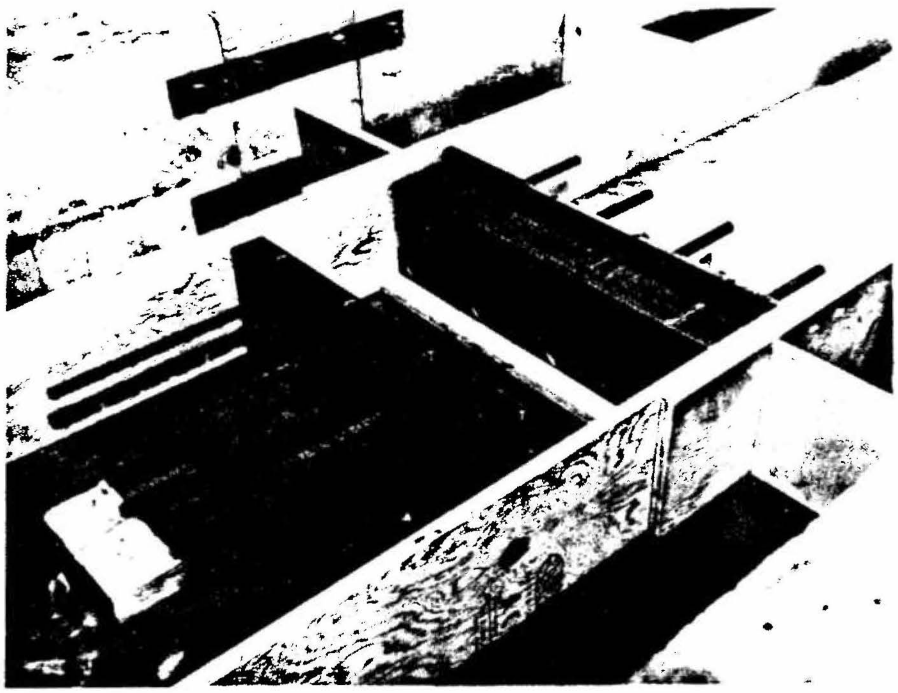


Figure 6 - Joint Before Concreting

Before prestressing, a horizontal reaction frame was built around the slab as shown in Figure 7. Concrete-filled lengths of rectangular structural tubing placed across slab ends were connected with 20-ft (6.1-m) long high strength steel threaded rods. Hydraulic rams at one end of the frame provided capability for joint width adjustment.

Following assembly of the reaction frame, bellows units in the closed position were installed in the joint. Bellows units were connected to the accumulator through a manifold with a pressure gage. Flexible medium-pressure hydraulic hose was used throughout the system. The slab was prestressed by charging the accumulator to a pressure of 680 psi (4.7 MPa).

Load Testing

Laboratory trials of the precompression joint using bellows were divided into 3 phases.

In Phase 1, joint-bellows system performance was observed through monitoring pressure changes due to changes in joint width. Horizontal movement was induced using rams at the end of the slab reaction frame. Fluid pressures were recorded by a manifold pressure gage during 50 full cycles of 2-in. (51 mm) movement.

In Phase 2, simulated traffic and environmental loads were applied to the joint. Performance was evaluated based on static tests determining load transfer efficiency. MTS hydraulic rams were used to apply static and repetitive vertical (traffic) loads. Environmental conditions were superimposed on the traffic loading by joint movements as shown in Figure 8.

A repetitive load of 6,000 lb (26.7 kN) was applied. This load produced a repetitive deflecton of approximately 0.040 in. (1.0 mm) at the joint. Repetitive loads were applied in sequence to the approach and departure slab to simulate a wheel crossing the joint at 40 mph (64.4 km/n). Figure 9 shows location of the loads. Application and release of a load during a load cycle is shown in Figure 10. Throughout repetitive load-

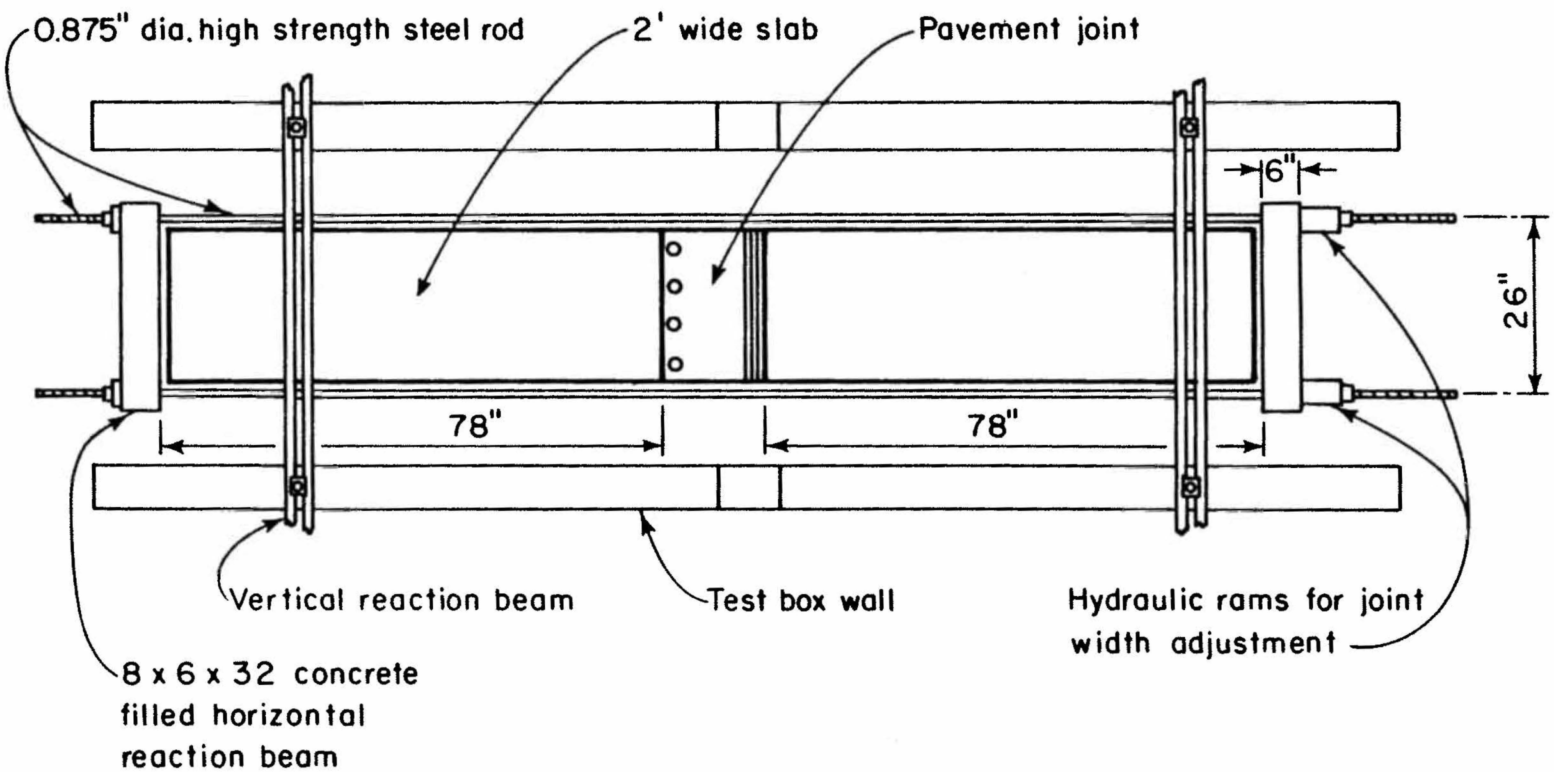


Figure 7 - Reaction Frame

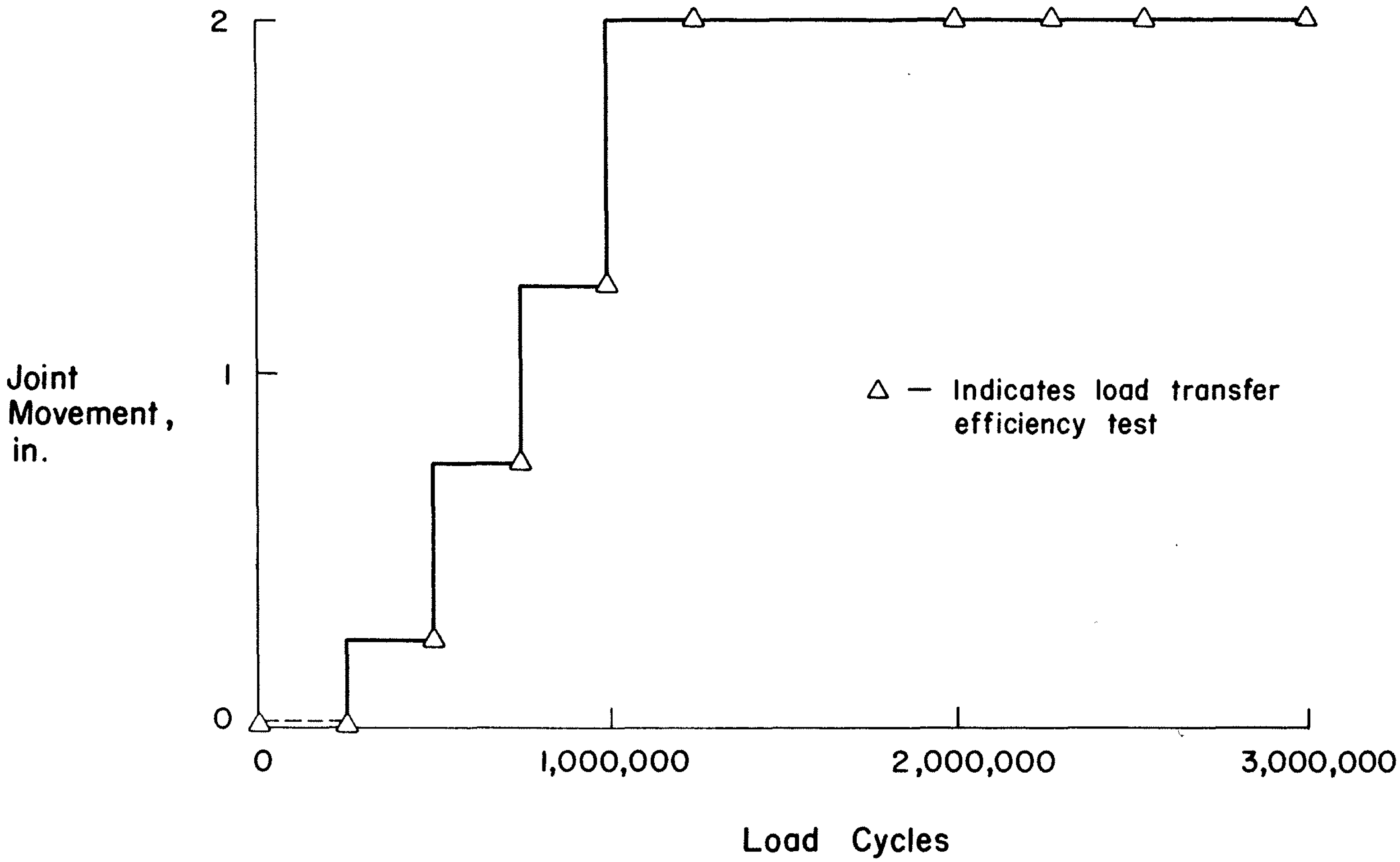


Figure 8 - Phase 2 Load Test Program

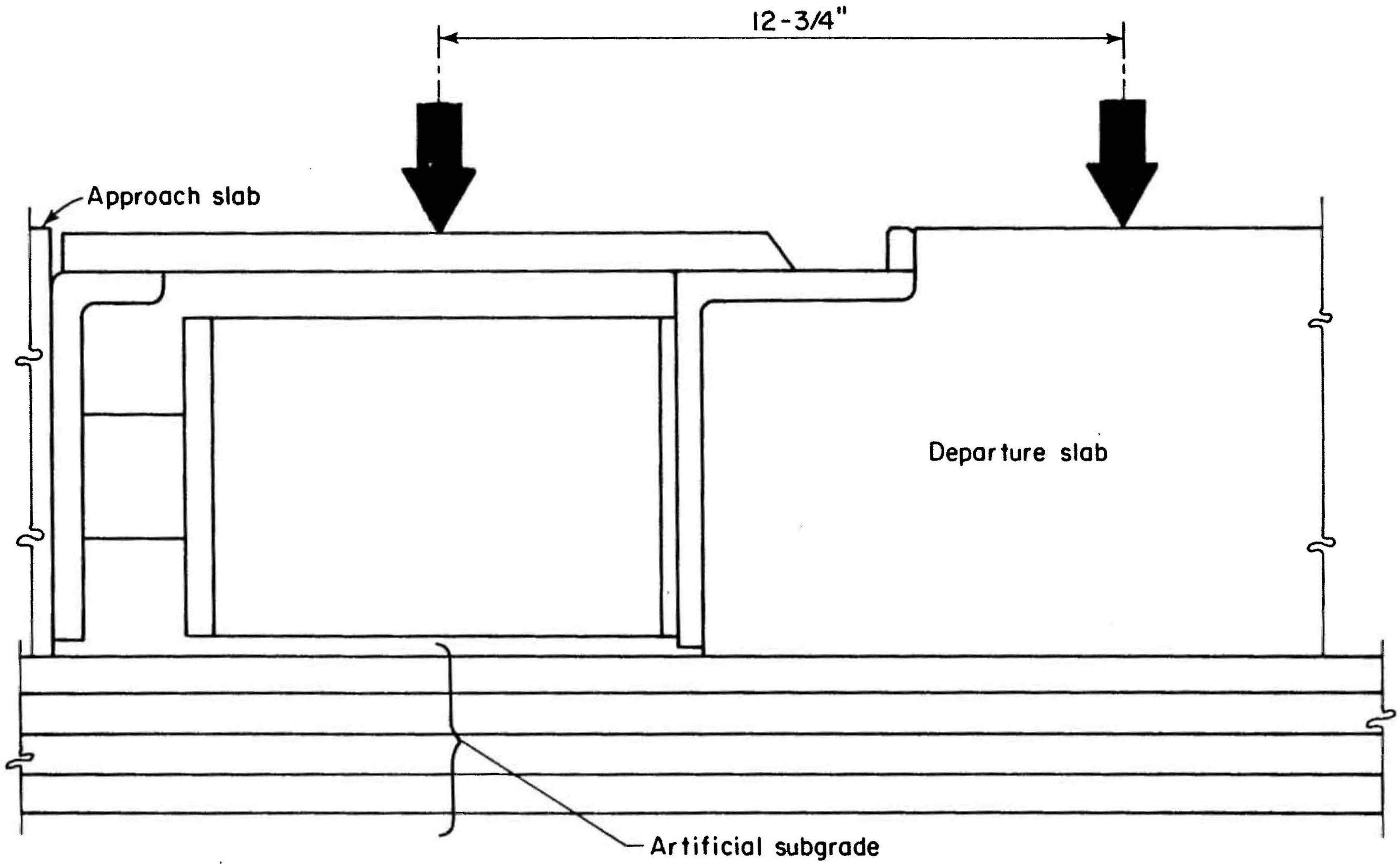


Figure 9 - Load Locations

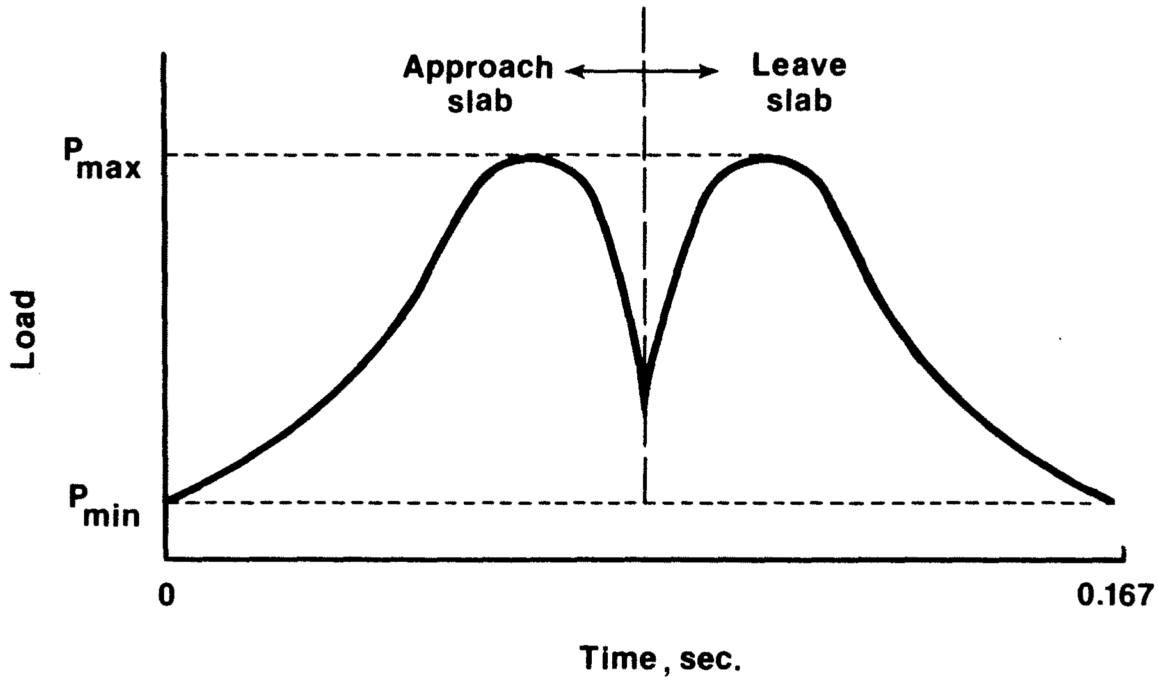


Figure 10 - Load Cycle

ing, a minimum load equal to 10% of maximum dynamic load was applied to maintain ram to slab contact. A vertical reaction system was placed transversely across the slab ends to simulate continuity of longer slabs and to prevent slab rocking.

Phase 3 testing consisted of endurance testing of a single bellows unit as shown in Figure 11. A single ram applied 30,000 full stroke applications of load to a bellows unit at system operating pressure. Frequency of loading was two cycles per minute. Movement and system pressure changes were observed periodically.

Results

Phase 1 testing showed that the 4 bellows units responded as designed during 50 cycles of horizontal movement. Prestress levels throughout testing remained at 226 psi (1.56 MPa) in the closed position and 211 psi (1.46 MPa) in the open position. No pressure fluctuations or leaks were observed.

Phase 2 testing indicated that 3 million simulated traffic loads together with joint movement had no adverse effects on the integrity of the precompression joint.

The ability of the joint structure to transfer load was determined on the basis of load transfer efficiency computed from the equation:

$$\text{Efficiency, \%} = \frac{d_2}{d_1 + d_2} \times 100 \qquad (1)$$

where d_2 = deflection of unloaded slab

d_1 = deflection of loaded slab

During static tests to determine the above deflections, the departure slab was loaded.

Load transfer efficiency data for test program variables of joint opening and number of load cycles are presented in Table 1. Results indicate that load transfer efficiency decreases primarily with increasing joint width. Decrease in load transfer efficiency due to repetitive loading appears to be negligible. The observed decreases in load transfer effi-

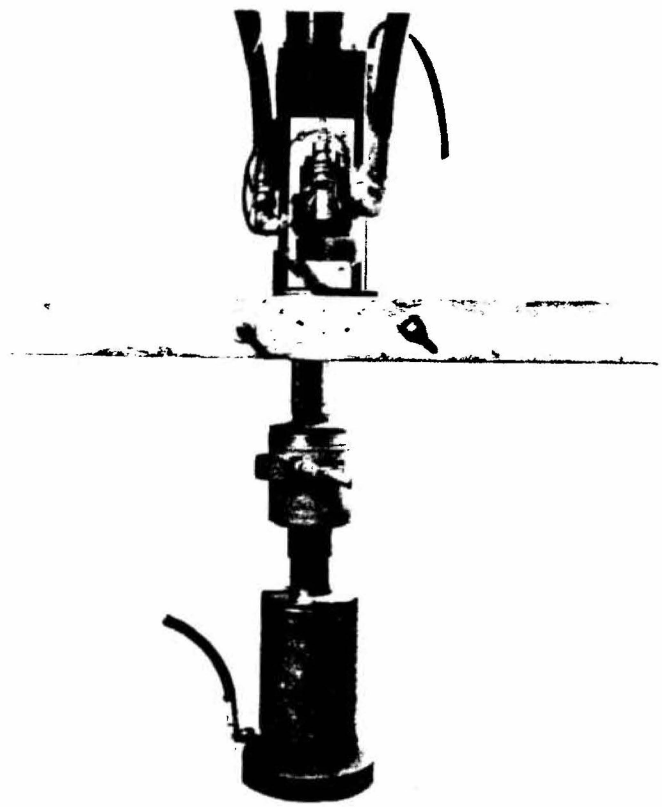


Figure 11 - Bellows Endurance Test

TABLE 1 - LOAD TRANSFER EFFICIENCY, BELLOWS JOINT

Number of Load Cycles	Joint Width, in.	Load Transfer Efficiency, %
0	9.63	49.0
250,000	9.63	49.0
500,000	9.88	46.7
750,000	10.38	47.2
1,000,000	10.88	46.8
1,250,000	11.63	43.1
2,000,000	11.63	43.3
2,300,000	11.63	43.3
2,500,000	11.63	43.4
3,000,000	11.63	44.0

ciency are small in magnitude and have been observed in tests of conventional doweled pavements. Good load transfer efficiency of this joint configuration can be attributed to the rigidity of the bellows units.

In Phase 3 testing, the bellows unit exhibited no leakage and no pressure drop after 30,000 full stroke load applications. The number of loads applied exceeded manufacturers design limits.

DESIGN CONCEPT II

The intent of the second design concept was to eliminate the need for an accumulator or other device to regulate external pressure. The design consisted of a flexible rubber bladder encased in a telescoping steel container. The system was pressurized with compressed air. Joint width changes caused by pavement thermal movements were compensated for by gas volume changes in the bladder. The following sections present design, construction, and laboratory evaluation.

Design

The bladder shown in Figure 12, was designed for pavement thickness of 8 in. (203 mm) and thermal slab length changes of 1.7 in. (43 mm). Bladder manufacturers aided in its design. Operating bladder pressure range was from 176 psi (1.21 MPa) to 343 psi (2.36 MPa) as width decreased from 6 in. (152 mm) to 4.25 in. (108 mm). This pressure range was based on a temperature range from -10 F (-23 C) to 110 F (43 C). The bladder pressure provides a minimum end of slab prestress of 130 psi (8.96 KPa) and a maximum of 240 psi (1.65 MPa).

A two-part telescoping steel container shown in Figure 13, confines and guides the bladder. The container was required to resist bladder pressures and to provide roadway continuity over the 6-in (152 mm) wide joint. The bladder valve fitting protruded through slotted end plates at one end of the container.

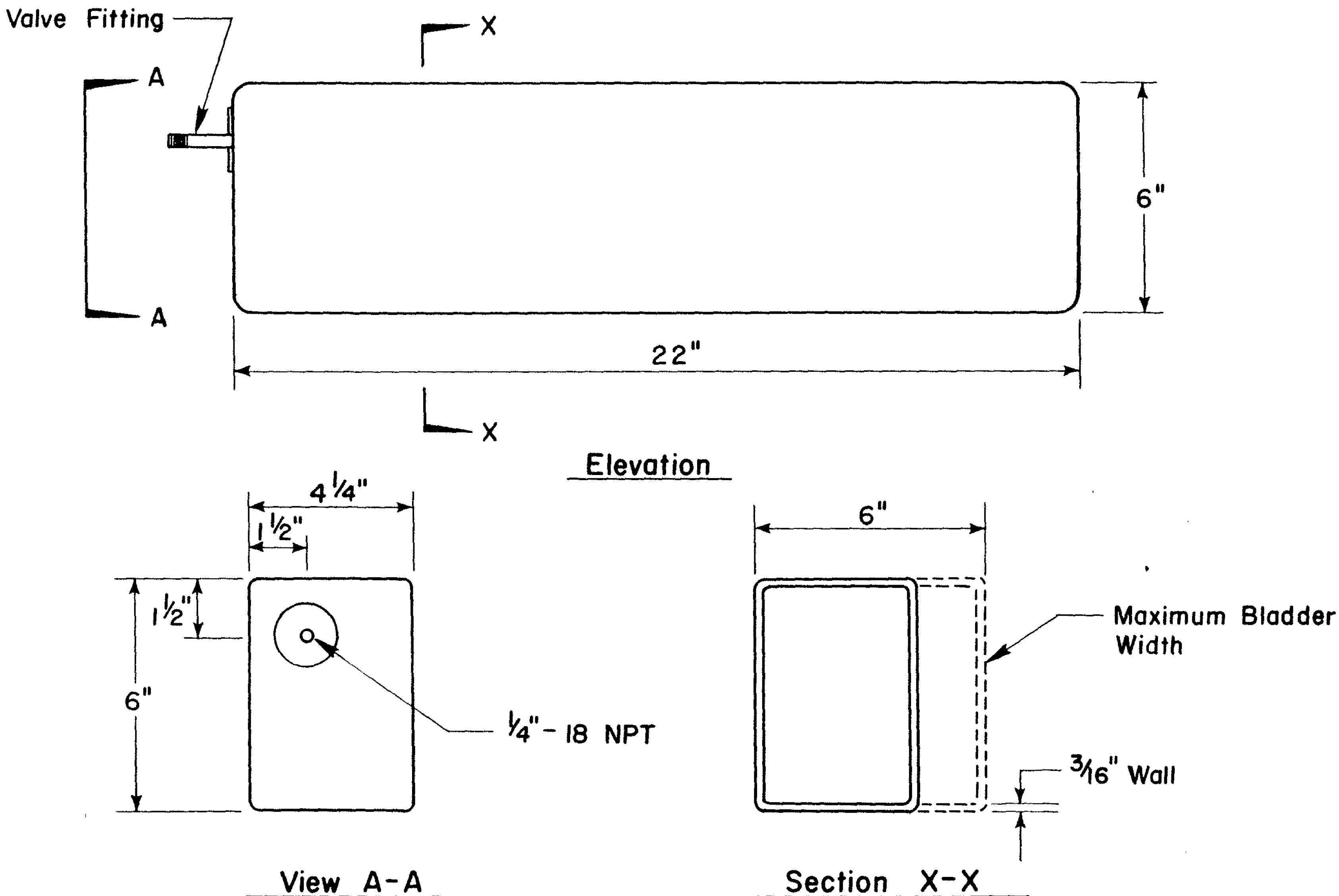
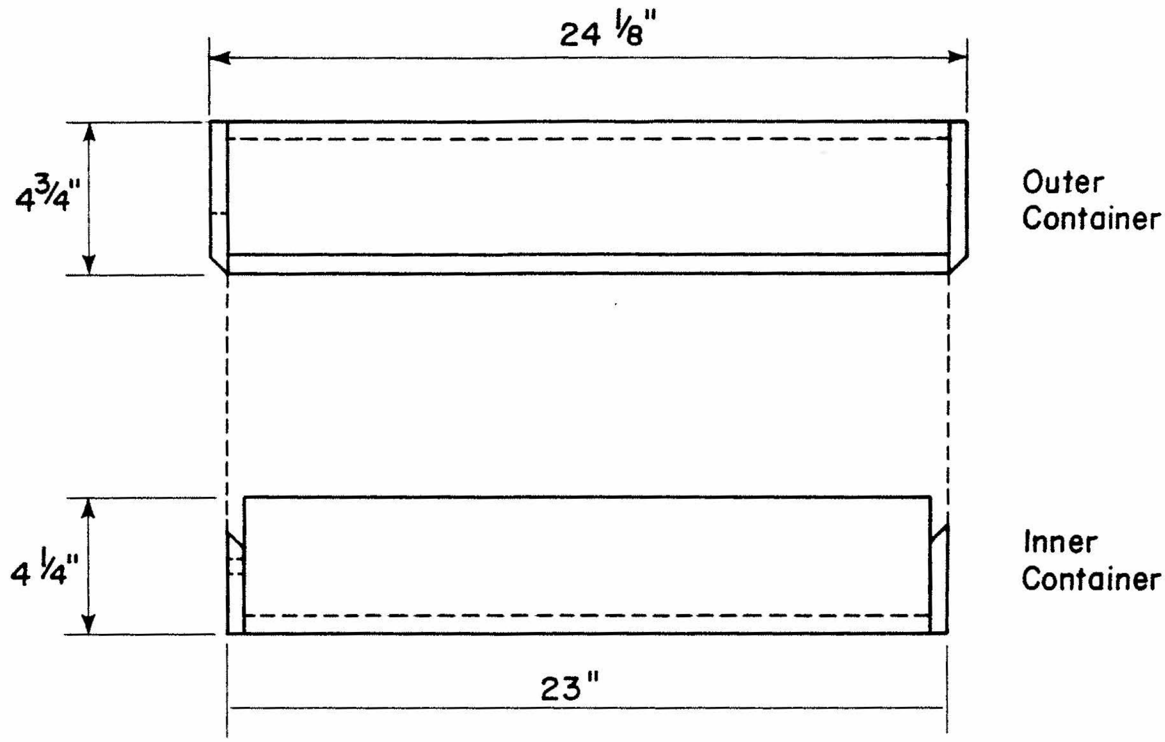
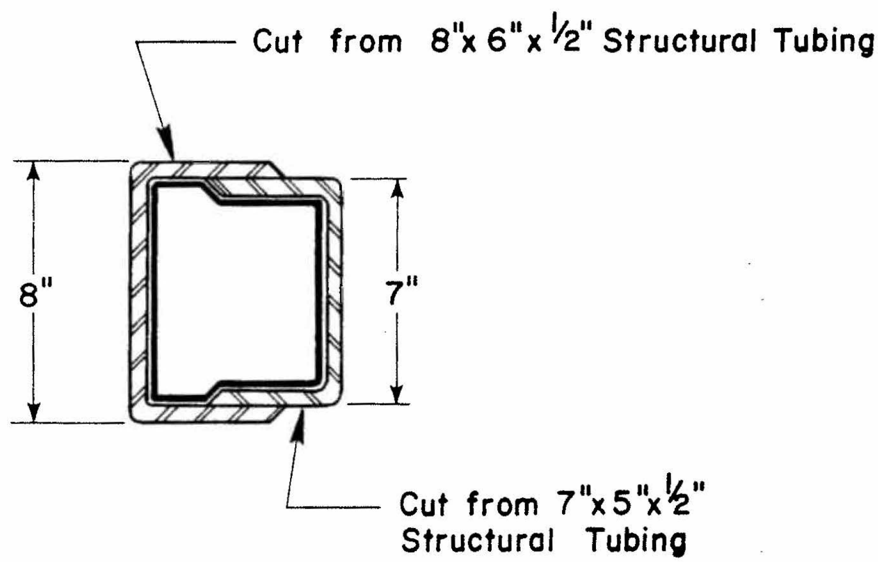


Figure 12 - Bladder



Plan — Bladder Container



Section — Assembled

Figure 13 - Bladder Container

Construction and Laboratory Evaluation

A 15.5x2-ft (4.72x0.61 m) slab was cast with transverse joint located at slab mid-length. The slab was cast on an artificial subgrade and cured for 14 days prior to testing. Figure 14 shows a sectional view of the bladder, container and slab.

Before prestressing the slab, a horizontal reaction frame similar to that shown in Figure 8 was built. Subsequently, the bladder was charged with compressed air. The bladder supplied burst at a pressure of 50 psi (344 kPa) instead of sustaining an expected 343 psi (2.41 MPa). Rupture occurred at the valve. The manufacturer redesigned the valve and built another bladder. However, the redesigned valve was also ineffective. The second bladder burst during charging at a pressure of 150 psi (1.03 MPa). Due to repeated bladder performance problems, Design Concept II was abandoned.

DESIGN CONCEPT III

To eliminate complexities and problems associated with hydraulically- and pnuematically-activated pavement prestressing systems, a mechanical self-compensating prestressing system was investigated. Initially, helical compression springs were considered for use in a precompression joint, however, the required springs were 25-in. (635 mm) long. This would require excessive joint width and present spring buckling problems.

Belleville, or disk springs were also investigated. These proved to provide an effective mechanical system. The following sections present joint design, construction, and evaluation.

Design

The disk spring joint was designed for an 8-in. (203 mm) thick pavement and a thermal length variation of 1.7 in. (43 mm) with capability of adjusting for slab elastic shortening, shrinkage, and creep. Springs were selected to optimize prestress force-joint movement characteristics.

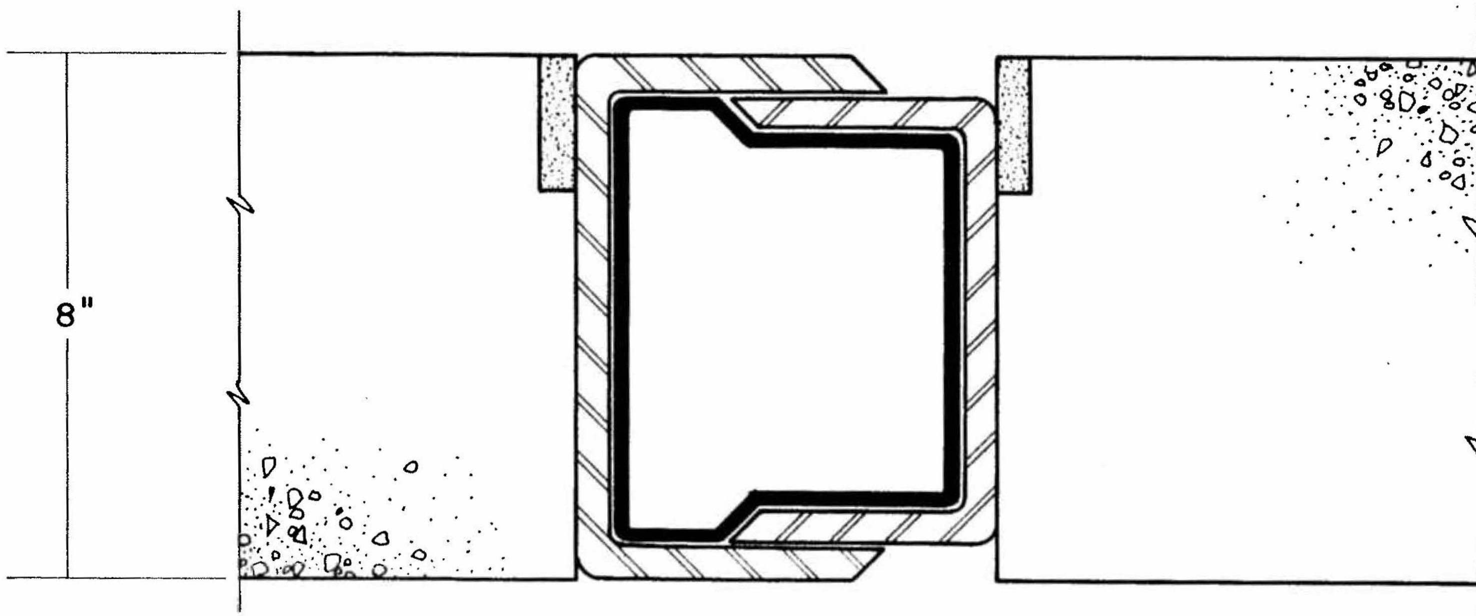


Figure 14 - Bladder Joint

A disk spring consists of a shell of truncated cone with a diametral cross section. On loading, the disk flattens out and spring action is obtained. Belleville springs are used where high load capacity is required in a small space. By stacking springs in parallel, load capacity is increased in proportion to the number of springs. Conversely, stacking springs in series gives a deflection proportional to the number in the stack for the same load. When springs are combined in a series-parallel arrangement, both an increase in deflection and load can be obtained.

A custom spring was designed. However, because it was not a stock item, price quotations were prohibitive. Therefore, an off-the shelf spring system having identical load capacity but 0.20 in. (5 mm) less deflection was selected for testing. The spring, designated C180, is shown in Figure 15.

Manufacturer's literature indicated that 10 series stacks of 3 such springs in parallel would provide the required force-deflection characteristics. Calibration tests of the spring stack provided the load-deflection curve shown in Figure 16. Three spring stacks are required per 2 ft (0.61 m) of joint width. This disk spring joint provides an end-of-slab prestress range of 156 psi (1.1 MPa) to 312 psi (2.1 MPa).

The disk spring joint is shown in Figure 17. The cover-plate protects disk springs and provides a smooth ride. Heavy steel shafts guide and align the springs and provide load transfer. The steel angles are designed to provide bearing stress distribution at the joint face. A shaft cap accommodates shaft movement. Figure 18 shows disk spring joint components before installation.

Construction

A 14x2-ft (4.27x0.61 m) slab was cast. Joint components, as shown in Figure 18, were positioned at slab mid-length before concreting. The slab was cast on an artificial subgrade made of cellotex. A double layer of 0.004-in. (0.1 mm) thick polyethylene was placed over the subgrade to break bond.

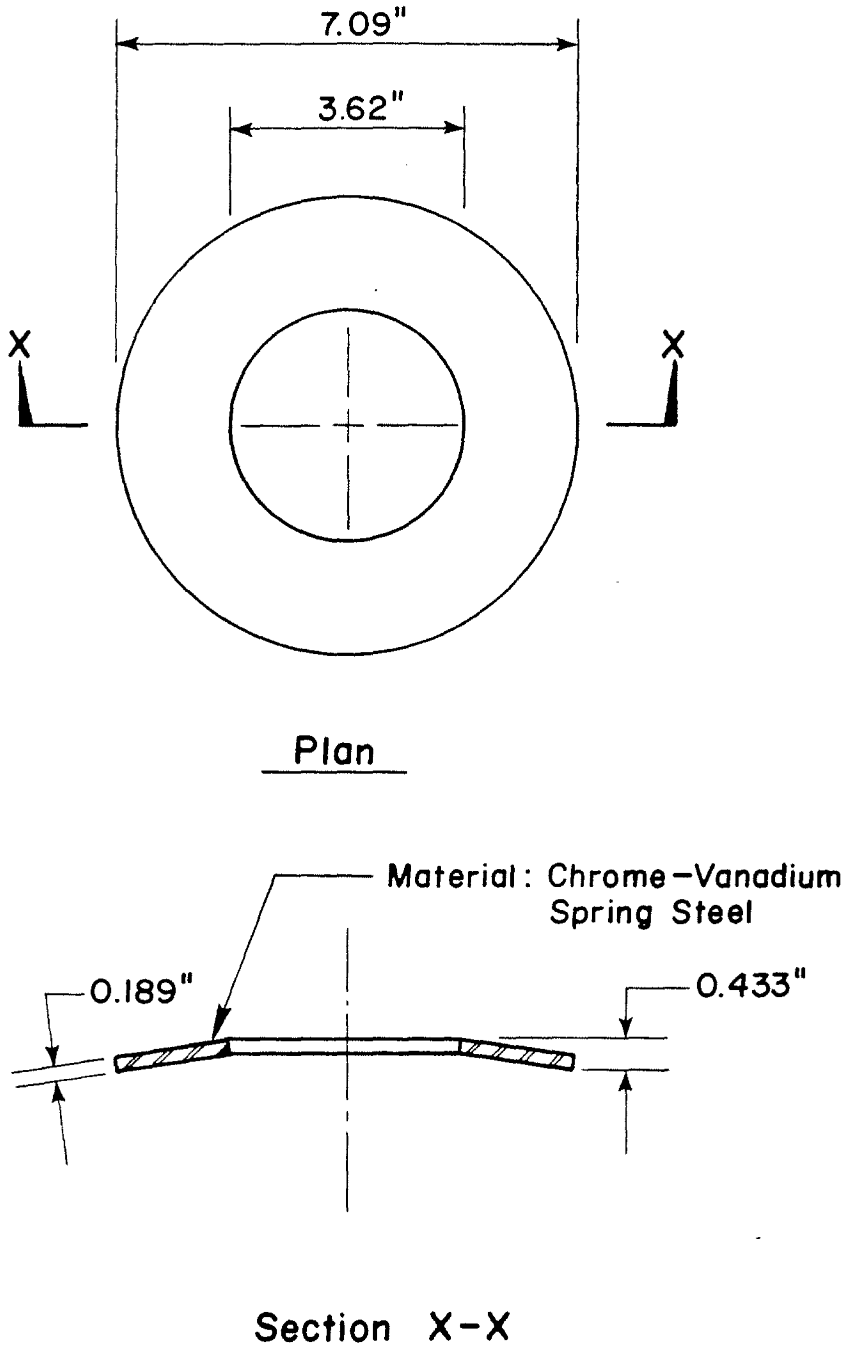


Figure 15 - C180 Disk Spring

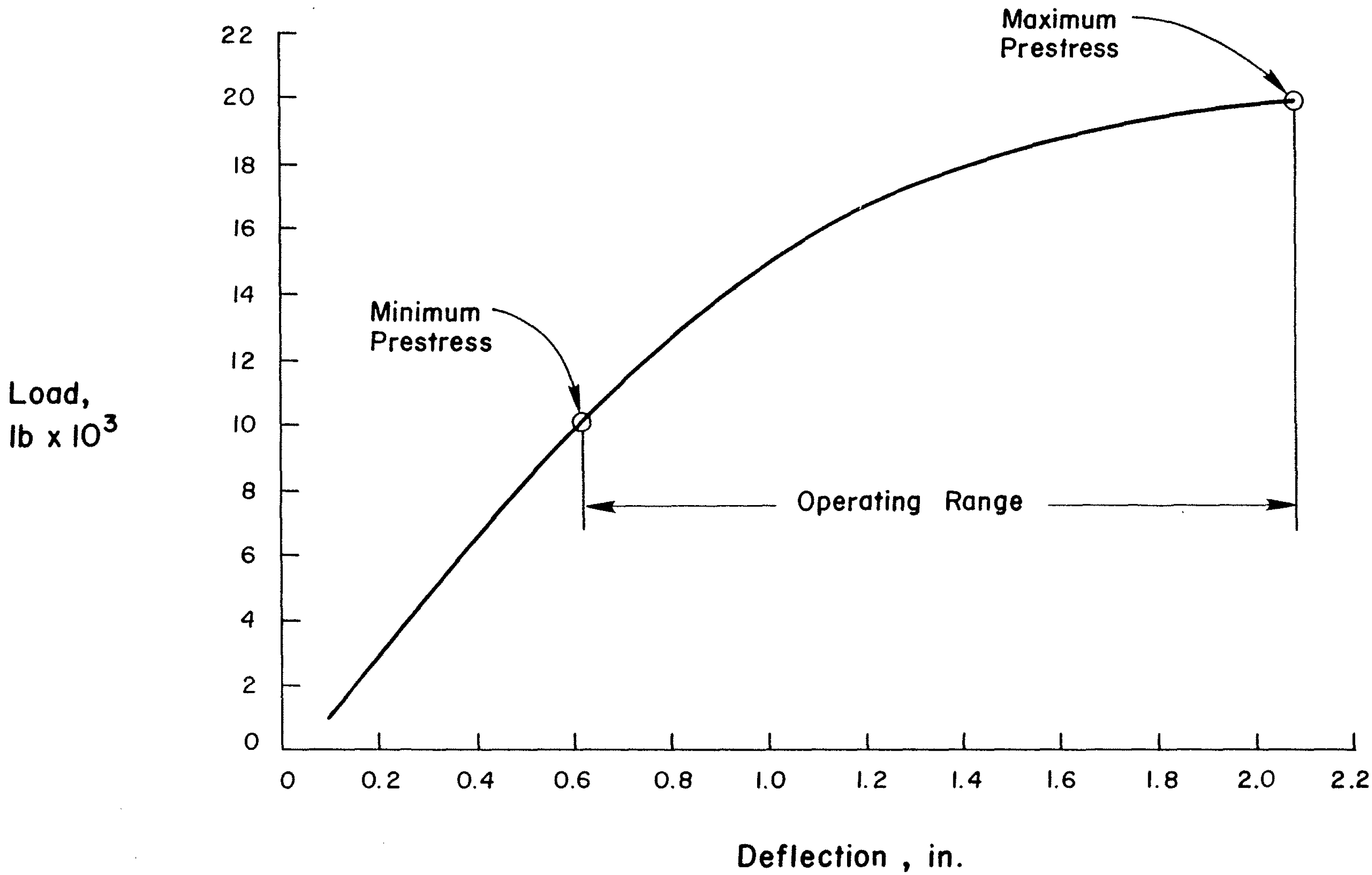


Figure 16 - Calibration Curve

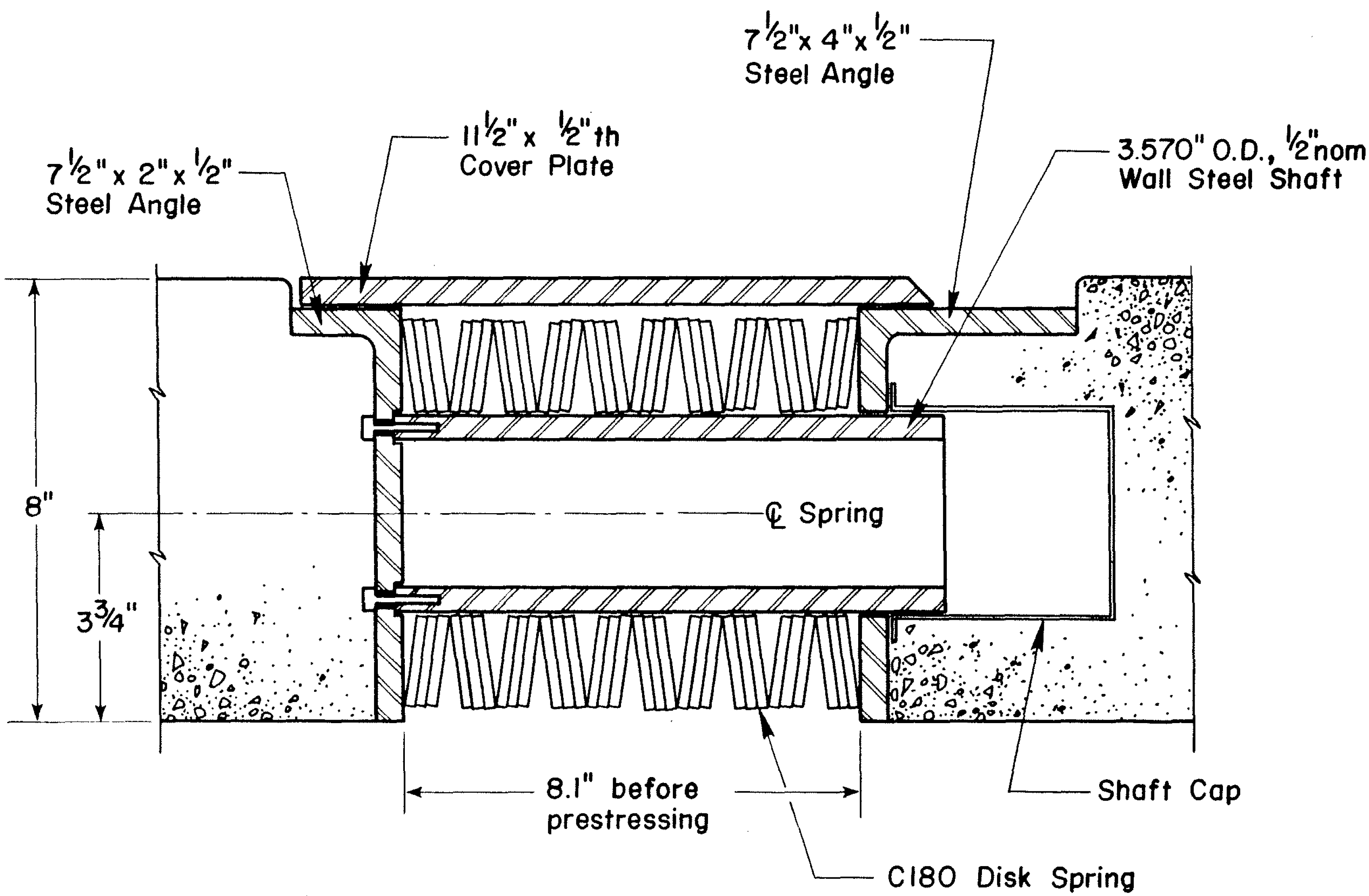


Figure 17 - Joint Section

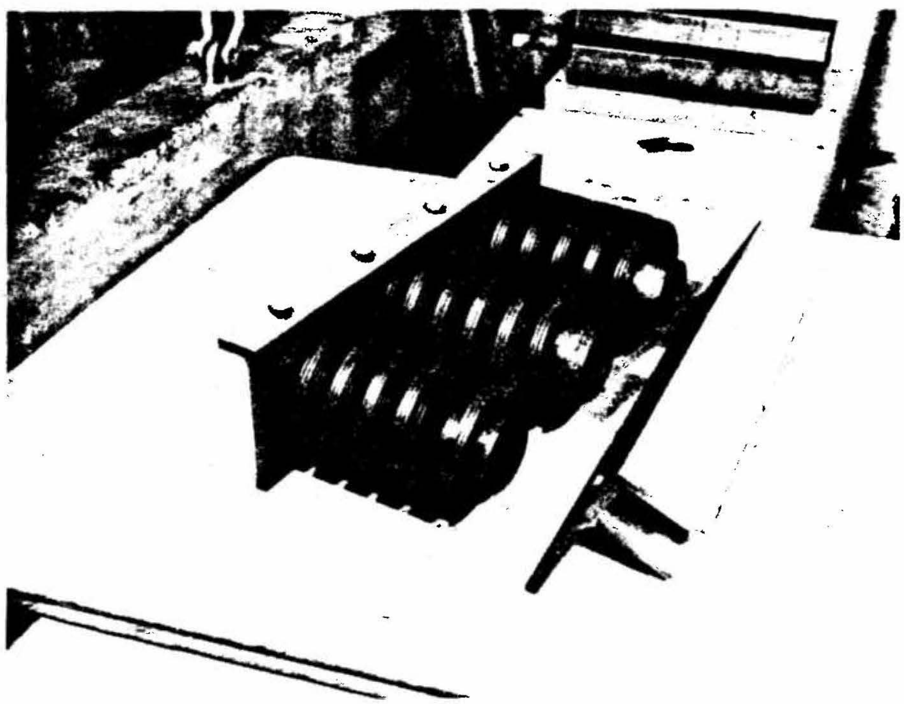


Figure 18 - Joint Components

To permit loading of the springs, stressing pockets and a construction joint were formed in the slab. Figure 19 shows a plan view of the test slab at the joint.

Before testing, a horizontal reaction frame similar to that shown in Figure 7 was built. Joint opening was monitored using gage plugs attached to the slab and a vernier caliper. Four deflection dial gages were used for measuring static load associated deflections. Load cells at the end of the reaction frame measured force applied by the springs.

Laboratory Evaluation

A two-phase accelerated test program was developed to investigate the following:

(a) Joint movement/spring force response

(b) Performance of the disk spring joint under simulated traffic loading.

This section describes test methods and results.

Load Testing

In the first phase of testing, disk spring joint performance was observed during prestress application and joint width changes. Load cells at the end of the reaction frame were monitored during spring compression. Test slab movements were induced with two hydraulic rams positioned in the stressing pockets, as shown in Figure 20. An initial prestress of 156 psi (1.1 MPa) was applied. At that point, steel shims were inserted into the open construction joint. Fifty full cycles of 1.5-in. (38.1 mm) movement were induced and spring load and joint opening, were recorded.

Simulated traffic loads were applied to the joint in the second phase of testing. Performance evaluation was based on load transfer efficiency. Pavement prestress level was maintained at 156 psi (1.1 MPa). At this level, joint width is largest and thus most significant to load transfer efficiency. During this phase of testing, rams were removed and the construction joint was cement grouted.

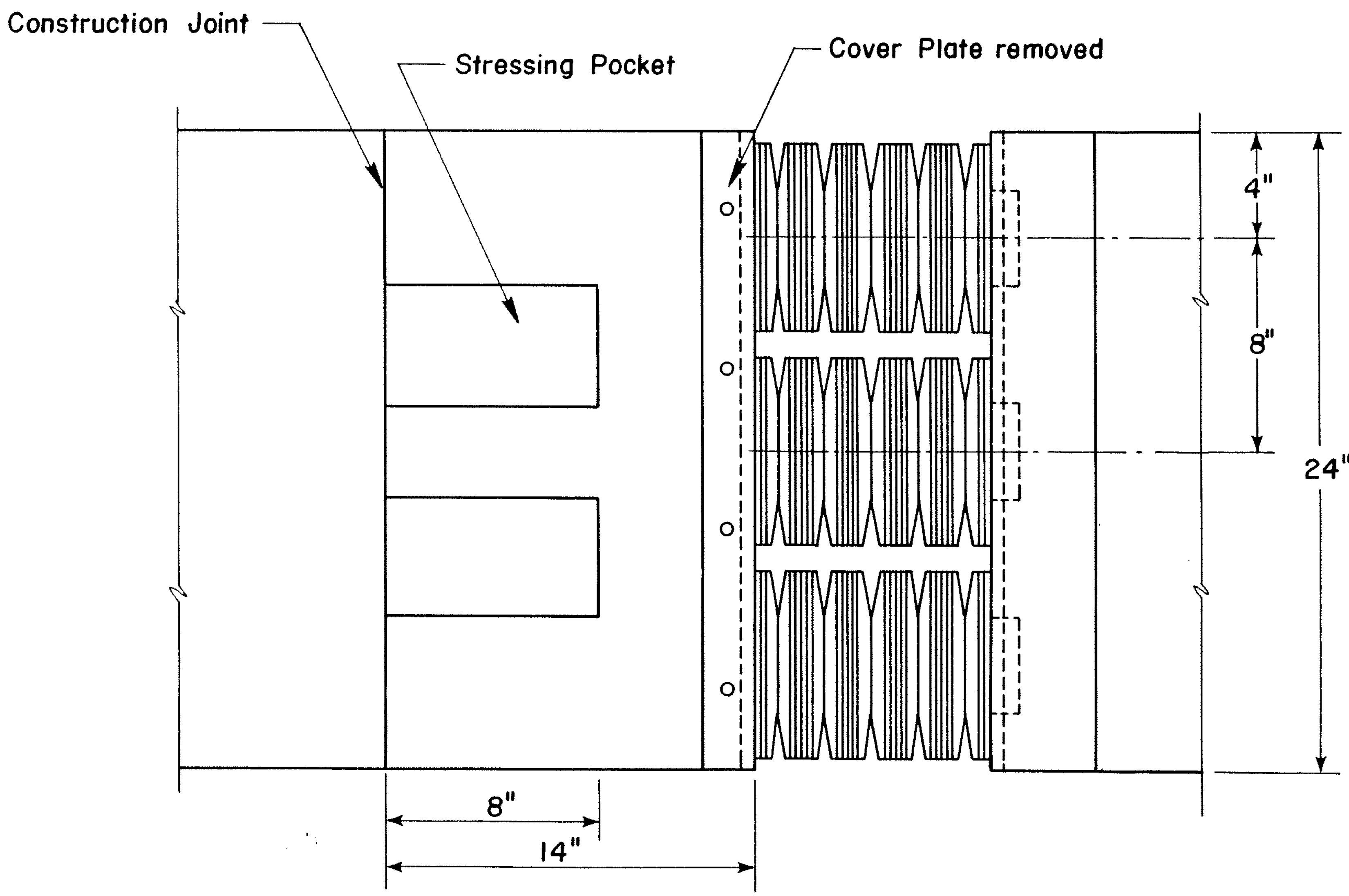


Figure 19 - Plan: Test Setup

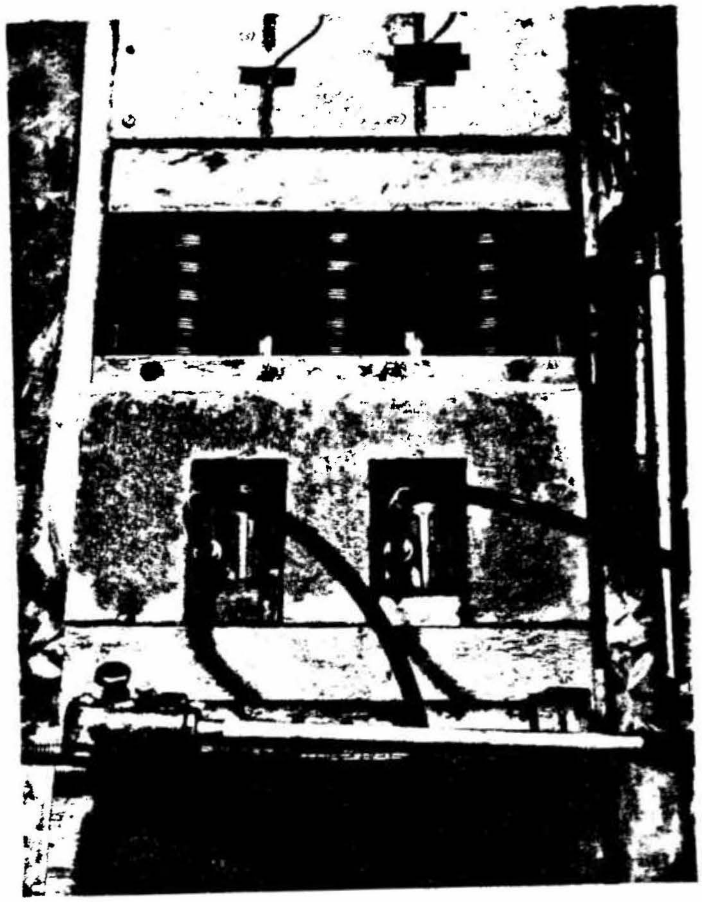


Figure 20 - Slab Prestressing

MTS hydraulic rams applied both static and repetitive traffic loads. A repetitive load of 6,000 lb (26.7 kN) was selected to produce joint deflections of approximately 0.040 in. (1 mm). Repetitive loads were applied in sequence to the approach and departure slab, as shown in Figure 9. A load sequence was selected to simulate a wheel crossing the joint at 40 mph (64.4 km/n).

During repetitive loading, a minimum load equal to 10% of the maximum dynamic load was applied to maintain ram to slab contact. Application and release of a load cycle is shown in Figure 10. Load transfer efficiency tests were performed at 0, 250,000, 1,000,000, 1,250,000, and 1,600,000 load cycles.

Results

First phase results showed that the disk spring precompression joint responded as designed for 50 cycles of horizontal movement. Prestress levels, as calculated from load cell data varied from 145 psi (1.0 MPa) to 306 psi (201 MPa) through a movement range of 1.5 in. (38 mm). These prestress levels agreed with the preliminary spring calibration curve shown in Figure 16.

Second phase testing indicated that 1,600,000 simulated traffic loads had no adverse effects on the precompression joint or the pavement slab.

The ability of the joint structure to transfer load was determined on the basis of load transfer efficiency computed from Eq. (1). During static tests to determine load transfer efficiency, the departure slab was loaded to a maximum of 6,000 lb (26.7 kN).

Load transfer efficiency data for the disk spring joint are presented in Table 2. No decrease in load transfer efficiency due to repeated loading is apparent. This good performance can be attributed to the rigidity of the joint structure.

TABLE 2 - LOAD TRANSFER EFFICIENCY, DISK SPRING JOINT

Number of Load Cycles	Joint Width in.	Load Transfer Efficiency %
0	7.5	43.2
250,000	7.5	44.1
1,000,000	7.5	44.3
1,250,000	7.5	44.4
1,500,000	7.5	44.3

PRESTRESSED OVERLAY

As required by Enclosure 1 of Contract No. DOT-FH-8894, Modification 6, the most promising of the design concepts was selected for use in prestressing portland cement concrete overlays. The following sections describe the basis for selection of a design concept recommended for use in overlay design.

Selection of Most Promising Design Concept

Selection of the design concept for use with prestressed overlays was based on performance in laboratory trials and on cost.

Of the three Design Concepts evaluated, I and III survived their laboratory test programs and provided satisfactory performance under simulated traffic and environmental loading. Both were able to compensate for joint width changes while holding their respective prestress forces within acceptable limits. Their ability to transfer load across a wide joint space was approximately equal and comparable to the performance of dowelled joints in conventional concrete pavements.

A cost comparison was made for a 12-ft (3.7 m) wide joint. It was assumed that joint hardware costs including coverplates and fabricated steel angles were equivalent for Design Concepts I and III. Table 3 lists itemized cost for prestressing components. This comparison does not consider maximum slab lengths for the two designs. Because Design Concept I is capable of 2 in. (50.8 mm) of joint movement and Design Concept III is capable of only 1.5 in. (38.1 mm), slab lengths for Design Concept III will be approximately 75% of those for I. Therefore, joint costs for Design Concept III are adjusted to $9,120. This compares with $30,200 for Design Concept I. Because of large cost difference between the two similarly performing systems, Design Concept III is recommended for overlay use.

TABLE 3 - COST COMPARISON - PRESTRESSING COMPONENTS

Design Concept I	Design Concept III
24 bellows units @ $ 950/unit*	
2-30 gallon accumulators @ $3,200/unit	18 spring stacks with 30 springs per stack = 540 springs @ $12/unit
Hose, fittings, and manifolds $1,000	18 spring shafts @ $20/unit
Total = $30,200	Total = $6,840

*Cost includes tooling for initial production of small quantities. Larger quantities may decrease this figure.

Design

The disk spring prestressed overlay joint is designed for 6-in. (152.4 mm) thick unbonded slab, a thermal slab length variation of 1.5 in. (38.1 mm) and a minimum end of slab prestress of 150 psi (1.03 MPa).

The spring selected, designated C125, is shown in Figure 21. A single spring provides a deflection of 0.16 in. (4.1 mm) at a maximum load of 3,600 lb (16.0 kN) with a regressive load-deflection curve, similar to that shown in Figure 16. To supply the required end of slab prestress, a minimum force of 5,400 lb (24 kN) is needed at 6-in. (152 mm) spacing. This is provided by stacking three C125 springs in parallel. This mobilizes the 5,400 lb. force at a deflection of 0.035 in. (0.89 mm). The remaining deflection of 0.125 in. (3.2 mm) is available as the operating range of this spring. Therefore, 12 series stacks are required to provide a 1.5-in. (38.1 mm) joint movement.

Figure 22 shows the prestressed overlay disk spring joint. Disk spring stacks are spaced on 6-in. (152.4 mm) centers. Joint hardware for protection and alignment of prestressing elements is similar to that for Design Concept III.

SUMMARY

Three methods for prestressing pavements without prestressing tendons were evaluated in a laboratory study.

One method consists of hydraulically pressurized thin-wall metal bellows as stressing elements at the pavement joint. The second method included a pneumatically charged rubber bladder and the third used stacked Belleville springs. On the basis of performance and cost, the Belleville spring system was selected as most promising for use in prestressed overlays.

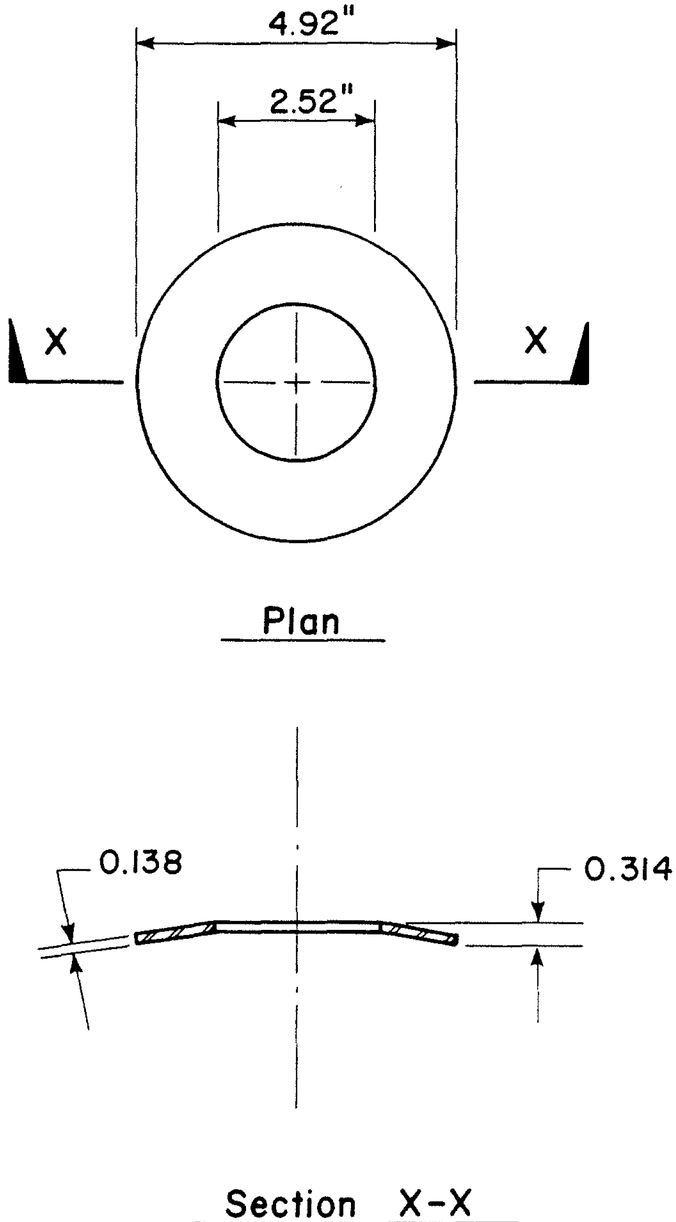


Figure 21 - C125 Disk Spring

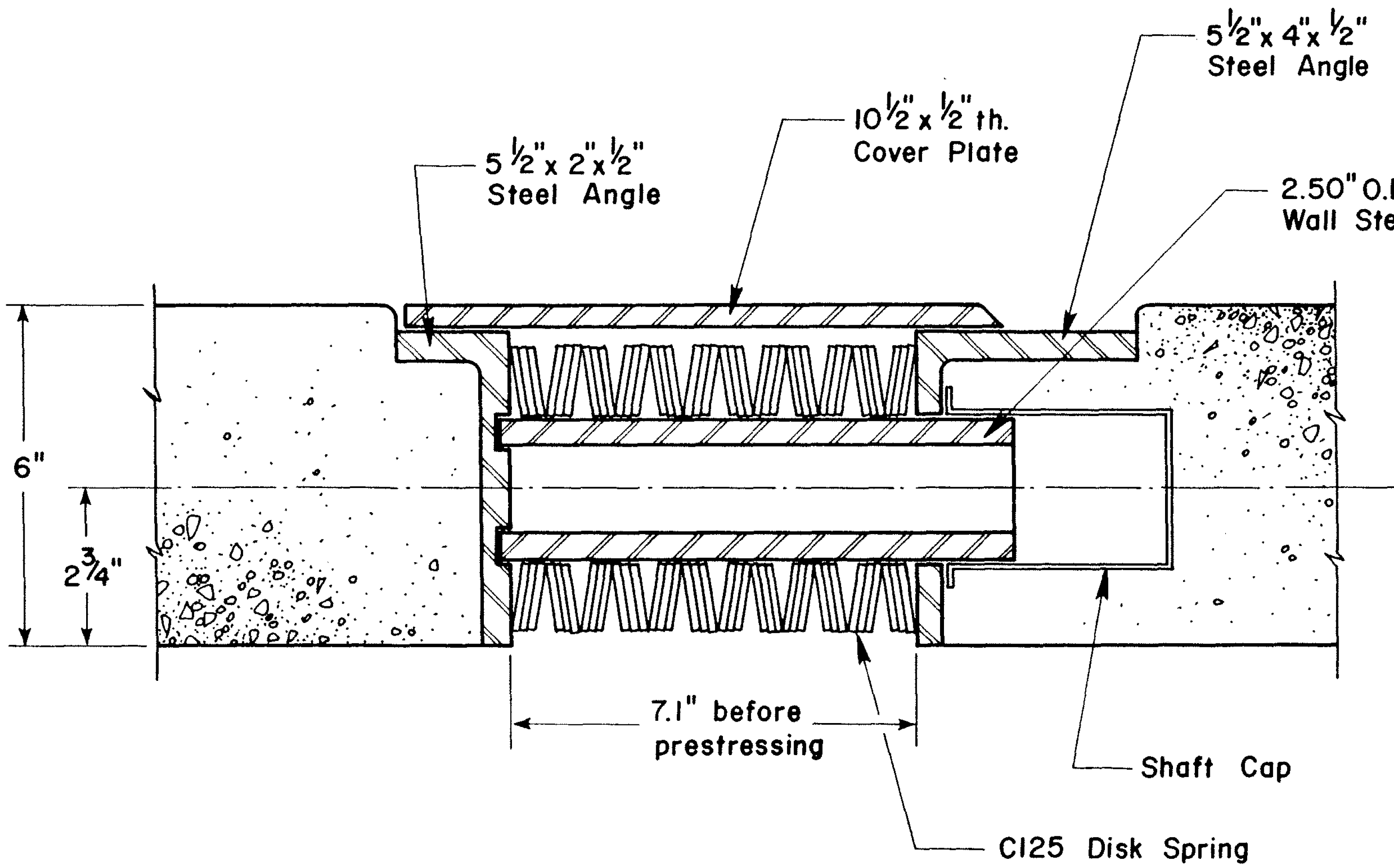


Figure 22 - Prestressed Overlay Joint

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APPENDIX A

SELF-COMPENSATING HYDRAULICALLY PRECOMPRESSED PAVEMENTS

by

Gene R. Morris, Arizona D.O.T.

A. Relation of Method to "Prestressed 'Zero Maintenance' Pavements"

The use of precompressed pavements is not new. The concept was considered by Bengt F. Friberg of Saint Louis in the middle 1930's. He referred to his concept as "stress-curing". By using fire hoses which he installed in concrete pavement joints, he was able to precompress the concrete pavement during curing to "eliminate the great majority of cracks" in up to 120-foot (36.6 m) long slabs. These pavements he subsequently observed in the field in 1967. He states that "The joints were in excellent shape without reveling, spalling and D-cracking in some 27-year (old) pavements." This system, however, did not provide for permanent prestress of the pavements, and was, therefore, unable to take full advantage of the benefits structurally.

The intent of this proposal is to present a system, which is similar in effect to this original method, but is quite dissimilar in several important ways. The intent of the new precompressing system is to provide an essentially zero-maintenance, low-cost, modular, prestressing system which may be installed in concrete pavement joints and will produce the design precompression with uncomplicated field techniques.

B. Technical Description of Method

The system that is being proposed for this project is an extension of existing technology. Mr. Friberg has proposed the use of a hydraulic system for precompressing, and suggests the use of a conventional hydraulic accumulator and hydraulic cylinders. This would be a reasonable system, but there are two inherent disadvantages to a system of this type. They are leakage and initial cost. For the purposes of this proposal, it is suggested that a hydraulic system be used with one major modification made possible by the latest technology. A stressing element consisting of a series of corrosion resistant metal bellows is suggested. This would be used in conjunction with an edgewelded, flat, plate reservoir which would operate exclusively in the elastic region of the stress-strain curve for the material used. The use of these two major elements and special high pressure leak-tight tubing connections will make this hydraulic system a long term, and completely leak-proof system. It is expected that a system of this type could exert constant stress for precompression of pavements over a design period of 30 to 50 years without maintenance.

The Arizona Department of Transportation has, under contract, the construction of a prestressed pavement test section on the primary system. Several other PCCP projects are in the design stage and the system being proposed here could be included in one of these as a full-scale test section. The assumptions that have been made are: (1) pavement thickness is six inches (152 mm), (2) width of slab is 34 feet (10.4 m), (3) slab length is 400 feet (122 m), (4) maximum temperature differential is 100 degrees F (37.8 C), and (5) minimum residual compression at slab center is 65 psi (448 kPa). It is desirable to make the stress elements into readily transported modules. The size being considered is a 24 inches long (610 mm), by 6 inches (152 mm) high, by 4 inches (102 mm) deep module.

Several additional assumptions have been made; for example, buckling will be prevented by the dead load weight of the slab, and the use of a sand leveling course and a polyethylene liner will reduce subgrade restraint to a reasonable figure. The contraction of the slab for prestressing force, the shrinkage due to hydration, and the creep deformation, can be readily accounted for.

It is assumed that the thermal slab length variation will, based upon a 100 degrees F (37.8 C) temperature variation, by approximately 2.4 inches (61 mm). The devices must be deformed to allow for variation due to ambient temperatures.

These items can be determined and values set for them using prediction techniques and laboratory data. Allowances for initial length changes can be made by using gap slab shimming and by scheduling for post-stressing. The initial calculations for this system have been based upon using eight, two-inch (51 mm) diameter metal bellows per module, or nine, three-inch diameter (76 mm) metal bellows per module. These bellows are available from several manufacturers such as Servometer Corporation, 501 Little Falls Road, Cedar Grove, New Jersey 07009, Phone 201-785-4630. These two systems were chosen to allow variations in hydraulic pressure exerted on the inside of the bellows. Using a two-inch O.D. nickle bellows on the eight bellow system, a 1,647 psi (11.4 MPa) strength working pressure can be obtained with a wall thickness of 0.028 inches (0.71 mm). The oil pressure required for the prestressing value of 28,800 pounds (128 kN) would be 1,150 psi (7.9 MPa). This would result in a total allowable compression and extension deflection of 0.83 of an inch (21 mm). However, using the nine, three-inch (76 mm) diameter bellows system, only 652 psi (4.5 MPa) oil pressure is required. Using a two-ply 0.0125 inch (0.32 mm) wall bellows with a pressure rating of 822 pounds per square inch (5.7 MPa), a total compression and extension stroke will be supplied of 3.00 inches (76 mm). This is above and below a 3.75-inch (95 mm) free length, and would appear to be adequate for the thermal elongation predicted.

C. Additional Requirements

It is believed that a reasonable prediction can be made as to the technical worth of this system by use of laboratory tests and a full-scale demonstration project which could be erected and monitored locally.

Additional design considerations are being made currently, and it is expected that a laboratory evaluation will be made at the conclusion of the current design considerations. After that, the project could be implemented in the field on an experimental basis.

If we may provide you with any further information about our progress, please feel free to request it.