POST-TENSIONED CONCRETE HAUNCHED SLAB BRIDGE STANDARDS

106 K-6469-01

PHASE I

Study & Prototype Design

Part I: Report

Kansas Department of Transportation

April, 1998

Booker Associates, Inc. of Kansas
Wichita, Kansas

DISCLAIMER

The information presented in this report is only for the purposes of a study performed to design and prepare standards for post-tensioned concrete haunched slab bridge superstructure. Booker Associates Inc. of Kansas and Kansas Department of Transportation assume no liability or responsibility for and make no representations or warranties as to applicability or suitability of this study. Anyone making use thereof or relying thereon assumes all responsibility and liability arising from such use or reliance.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

A great number of individuals were instrumental in the successful completion of this study of an important new bridge solution. Booker Associates, Inc. of Kansas wishes to extend their appreciation to Mr. Ken Hurst, P.E., State Bridge Engineer, and his highly motivated bridge design staff for their encouragement and valuable assistance throughout the project. Input from various groups including contractors, suppliers and fabricators from the region were extremely valuable in performing this study. Special thanks go to Mr. David Rushton, P.E., Bridge Engineer, Sedgwick County, for his voluntary contribution in sharing practical experience in constructing such bridges in the past. The enthusiasm and support received from many departments within KDOT are very much appreciated. The project manager also appreciates the encouragement and support received from the Senior Management of Booker Associates, Messrs. T.R. Peterson, P.E., and Steve Bachenberg, P.E., throughout the project.

February, 1998
Wichita, Kansas

Booker Associates, Inc. of Kansas
Raja Govindaswamy, P.E.
Executive Vice President
Project Manager

PROJECT TEAM

OWNER: **Kansas Department of Transportation (KDOT)**

Mr. G. David Comstock, P.E.
Chief - Bureau of Design

Mr. Ken Hurst, P.E.
State Bridge Engineer

Mr. Dean Testa, P.E. - Chief, Bureau of Construction and Maintenance
Mr. Richard Elliott, P.E. - Senior Squad Leader
Mr. Loren Risch, P.E. - Bridge Design Engineer
Mr. Richard Mesloh, P.E. - Bridge Manual Engineer
Mr. Bruce Fillippi, P.E. - Bridge Engineer, Local Projects

CONSULTANT: **Booker Associates, Inc. of Kansas**

Mr. Raja Govindaswamy, P.E. - Project Manager and Principal Designer

Mr. Abdel Hamada, P.E. - Project Engineer

Dr. Hani Melhem, Ph.D. - Assoc. Professor, Kansas State University

Ms. Angela Perez - (Report)

Ms. Deana Friebus - (Graphics)

I. INTRODUCTION

I.1 History of Concrete Slab Bridges:

Reinforced concrete slab bridges of various types have been part of bridge solutions in Kansas and throughout United States since 1940's. A slab bridge typically consists of either prismatic or non-prismatic superstructure slab with primary reinforcement in the longitudinal direction parallel to the traffic. The slab bridges are primarily used where there is limited headroom below the bottom of the superstructure over streams or other crossings requiring a shallow depth superstructure. Slab bridges are simple to design and construct requiring very little maintenance and hence one of the most economical types of bridge structures, especially in the midwest.

The superstructure is usually designed to be continuous over the interior piers. The span range for concrete slabs are typically from 30' (9m) to 60' (18m). There are several types of superstructure slabs that have been in use depending on span lengths. Flat slabs are suitable for short spans, 20' (6m) to 30' (9m) range. For spans in the 30' (9m) to 60' (18m) range the slab thickness is increased over the piers to achieve an optimum design. This can be achieved by providing a column 'capital' at the piers as was done in older structures or increasing the slab thickness gradually from midspan to the piers by straight or parabolic haunching. The latter type, using parabolic variation of the slab soffit commonly referred to as 'Reinforced Concrete Haunched Slab' has been very successful in Kansas and several other states since the 1950's.

The parabolic variation of slab thickness in the longitudinal direction follows the parabolic variation of the design moment resulting in a highly efficient and optimum design. The material is placed where it is needed the most. The formwork for the cast-in-place superstructure slab is relatively simple to construct. The prevailing cost for Reinforced Concrete Haunched Slabs in Kansas is about $50 per Sq.Ft ($550 per Sq.M) based on Year 1997 construction prices.

In Kansas, the reinforced concrete haunched slabs have been very effective bridge solution for spans in the range of 30' to 60' (9m to 18m).

I.2 Post-tensioning of concrete slab bridges:

Reinforced concrete haunched slab bridges offer a shallow-depth superstructure solution where it is needed to maximize the vertical opening below the bridge, such as shallow stream crossings and overpasses with restricted headroom conditions. This also provides one of the most economical types of structure. However, the maximum practical span length is in the 60' (18m) range which precludes its use for longer span requirements.

The application of post-tensioning to the concrete haunched slab extends the maximum span capability to nearly 100' (30m) while maintaining the shallowness of the superstructure depth. In addition to a significant increase in the span range, the superstructure is designed to be in a state of compression or very little tension, thus increasing the durability of the concrete deck. The combination of post-tensioning and variable slab depth results in a highly efficient design for the superstructure.

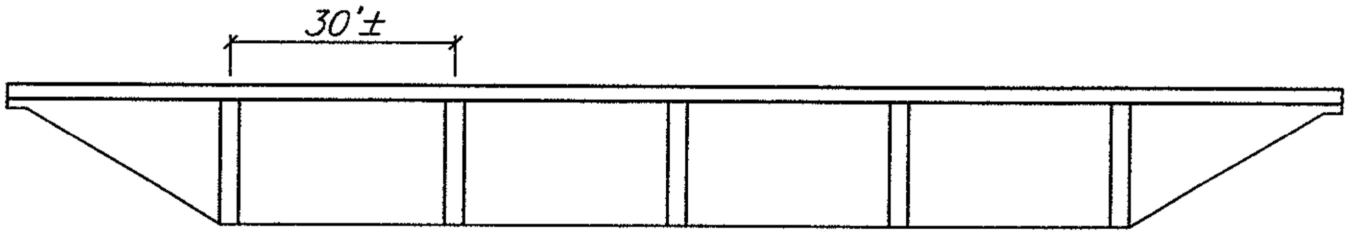
The average slab depth for reinforced concrete haunched slabs is about 1/32nd of the span length. The total superstructure depth for steel beam bridges is about 1/22nd of the span, and about 1/19th of the span for prestressed concrete bridges. The corresponding span/depth ratio for post-tensioned concrete haunched slabs is about 1/40th. Where site conditions do not preclude construction of a cast-in-place type structure, post-tensioned concrete haunched slabs may be considered as an alternate to girder-type bridges if a shallow superstructure is preferred.

The historic evolution of various types of slab bridges is shown in Figure I.1.

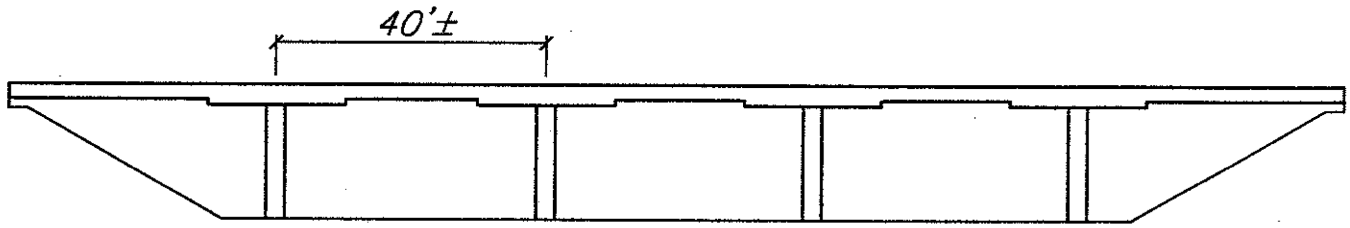
I.3 History of Post-tensioned Concrete Slab Bridges:

The first post-tensioned concrete slab bridge in United States was built in 1954 in Houston, Texas, consisting of 40'-2@70'-40' (12.2.m– 2@21.3 m- 12.2 m) using constant depth (prismatic) slab. There have been several other constant depth post-tensioned slabs constructed in the U.S. since that time including 100' spans in Texas as ramp structures.

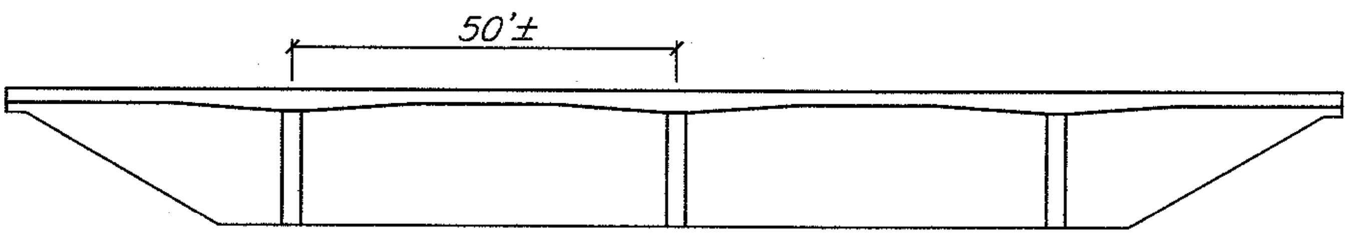
The first post-tensioned concrete *haunched* slab in the U.S. was built in Sedgwick County, Kansas in 1989 consisting of 45'-70'-45' (13.7 m –21.3 m- 13.7 m) spans and 28' (8.5 m) roadway. It was designed for Sedgwick County Bureau of Public Services by Booker Associates Inc. of Kansas. Following the successful application of this technique, several other post-tensioned concrete haunched slab bridges have been built in Sedgwick County with spans from 70' (21.3 m) to 102' (31.1 m). The 79'-102'-79' post-tensioned concrete haunched slab bridge, built in Sedgwick County, Kansas in 1996, appears to have the longest slab span in the United States. Table I.1 contains spans, roadway width, slab depth, skew and cost data for six (6) post-tensioned concrete haunched slab bridges built in Sedgwick County from 1989 to 1996.



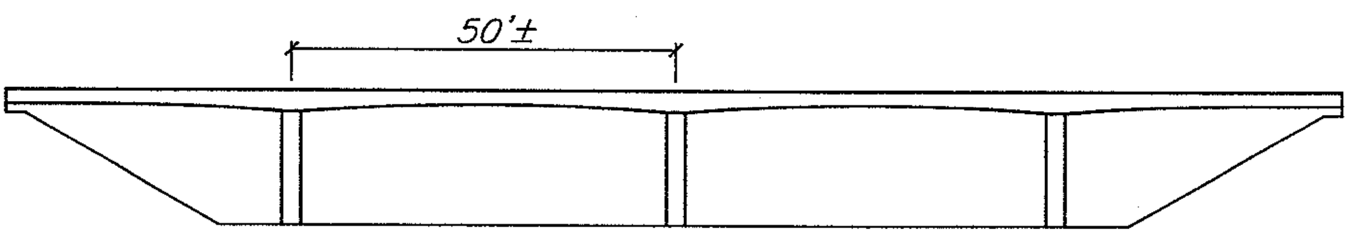
Flat slab spans



Flat slab spans with "capitals"

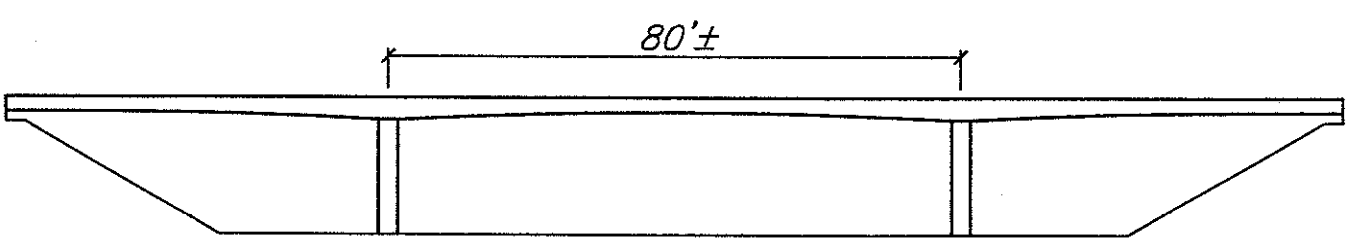


Straight haunched slab spans



Parabolic haunched slab spans

Conventional reinforced concrete slab bridges



Post-tensioned concrete haunched slab spans

Fig. I.1

TABLE I.1

POST-TENSIONED CONCRETE HAUNCHED BRIDGES-HISTORIC DATA

SEDGWICK COUNTY, KANSAS

SPANS	ROADWAY	SKEW	DEPTH @ MIDSPAN	DEPTH @ PIER	YEAR BUILT	COST PER SQ. FT.
45'-70'-45'	28'	0°	18"	30"	1989	$35
45'-70'-45'	28'	0°	18"	30"	1992	$41
62'-81'-62'	28'	30°	20"	34"	1992	$41
62'-81'-62'	28'	0°	20"	34"	1993	$47
45'-70'-45'	28'	0°	18"	30"	1995	$49
79'-102'-79'	32'	0°	22"	40"	1996	$63

II. STUDY OBJECTIVES

II.1 Plan Standards:

Kansas Department of Transportation has produced standard design and plan details for Reinforced Concrete Haunched Slabs (RCHS) both in US Customary and Metric units for spans from 40' to 72' (12 m to 22 m) with roadway widths from 28' to 44' (8.6 m to 13.4 m).

The purpose of the Study Phase I is to investigate and design four (4) prototypes of post-tensioned concrete haunched slab bridges to be used in developing standard construction plans for Post-tensioned Concrete Haunched Slabs (PCHS) during Phase II. Upon completion of Phase II, standard plans will be made available for use on local, state and interstate highway systems for four (4) span arrangements and five (5) roadway widths. The standards will be available in SI units only in Bentley Microstation CADD format.

II.2 Specific Project Scope for Phase I:

Four (4) span arrangements have been selected as the most commonly required combinations for 3-span PCHS bridges:

15 m – 20 m – 15 m
17 m – 22 m – 17 m
19 m – 25 m – 19 m
21.5 m – 28 m – 21.5 m

Design roadway widths are 8.6 m, 9.8 m, 11.0 m, 12.2 m and 13.4 m.

During Phase I, the prototypes will be subjected to a series of intensive theoretical analysis as well as constructability checks. The goal of developing plan standards in Phase II is to meet the current and future AASHTO & Kansas bridge specifications and to provide a design that can be successful in inviting competitive bidding from contractors. Therefore, standardization, duplication and simplicity will be essential in developing cost-effective prototype designs.

II.3 Design Criteria:

A. Design Loads:

The prototypes are designed to meet the following dead and live loads:

Dead Loads: Concrete Unit Weight = 145 pcf (22.8 kN/m^3)
Traffic Barrier Load = 275 plf/rail (4.0 kN/m)
Future Wearing Surface = 25 psf (1.2 kPa)

Live Loads: Current AASHTO HS-20 (M18 - 44)
HS-25 (M22.5 - 44) (Kansas Overload)
Future LRFD HL-93

B. Design Methodologies:

LFD (Load Factor Design) will be utilized for HS-20 & HS-25 design.
LRFD (Load Resistance Factor Design) will be utilized for HL-93 design.

C. Inventory Load Rating:

The prototypes shall be designed such that a minimum 1.10 is rated for the HS-20 truck. The structure shall also pass all Kansas 7 truck rating.

D. Design Check:

The prototypes shall be checked for flexural stresses under Service Conditions, Ultimate Flexural Strength, Shear Stresses and Deflections allowed by AASHTO codes.

E. Construction Tolerances:

The prototypes shall be checked for tolerance variations in slab thicknesses and P/T tendon layout in the vertical direction.

F. Structural Model:

The assumed base superstructure model for the prototype structural analysis is a three span continuous beam of a selected uniform width with pinned support at the abutments. No moment is assumed to be transferred between the substructure and superstructure in the base model analysis. A frame analysis of the entire structure including frame action at the abutments and piers is also performed for each prototype to check the effect of "negative moment" at the abutments and restraint caused by piers during elastic shortening

G. Life-cycle cost comparison:

The study report includes a discussion regarding the initial and long-term direct and in-direct costs related to conventional slab, girder and post-tensioned haunched slab bridges. An accurate quantitative life-cycle cost comparison is not feasible at this time due to lack of required long-term cost data for various types of bridges. However a qualitative discussion of the various cost and performance related items are included to present a clear understanding of the advantages and problems of using post-tensioned concrete haunched slab bridges.

III. STUDY PROCESS

III.1 Partnering Concept:

Throughout the study, input from many groups including KDOT Design, Materials and Construction; Contractors, Fabricators, Suppliers, Academia and Counties was sought in the development of the prototype design. Meetings with these groups were held at several project milestones. The Consultant presented design data for the groups' review to consider the requirements of KDOT expectations, constructability, long-term maintenance issues, specifications, bidding process, etc.

The comments received were evaluated by the design team and modifications to the design were made when deemed necessary throughout the study phase. This process facilitated an evolution of prototype designs which could successfully meet the requirements of design, performance, cost, constructability, special material specifications, project special provisions, inspection, load rating and maintenance. A list of the participants and minutes of the meetings are included in the appendix section of the report.

The partnering process used in this study was designed to produce Post-tensioned Concrete Haunched Slab Standards for KDOT which meet the following criteria:

- Current (LFD) & Future (LRFD) AASHTO Design Specifications
- Minimum initial cost and long-term maintenance
- Practicality in fabrication, construction and inspection
- Facilitate competitive bidding from Contractors, Fabricators and Suppliers from the entire region.
- Simple and easy to use plan standards.

III.2 Design Details:

Though the preparation of detailed plans was not part of the study phase, several design details were considered and developed during the study phase which affected the design of slab depth and P/T tendon layout:

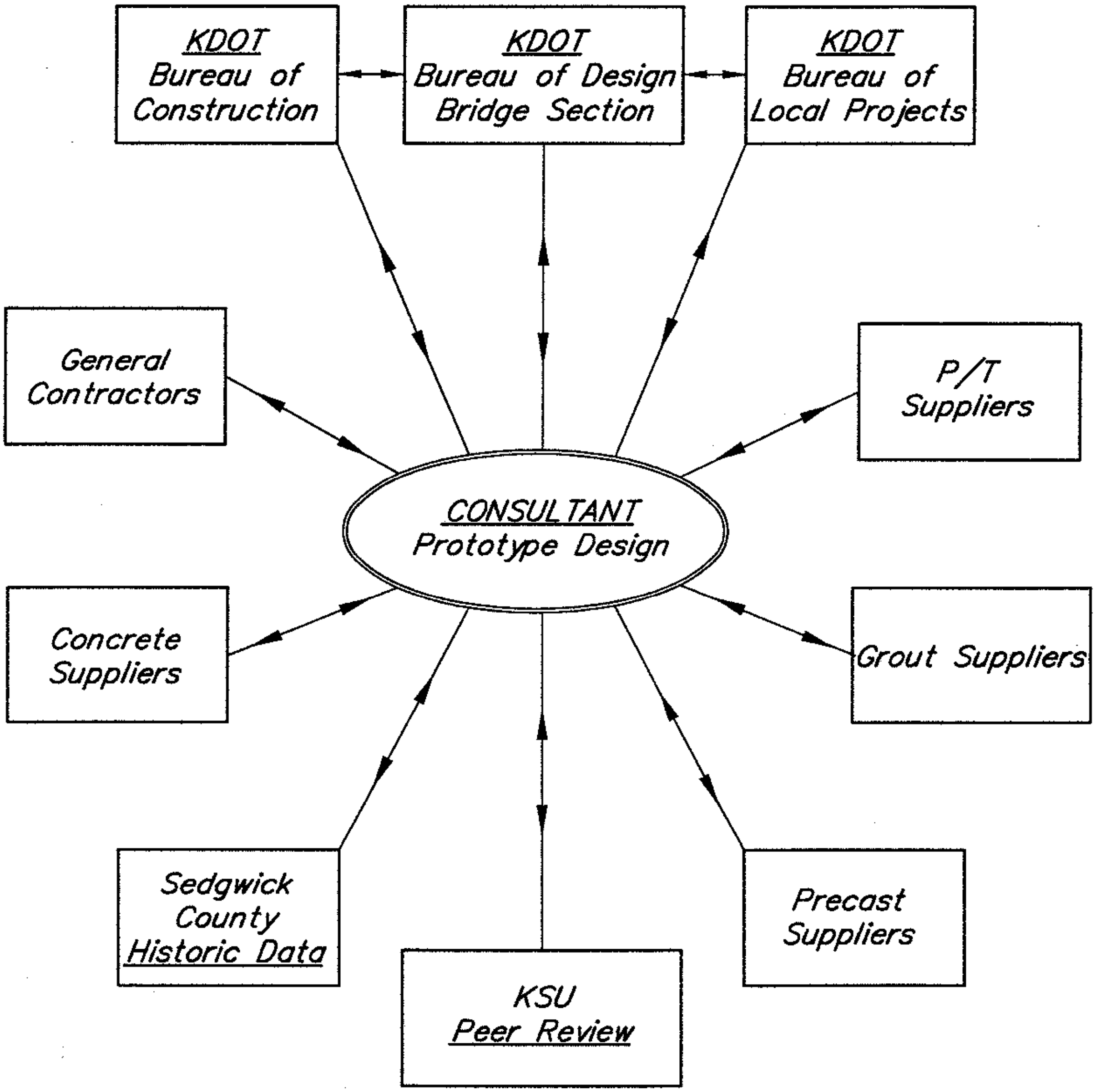
- Post-tension systems affecting size & number of strands, type & size of P/T ducts
- Concrete cover requirements affecting the path of center-of-gravity of P/T tendons
- Exact spacing of longitudinal P/T tendons including "edge beam" effect affecting Spacer Frame placement and fabrication
- Traffic Barrier (Corral Rail) layout and transverse P/T tendon placement avoiding rail posts

III.3 Independent Peer Review:

An independent review of the prototype designs was performed by Dr. Hani Melhem, Ph.D., Associate Professor of Civil Engineering at Kansas State University, Manhattan, Kansas. The peer review included comments regarding structural analysis model, analysis results, post-tensioning concepts, losses & secondary moments, other theoretical considerations and constructability issues.

The goal of the independent peer review was primarily to check the analysis and assumptions of the original design process. Peer review is considered important for a new type of bridge design solution such as this.

Fig. III.1 illustrates the study process used in this project phase.



Study Process & Partners

FIG. III.1

IV. STRUCTURAL ANALYSIS & DESIGN

IV.1 Base Structural Model:

During the preliminary analysis-design iterative process, it was discovered that 600 mm (1.97') was the optimum spacing for longitudinal post-tension tendons, both from theoretical and practical considerations for all span and roadway combinations. Based on the span/roadway parameters, under current LFD as well as future LRFD specifications, it was determined that 'unit strip width' method of analyzing the superstructure slab would be a practically acceptable approach in designing the prototypes.

The Base Model consists of a 3 span, uniform width, non-overlain 600 mm (1.97') wide rectangular concrete beam of parabolically variable depth, continuous over abutment and pier supports as shown in Fig. IV.1. The Base Model assumes no transfer of moments between the superstructure and substructure. The abutments and piers are assumed to be designed to allow the elastic shortening due to post-tensioning and ambient temperature changes. However a check is made for each prototype investigating the effect of potential 'frame action' that will occur between the substructure and superstructure.

The concept of this Base Model is used in the prototypes to meet the design requirements of LFD & LRFD specifications for Service & Strength limitations including allowable stresses, live load deflections and ultimate strengths. Deviations from design limitations were evaluated for a number of practical and theoretical scenarios such as overall structural frame action and construction tolerances for each prototype by modifying the Base Model accordingly. <u>The concept of the Base Model is expected to result in a conservative design for post-tensioning requirements.</u>

IV.2 Analysis & Design Tools:

Several computer softwares are used in the analysis-design process.

BDS Software:

The computer software BDS (Bridge Design System) developed and maintained by Imbsen & Associates is the primary tool for post-tensioned bridge design. The PC version of the software generates the moments & shear due to user specified dead loads and AASHTO HS live loads and calculates the resulting flexural stresses, deflections and ultimate strengths due to <u>ALL</u> loads including post-tensioning.

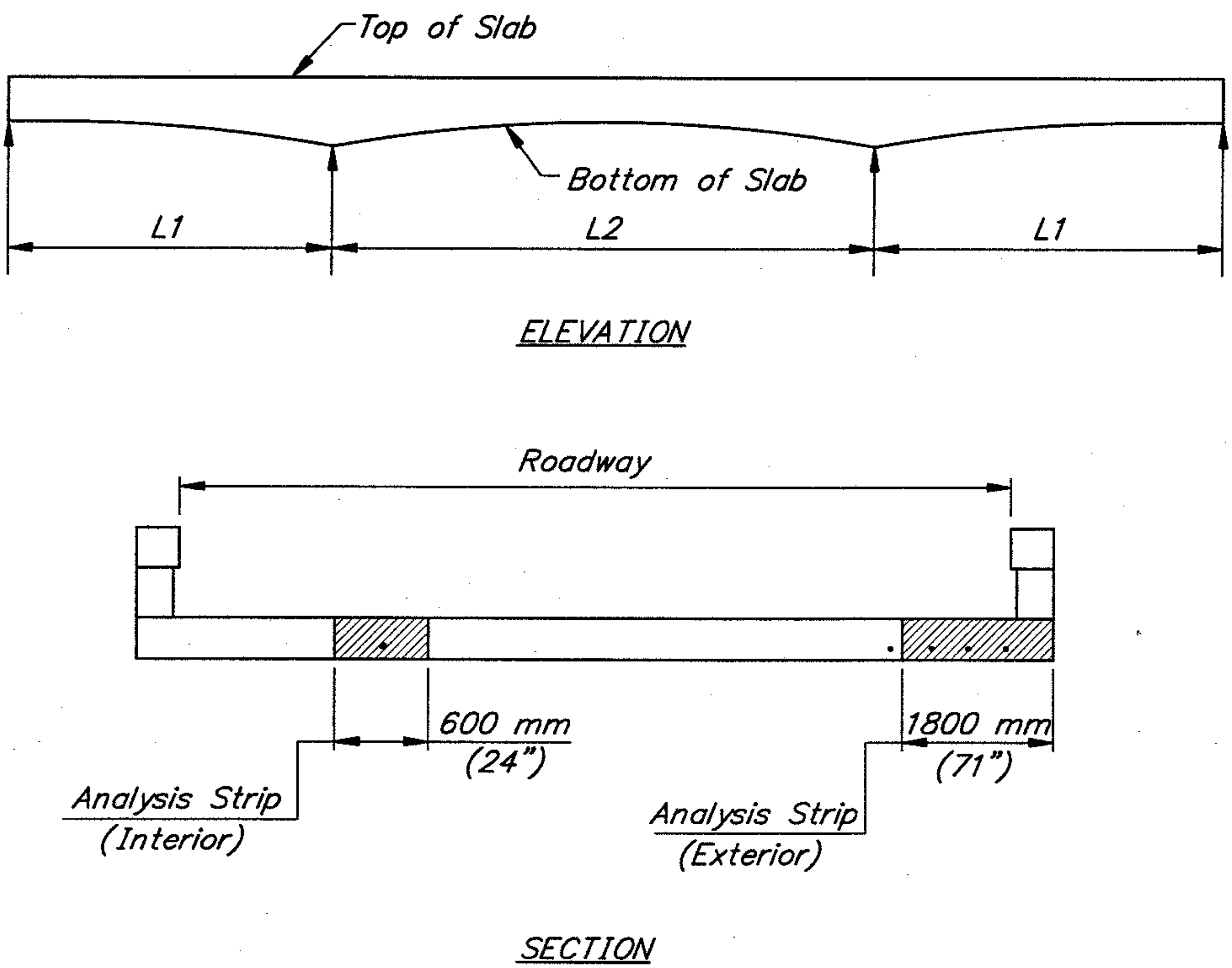

Top of Slab
Bottom of Slab
L1
L2
L1
ELEVATION
Roadway
600 mm
(24")
1800 mm
(71")
Analysis Strip
(Interior)
Analysis Strip
(Exterior)
SECTION

FIG. IV.1

Post-tensioning design includes selection of jacking prestress force for an assumed cable layout as well as analyzing the structure for the user-defined jacking force. The software computes the cable profile automatically (parabolic variation) for a user defined low and high points of the tendon. The center-of-gravity of the post-tension tendon (CGS) is printed out at each 10^{th} point of the span. All losses due to prestressing (Friction, Shrinkage, Creep, Elastic Shortening, Relaxation) are accounted for in the analysis, both instantaneous and long-term.

The structure can be modeled as a continuous beam over rigid supports or as a frame including the stiffness of substructure. All members can be described as either prismatic or variable depth. Extensive modification to the member section such as addition of fillets and deduction of duct holes can be made to perform a very accurate analysis of the structure, especially critical for prestress deign. BDS software is used extensively in the study for LFD & LRFD design.

BRASS Software:

Developed and maintained by Wyoming Department of Transportation, this software is primarily used to load rate bridge structures. BRASS software, though provided with prestress options, is not quite efficient for the analysis of post-tensioned bridges in its present form. BRASS software is used in the study primarily to generate moments for various load rating trucks.

BTBEAM Software:

Developed and maintained by Bridge Tech. Inc. (consultants to BRASS) headed by Dr. Jay Puckett (co-author of a popular book on LRFD Bridge Design), this software generates dead and live load moments and shear due to the HL-93 loads specified in the new AASHTO LRFD bridge design specifications for a user-defined bridge superstructure continuous over supports. Non-prismatic superstructure is allowed in the analysis. BTBEAM program is used in the study to develop HL-93 moments for the LRFD analysis.

PLANESTEEL Software:

This software developed by Structural Analysis Inc. (SAI), intended primarily for design of steel structures, is an efficient tool to analyze continuous beam models for moments and deflections. This program is used in the study to model the prototypes and apply HS-20 Design truck at critical locations to calculate live-load deflections.

STAAD-III Software:

A finite element analysis of the superstructure slab is carried out using STAAD-III software for the purposes of investigating requirements for transverse post-tensioning. This software is developed and maintained by Research Engineers Inc.

PCHS Spreadsheet:

Developed by Booker Assoc. Inc. of Kansas exclusively for the study, this spreadsheet software integrates the results from BDS, BRASS, PLANESTEEL & BTBEAM output summarizing the results of HS-20, HS-25, HL-93 Service Load Stresses, Load Rating for HS-20, Live Load Deflections and LRFD Strength Conditions. The spreadsheet performs a variety of calculations based on span lengths, slab depths and P/T data. Since no software is available at this time to analyze and design post-tensioned concrete bridges under LRFD specifications, this spreadsheet was developed to achieve that purpose.

A flow chart depicting the analysis and design process using the various computer softwares is shown in Fig. IV.2.

IV.3 Critical Structural Design Criteria:

During the initial analysis-design iterations and design review meetings, it was discovered that three items appear to control the key design parameters of slab depths and prestress force. Those are:

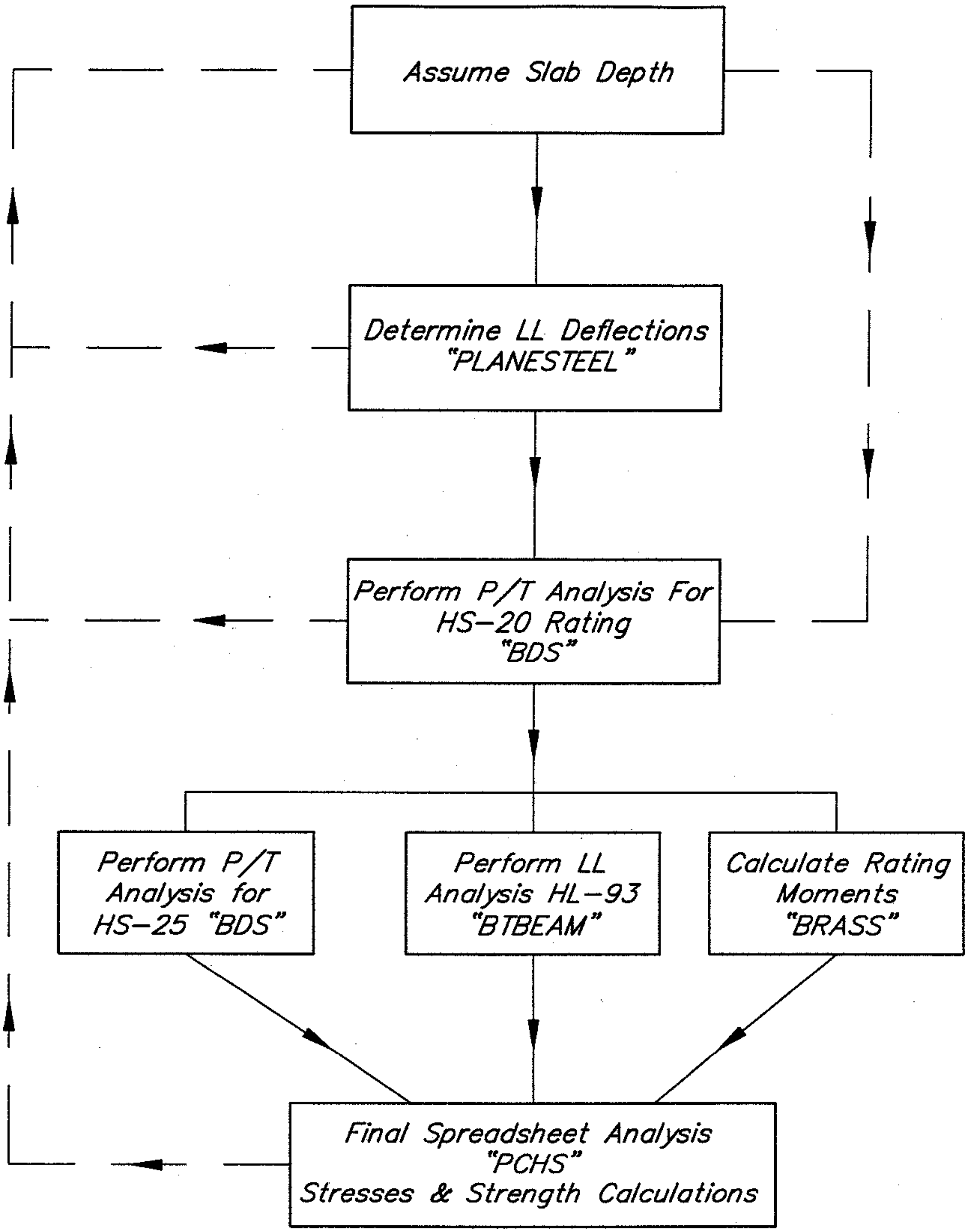
1. *Live Load Deflection*
2. *Allowable Concrete Tensile Stress*
3. *Load Rating for HS-20*

Even though the live load deflection criteria is left as an option under LRFD specification, it was felt by the design group due to the shallowness of the superstructure slab, the limitation of the HL-93 live load deflection to 1/800th of the span length will be highly desirable. Excessive live load deflections may cause discomfort to the drivers and pedestrians especially in urban areas. This criterion was used to set the minimum slab depths for the prototypes.

KDOT prefers to limit the allowable concrete tensile stresses under full dead plus live loads to '0' psi for HS-20 design and Inventory load rating. The principle behind this limitation is to allow for long-term loads such as creep & shrinkage, temperature gradient as well as provide for contingencies. However, this limitation has been increased to a maximum of 214 psi (3 x Sqrt (F'c)) for HS-25 or HL-93 (Service Condition) in the design of the prototypes to avoid excessive conservatism.

It was determined for the prototype designs, that HS-20 truck loads controlled the load rating. Under the current LFD method, a minimum 1.0 Inventory Rating would be required for HS-20 loads. However, in light of future LRFD rating provisions, an HS-20 Inventory Rating of 1.1 is set as preferred rating for the prototype designs.

These three basic requirements along with several practical considerations (Section III.2) formed the basis for slab depths, required post-tension force and tendon layout for the prototypes.



Design Flow Chart

FIG. IV.2

IV.4 Section Properties:

Two sets of section properties (area & section modulus) are used at any given section of the design strip. A rectangular section with the P/T duct hole deducted at the appropriate tendon location is used for the applied prestress, self-weight and traffic barrier loads until the ducts are grouted. After the ducts are grouted full, the gross section properties are used for the applied future wearing surface and live loads.

Even though this procedure did not appear to alter the final stresses significantly, deduction of duct holes from the section properties is an important step recommended in the analysis of initial prestress stages and member stress calculations – a good practice.

IV.5 LRFD Service Conditions:

The LRFD design of prestressed concrete bridges needs to satisfy both Service and Strength requirements. Under Service conditions, SERVICE III is critical for all prestress designs since it deals with 'tensile' stresses which are often the governing design condition. Under LRFD SERVICE III condition, live load moments are reduced by 20%, only for checking tensile stresses produced by the live load. This allowance has been taken into consideration in the development of the formulas in the PCHS Spreadsheet.

IV.6 Shear Stress:

One of the concerns in designing shallow-depth slabs is the shear stresses in the slab. During initial analysis of the prototypes, an investigation of the 'principal' stress was carried out at the 10^{th} points of spans to take into account the concurrent action of shear and bending due to all dead, live and prestress load. It was discovered during the analysis that the maximum principal stresses were in the order of 20 psi, tension. This is well below 135 psi (1.9 x Sqrt(F'c)) used as guideline by leading designers and U.K. Code (no code specified limit is present in AASHTO).

The shear stress is maximum at the neutral axis where the prestress produces a moderate level of compressive stresses. This phenomenon helps to reduce the net principal stresses and in many instances even eliminates the tensile stresses caused by shear - a distinctive advantage of prestress. The analysis of principal stresses is shown in Table IV.1. A schematic of principal stress phenomenon is shown in Fig. IV.3.

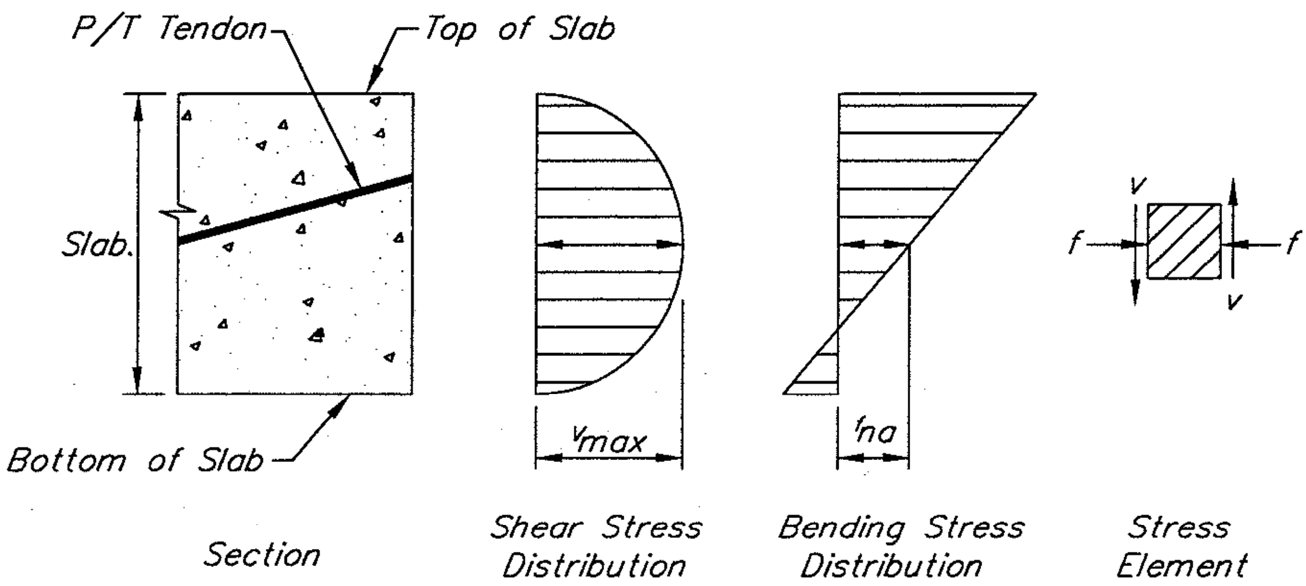
Based on investigation results, it is concluded that shear stresses are not at all critical in the design of the prototypes.

TABLE IV.1

Principal Stress Check

Prototype Span 2 : 17 m-22 m-17 m

< LRFD Shear Check Serv I				HL-93				>
< BDS		> BTBM		Allow.Princ.Strs (psi):				135
V	V	V	V			v		
	rl+		L+I	V		VQ/	fc	Prin.
Sl.	fws	P/T	HL-93	Des.	Q/I*b	I*b	@NA	St
K	K	K	K	K	1/In^2	psi	psi	psi
4.3	0.7	-5.0	7.3	7.3	0.007	48	635	4
3.1	0.5	-4.0	6.0	5.6	0.007	37	638	2
1.8	0.3	-2.0	4.9	5.0	0.007	33	641	2
0.5	0.1	-1.0	3.9	3.5	0.007	23	644	1
-0.8	-0.1	1.0	-3.2	-3.1	0.007	20	641	1
-2.1	-0.4	1.0	-4.1	-5.6	0.006	36	625	2
-3.5	-0.6	2.0	-5.1	-7.2	0.006	43	592	3
-5.0	-0.8	4.0	-6.2	-8.0	0.006	44	546	4
-6.6	-1.0	5.0	-7.1	-9.7	0.005	48	495	5
-8.4	-1.2	7.0	-8.0	-10.6	0.004	47	442	5
-10.4	-1.5	1.0	-8.8	-19.7	0.004	77	397	14
10.2	1.4	-2.0	8.9	18.5	0.004	72	397	13
7.6	1.1	-7.0	7.9	9.6	0.005	44	455	4
5.4	0.8	-5.0	6.8	8.0	0.005	42	523	3
3.4	0.6	-4.0	5.6	5.6	0.006	33	583	2
1.7	0.3	-2.0	4.4	4.4	0.006	28	626	1
0.0	0.0	0.0	3.3	3.3	0.007	22	643	1



PRINCIPAL STRESSES

$$v_{na} = v_{max} = \frac{VQ}{Ib}$$

V – Design Shear Force.

Q – Moment of area above neutral axis (na) about the neutral axis

I – Moment of Inertia of the section

b – Design width = 600 mm (24")

f_{na} = net axial stress at neutral axis due to <u>ALL</u> loads including prestress

$$P = \sqrt{v_{na}^2 + (0.5 \times f_{na})^2} - 0.5 f_{na}$$

P = Principal stress

FIG. IV.3

IV.7 Ultimate Flexural Strength:

For the LFD method of design under current AASHTO, BDS software calculates the Ultimate Flexural Strength of the post-tensioned superstructure slab and applied factored moments at 10th points of the spans. For all prototypes, this is shown in the computer printouts included in Part II, "Calculations." The PCHS spreadsheet includes the calculation of Ultimate Flexural Strength and applied factored moments under LRFD Strength Condition shown in Table IV.2 through Table IV.5. As seen from the results, the Ultimate Flexural Strength, though an important design requirement, did not appear to govern the prototype designs.

IV.8 Load Rating:

As discussed in Section IV.3, the load rating requirement was a significant factor in the design of the prototypes. The HS-20 truck produces governing rating moments for all prototypes. A rating formula is developed in PCHS spreadsheet as a ratio of <u>Available Resisting Moment</u> and <u>Applied Live Load Moment</u> based on "0" psi allowable tension and "0.4*F'c" allowable compression. A minimum 1.1 ratio is preferred for the prototype design.

The Inventory rating controlled by both top & bottom fiber of the slab at the 10th points of the spans is shown in Page 2 of Table IV.2 through Table IV.5.

IV.9 Summary of Prototype Design Results:

Table IV.2 through Table IV.5 contain results of structural analysis for Spans 1 through 4 at 10th points along each span.

<u>Page 1</u> contains span lengths, minimum & maximum slab depths, P/T tendon spacing, concrete and prestress steel strengths, P/T strands & duct data, section properties, P/T tendon layout, stresses due to prestress & dead loads, P/T secondary moments, dead load moments (Slab, Rail & FWS) and HS-20, HS-25 & HL-93 live load moments.

<u>Page 2</u> contains final top & bottom of slab stresses under all dead loads, prestress and live loads - HS-20, HS-25 and HL-93 service conditions. Also shown on this page is inventory ratings controlled by top & bottom slab stresses for the governing HS-20 truck.

<u>Page 3</u> contains the tabulation of applied factored moments and resisting Ultimate Flexural Moments under LRFD specifications.

Posttensioned Concrete Haunched Slab				TABLE IV.2	Page 1
Prototype S1:	15m-20m-15m				Input Data
					S1T1D
Analysis per	600 mm	width of slab			K-9700
					04-10-98

Span 1:	15.0	m	49.2	'	Dm:	430 mm	16.93 "	F'c:	35	MPa	Fu:	1860	MPa	Asp:	1.736	In ^2	(1120) mm^2
Span 2:	20.0	m	65.6	'	Dm:	740 mm	29.13 "	F'c:	5076	psi	Fu:	270	ksi	Dct D:	3.00	In	(76) mm
Span 3:	15.0	m	49.2	'	C1:		0.011							Sp:	600	mm	(23.62) in
Rdwy:	11.0	m	36	'	C2:		16.40 '							z:	0.625	In	(16) mm

< Geometry >							< BDS										> BTBM		< BDS	> BTBM	
			< Dct.Ded.>		< Full Sec. >																
			< P/T+DL >		< SDL+LL >		P/T			DL Slb+	DL Slb+	P/T	K/Ft->	0.018	0.074	L+I	L+I	L+I	L+I	L+I	L+I
		Slab	Sec.	Sec.	Sec.	Sec.	T/Sl.to	DL Slb+	DL Slb+	Rl+fws+	Rl+fws+	Sec.	Slab	Rail	FWS	HS-20	HS-25	HL-93	HS-20	HS-25	HL-93
Node	Dist.	Dpth.	Mod.	Mod.	Mod.	Mod.	CG Str.	Fn.Prs	Fn.Prs	Fn.Prs	Fn.Prs	Mom.	Mom.	Mom.	Mom.	Pos.M.	Pos.M.	Pos.M.	Neg.M.	Neg.M.	Neg.M.
	Ft	In	In^3	In^3	In^3	In^3	Ft	top - psi	bot - psi	top - psi	bot - psi	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft
			(St)	(Sb)	(St)	(Sb)					(Gm>)	1.25	1.25	1.25	1.50			1.75			1.75
100	0.0	16.93	1128	1128	1128	1128	0.71	679	708	679	708	0	0	0	0	0	0	0	0	0	0
101	4.9	16.93	1128	1116	1128	1128	0.87	524	870	588	806	3	27	1	5	40	50	57	-9	-11	-13
102	9.8	16.93	1124	1104	1128	1128	0.99	398	1005	504	899	7	44	2	8	66	82	94	-18	-22	-27
103	14.8	16.93	1119	1096	1128	1128	1.06	302	1110	430	982	10	51	2	10	78	97	113	-26	-33	-40
104	19.7	17.05	1135	1111	1145	1145	1.08	273	1127	388	1012	14	49	2	9	82	102	120	-35	-44	-53
105	24.6	17.69	1226	1205	1232	1232	1.06	330	1023	408	945	17	37	2	6	78	97	115	-44	-55	-67
106	29.5	18.88	1403	1389	1404	1404	0.99	457	811	483	785	21	15	1	2	68	85	102	-53	-66	-80
107	34.4	20.62	1675	1671	1674	1674	0.88	598	564	569	593	24	-17	-1	-3	50	62	78	-62	-77	-94
108	39.4	22.91	2050	2067	2066	2066	0.72	716	339	635	420	28	-62	-3	-11	29	36	52	-70	-88	-108
109	44.3	25.75	2563	2598	2610	2610	0.52	796	145	681	260	31	-120	-5	-20	25	31	36	-79	-99	-129
110	49.2	29.13	3255	3307	3342	3342	0.34	773	72	633	212	34	-192	-8	-31	27	34	39	-103	-129	-169
200	0.0	29.13	3255	3307	3342	3342	0.34	773	72	633	212	34	-192	-8	-31	27	34	39	-103	-129	-169
201	6.6	24.74	2372	2402	2410	2410	0.56	851	136	746	241	34	-99	-4	-17	18	22	28	-66	-82	-116
202	13.1	21.32	1788	1791	1790	1790	0.80	766	373	719	420	34	-32	-1	-6	31	39	57	-50	-62	-75
203	19.7	18.88	1404	1391	1404	1404	0.96	619	661	636	644	34	13	0	2	57	71	84	-40	-50	-58
204	26.2	17.42	1187	1164	1194	1194	1.07	464	926	544	846	34	40	2	6	73	91	109	-30	-38	-47
205	32.8	16.93	1116	1091	1128	1128	1.10	389	1043	495	937	34	48	2	8	78	97	117	-26	-33	-36

Posttensioned Concrete Haunched Slab

Prototype S1:

TABLE IV.2

Service Check

K-9700
04-10-98

	Wrk.Str. HS-20				Wrk.Str. HS-25				Srv I & III HL-93				Ld Rtng for HS-20			
	Ft: 0 psi				Ft: -214 psi				Ft: -214 psi				Ft: 0 psi			
	Fc: 2030 psi (0.4F'c)				Fc: 2030 psi (0.4F'c)				Fc: 3046 psi (0.6F'c)				Fc: 2030 psi (0.4F'c)			
	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+
Nd	<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->	
	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi
100	679	708	679	708	679	708	679	708	679	708	679	708	N/A	N/A	N/A	N/A
101	1013	381	494	900	1120	274	471	923	1194	321	477	944	3.39	1.90	6.28	13.08
102	1202	201	317	1086	1376	27	270	1133	1504	99	275	1186	2.19	1.29	2.69	6.05
103	1255	157	149	1263	1461	-49	79	1333	1631	21	89	1408	1.94	1.19	1.53	3.73
104	1244	156	19	1381	1458	-58	-73	1473	1646	5	-56	1567	1.92	1.18	1.05	2.76
105	1164	189	-21	1374	1352	1	-128	1481	1528	49	-114	1598	2.15	1.25	0.95	2.53
106	1064	204	31	1237	1209	59	-82	1350	1350	91	-64	1469	2.66	1.35	1.07	2.76
107	925	237	128	1034	1014	148	17	1145	1128	145	30	1266	4.11	1.67	1.29	3.26
108	802	253	226	829	844	211	124	931	937	179	133	1048	8.34	2.51	1.55	3.94
109	795	146	317	624	824	117	226	715	847	128	207	853	11.83	2.28	1.87	4.86
110	731	114	262	583	755	90	170	675	773	100	147	819	14.31	2.17	1.71	4.91
200	731	114	262	583	755	90	170	675	773	100	147	819	14.31	2.17	1.71	4.91
201	834	153	420	567	856	131	338	649	886	129	284	818	14.65	2.74	2.28	5.48
202	928	211	387	752	981	158	303	836	1101	114	317	923	6.27	2.01	2.16	4.84
203	1122	158	294	986	1243	37	209	1071	1354	69	239	1140	2.87	1.33	1.86	4.05
204	1276	114	239	1151	1459	-69	163	1227	1640	-31	167	1318	2.03	1.16	1.78	3.88
205	1321	111	215	1217	1527	-95	144	1288	1740	-59	189	1320	1.86	1.13	1.76	3.90

P/T Concrete Haunched Slab — TABLE V.2 — Page 3

Prototype S1: — Strength Check

K-9700

04-10-98

Nd	Nr	Ni	N	B1
0.95	0.95	1.05	0.95	0.80

LRFD Strength I Check HL-93

Nd	dp mm (+)	dp mm (-)	c mm (+)	c mm (-)	a mm (+)	a mm (-)	Fps MPa (+)	Fps MPa (-)	phi*Mn N-mm (+)	phi*Mn N-mm (-)	Res. Mom phi* Mn K-Ft (+)	Load. Mom. N.Sum Gm.Q K-Ft (+)		Res. Mom phi* Mn K-Ft (-)	Load. Mom. N.Sum Gm.Q K-Ft (-)	
100	216	214	123	122	104	104	1565	1561	2.9E+08	-2.8E+08	212	0	ok	-208	0	ok
101	265	165	126	117	107	99	1612	1491	3.8E+08	-1.9E+08	282	139	ok	-142	22	ok
102	302	128	128	111	109	94	1638	1411	4.5E+08	-1.3E+08	334	231	ok	-95	29	ok
103	323	107	130	106	110	90	1651	1346	5.0E+08	-9.4E+07	366	277	ok	-69	22	ok
104	329	104	130	105	110	89	1655	1335	5.1E+08	-8.9E+07	375	289	ok	-66	2	ok
105	323	126	130	110	110	94	1651	1405	5.0E+08	-1.3E+08	366	266	ok	-92	-36	ok
106	302	178	128	119	109	101	1638	1513	4.5E+08	-2.2E+08	334	216	ok	-159	-86	ok
107	268	256	127	126	108	107	1614	1604	3.9E+08	-3.6E+08	286	132	ok	-268	-153	ok
108	219	362	123	131	105	111	1568	1672	2.9E+08	-5.7E+08	217	27	ok	-424	-239	ok
109	158	495	116	135	99	115	1479	1718	1.8E+08	-8.4E+08	133	-80	ok	-622	-355	ok
110	104	636	105	137	89	117	1334	1748	8.8E+07	-1.1E+09	65	-177	ok	-835	-522	ok
200	104	636	105	137	89	117	1334	1748	8.8E+07	-1.1E+09	65	-177	ok	-835	-522	ok
201	171	458	118	134	100	114	1501	1708	2.0E+08	-7.7E+08	150	-60	ok	-565	-299	ok
202	244	298	125	128	106	109	1593	1636	3.4E+08	-4.5E+08	251	87	ok	-329	-132	ok
203	293	187	128	120	109	102	1632	1527	4.4E+08	-2.3E+08	321	198	ok	-172	-38	ok
204	326	116	130	108	110	92	1653	1376	5.0E+08	-1.1E+08	370	280	ok	-80	21	ok
205	335	95	130	102	111	87	1658	1300	5.2E+08	-7.5E+07	384	306	ok	-55	51	ok

Posttensioned Concrete Haunched Slab | TABLE IV.3 | Page 1

Prototype S2: 17m-22m-17m | Input Data

Analysis per 600 mm width of slab | S2T3D

K-9700

04-10-98

Span 1:	17.0	m	55.8	' Dm:	460	mm	18.11	"	F'c:	35	MPa	Fu:	1860	MPa	Asp:	1.953	In ^2 (1260) mm^2
Span 2:	22.0	m	72.2	' Dp:	780	mm	30.71	"	F'c:	5076	psi	Fu:	270	ksi	Dct D:	3.00	In (76) mm
Span 3:	17.0	m	55.8	'	C1:		0.010								Sp:	600	mm (23.62) in
					C2:		19.69	'							z:	0.625	In (16) mm

< Geometry						>	< BDS										> BTBM	< BDS	> BTBM	
			< Dct.Ded.>		< Full Sec. >																
			< P/T+DL >		< SDL+LL >		P/T			DL Slb+	DL Slb+	P/T	K/Ft->	0.018	0.074	L+I	L+I	L+I	L+I	L+I	L+I
		Slab	Sec.	Sec.	Sec.	Sec.	T/Sl.to	DL Slb+	DL Slb+	Rl+fws+	Rl+fws+	Sec.	Slab	Rail	FWS	HS-20	HS-25	HL-93	HS-20	HS-25	HL-93
Node	Dist.	Dpth.	Mod.	Mod.	Mod.	Mod.	CG Str.	Fn.Prs	Fn.Prs	Fn.Prs	Fn.Prs	Mom.	Mom.	Mom.	Mom.	Pos.M.	Pos.M.	Pos.M.	Neg.M.	Neg.M.	Neg.M.
	Ft	In	In^3	In^3	In^3	In^3	Ft	top - psi	bot - psi	top - psi	bot - psi	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft
			(St)	(Sb)	(St)	(Sb)					(Gm>)	1.25	1.25	1.25	1.50			1.75			1.75
100	0.0	18.11	1291	1291	1291	1291	0.76	711	740	711	740	0	0	0	0	0	0	0	0	0	0
101	5.6	18.11	1291	1276	1291	1291	0.96	543	915	617	841	5	38	2	6	47	59	67	-10	-12	-15
102	11.2	18.11	1284	1262	1291	1291	1.10	408	1059	529	938	10	62	3	10	77	96	112	-19	-24	-30
103	16.7	18.11	1278	1251	1291	1291	1.18	308	1170	457	1021	15	74	3	13	91	114	135	-29	-36	-45
104	22.3	18.18	1286	1257	1301	1301	1.21	271	1202	409	1064	20	72	3	12	96	120	145	-38	-48	-60
105	27.9	18.76	1376	1350	1386	1386	1.18	329	1100	433	996	25	57	2	10	91	114	139	-48	-60	-75
106	33.5	19.95	1565	1546	1566	1566	1.10	460	887	506	841	30	28	1	5	80	100	123	-58	-72	-90
107	39.0	21.73	1862	1855	1860	1860	0.97	610	630	584	656	35	-16	-1	-3	58	73	92	-67	-84	-105
108	44.6	24.12	2277	2292	2291	2291	0.79	744	376	665	455	40	-76	-3	-12	34	42	61	-77	-96	-122
109	50.2	27.12	2846	2882	2895	2895	0.55	829	177	705	301	45	-153	-6	-24	28	35	43	-86	-108	-161
110	55.8	30.71	3619	3675	3713	3713	0.34	797	105	642	260	50	-251	-9	-39	31	39	46	-121	-151	-217
200	0.0	30.71	3619	3675	3713	3713	0.34	797	105	642	260	50	-251	-9	-39	31	39	46	-121	-151	-217
201	7.2	26.17	2657	2688	2697	2697	0.59	875	162	759	278	50	-131	-5	-21	20	25	34	-77	-96	-148
202	14.4	22.65	2018	2019	2019	2019	0.86	797	393	738	452	50	-45	-2	-8	38	48	66	-59	-74	-92
203	21.7	20.13	1595	1580	1595	1595	1.05	661	671	676	656	50	14	0	2	67	84	100	-48	-60	-71
204	28.9	18.61	1355	1330	1364	1364	1.16	517	922	605	834	50	49	2	8	85	106	129	-37	-46	-58
205	36.1	18.11	1277	1249	1291	1291	1.20	446	1035	558	923	50	60	2	10	90	112	138	-33	-41	-45

Posttensioned Concrete Haunched Slab
Prototype S2:

TABLE IV.3

Service Check

K-9700
04-10-98

	Wrk.Str. HS-20				Wrk.Str. HS-25				Srv I & III HL-93				Ld Rtng for HS-20			
	Ft: 0 psi				Ft: -214 psi				Ft: -214 psi				Ft: 0 psi			
	Fc: 2030 psi (0.4F'c)				Fc: 2030 psi (0.4F'c)				Fc: 3046 psi (0.6F'c)				Fc: 2030 psi (0.4F'c)			
	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+
Nd	<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->	
	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi
100	711	740	711	740	711	740	711	740	711	740	711	740	N/A	N/A	N/A	N/A
101	1056	402	528	930	1166	292	506	952	1240	343	506	980	3.22	1.92	6.92	13.34
102	1243	224	350	1117	1421	46	306	1161	1570	106	306	1217	2.10	1.31	2.96	6.12
103	1304	174	189	1289	1516	-38	122	1356	1711	18	122	1440	1.86	1.21	1.71	3.77
104	1295	178	55	1418	1516	-43	-33	1506	1747	-7	-33	1617	1.83	1.20	1.16	2.73
105	1223	206	17	1412	1420	9	-87	1516	1637	33	-87	1646	2.02	1.26	1.04	2.49
106	1119	228	65	1282	1272	75	-46	1393	1448	87	-46	1530	2.49	1.37	1.15	2.70
107	961	279	151	1089	1055	185	42	1198	1178	181	42	1333	3.84	1.74	1.35	3.17
108	841	279	263	857	885	235	163	957	985	199	154	1094	7.76	2.58	1.65	3.92
109	821	185	346	660	850	156	257	749	883	159	171	969	11.42	2.60	1.97	4.83
110	743	159	251	651	768	134	154	748	791	141	81	962	13.77	2.58	1.64	4.53
200	743	159	251	651	768	134	154	748	791	141	81	962	13.77	2.58	1.64	4.53
201	848	189	418	619	871	166	332	705	911	157	233	936	14.28	3.12	2.22	5.13
202	966	224	386	804	1023	167	298	892	1130	139	300	999	5.66	1.98	2.10	4.48
203	1182	150	315	1017	1308	24	225	1107	1429	54	249	1190	2.68	1.30	1.87	3.81
204	1351	88	281	1158	1537	-98	200	1239	1740	-74	197	1344	1.91	1.12	1.87	3.70
205	1390	91	253	1228	1598	-117	176	1305	1840	-102	223	1342	1.77	1.11	1.83	3.63

P/T Concrete Haunched Slab — TABLE IV.3 — Page 3

Prototype S2: — Strength Check

K-9700
04-10-98

Nd	Nr	Ni	N	B1
0.95	0.95	1.05	0.95	0.80

LRFD Strength I Check HL-93

Nd	dp mm (+)	dp mm (-)	c mm (+)	c mm (-)	a mm (+)	a mm (-)	Fps MPa (+)	Fps MPa (-)	phi*Mn N-mm (+)	phi*Mn N-mm (-)	Res. Mom phi* Mn K-Ft (+)	Load. Mom. N.Sum Gm.Q K-Ft (+)		Res. Mom phi* Mn K-Ft (-)	Load. Mom. N.Sum Gm.Q K-Ft (-)	
100	232	228	137	137	116	116	1552	1548	3.4E+08	-3.3E+08	250	0	ok	-245	0	ok
101	293	167	142	129	121	109	1608	1459	4.7E+08	-2.1E+08	347	173	ok	-153	37	ok
102	335	125	144	120	123	102	1636	1359	5.6E+08	-1.3E+08	416	290	ok	-93	54	ok
103	360	100	146	113	124	96	1649	1276	6.2E+08	-8.4E+07	456	352	ok	-62	53	ok
104	369	93	146	110	124	93	1654	1244	6.4E+08	-7.2E+07	472	371	ok	-53	30	ok
105	360	117	146	118	124	100	1649	1335	6.2E+08	-1.1E+08	456	345	ok	-83	-11	ok
106	335	171	144	129	123	110	1636	1467	5.6E+08	-2.2E+08	416	282	ok	-159	-72	ok
107	296	256	142	139	121	118	1610	1577	4.8E+08	-3.9E+08	352	170	ok	-289	-158	ok
108	241	372	138	146	117	124	1562	1655	3.6E+08	-6.5E+08	264	38	ok	-477	-266	ok
109	168	521	129	151	109	128	1460	1709	2.1E+08	-9.8E+08	153	-98	ok	-726	-437	ok
110	104	676	114	154	97	131	1289	1742	9.0E+07	-1.3E+09	66	-228	ok	-989	-666	ok
200	104	676	114	154	97	131	1289	1742	9.0E+07	-1.3E+09	66	-228	ok	-989	-666	ok
201	180	485	131	150	111	127	1481	1699	2.3E+08	-9.0E+08	171	-76	ok	-665	-378	ok
202	262	313	140	143	119	122	1583	1622	4.0E+08	-5.2E+08	298	102	ok	-380	-161	ok
203	320	191	144	132	122	112	1626	1500	5.3E+08	-2.5E+08	392	245	ok	-188	-39	ok
204	354	119	145	118	123	101	1646	1343	6.1E+08	-1.2E+08	446	346	ok	-86	35	ok
205	366	94	146	110	124	94	1652	1250	6.3E+08	-7.5E+07	467	377	ok	-55	72	ok

Posttensioned Concrete Haunched Slab
Prototype S3: 19m-25m-19m

TABLE IV.4

Page 1
Input Data
S3T1D
K-9700
04-10-98

Analysis per 600 mm width of slab

Span 1:	19.0	m	62.3	' Dm:	500	mm	19.69	"	F'c:	35	MPa	Fu:	1860	MPa	Asp:	2.387 In ^2 (1540) mm^2
Span 2:	25.0	m	82.0	' Dp:	870	mm	34.25	"	F'c:	5076	psi	Fu:	270	ksi	Dct D:	3.41 In (87) mm
Span 3:	19.0	m	62.3	'	C1:		0.009								Sp:	600 mm (23.62) in
					C2:		21.33	'							z:	0.750 In (19) mm

< Geometry						>	<				BDS						> BTBM	< BDS	> BTBM	
			< Dct.Ded.>		< Full Sec. >															
			< P/T+DL >		< SDL+LL >		P/T			DL Slb+	DL Slb+	P/T	K/Ft->	0.018	0.076	L+I	L+I	L+I	L+I	L+I	L+I
		Slab	Sec.	Sec.	Sec.	Sec.	T/Sl.to	DL Slb+	DL Slb+	Rl+fws+	Rl+fws+	Sec.	Slab	Rail	FWS	HS-20	HS-25	HL-93	HS-20	HS-25	HL-93
Node	Dist.	Dpth.	Mod.	Mod.	Mod.	Mod.	CG Str.	Fn.Prs	Fn.Prs	Fn.Prs	Fn.Prs	Mom.	Mom.	Mom.	Mom.	Pos.M.	Pos.M.	Pos.M.	Neg.M.	Neg.M.	Neg.M.
	Ft	In	In^3	In^3	In^3	In^3	Ft	top - psi	bot - psi	top - psi	bot - psi	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft
			(St)	(Sb)	(St)	(Sb)					(Gm>)	1.25	1.25	1.25	1.50			1.75			1.75
100	0.0	19.69	1525	1525	1526	1526	0.82	814	814	814	814	0	0	0	0	0	0	0	0	0	0
101	6.2	19.69	1525	1505	1526	1526	1.03	625	1012	704	933	7	50	2	8	54	67	79	-11	-14	-18
102	12.5	19.69	1515	1484	1526	1526	1.19	469	1180	603	1046	13	82	3	14	88	110	131	-22	-28	-36
103	18.7	19.69	1507	1469	1526	1526	1.28	350	1313	499	1164	20	97	4	15	105	131	159	-34	-42	-54
104	24.9	19.80	1522	1482	1543	1543	1.31	303	1353	451	1205	27	93	4	15	110	138	171	-46	-57	-73
105	31.2	20.52	1645	1609	1658	1658	1.28	370	1228	471	1127	34	72	3	11	105	131	164	-57	-71	-91
106	37.4	21.92	1890	1864	1892	1892	1.20	516	980	554	942	40	31	1	5	92	115	145	-68	-85	-109
107	43.6	24.00	2269	2261	2267	2267	1.05	673	700	641	732	47	-29	-1	-5	68	85	109	-79	-99	-127
108	49.9	26.74	2792	2816	2815	2815	0.85	808	429	718	519	54	-111	-4	-17	40	50	72	-90	-113	-148
109	56.1	30.16	3509	3562	3581	3581	0.60	892	213	758	347	60	-218	-8	-32	34	42	52	-106	-132	-204
110	62.3	34.25	4481	4562	4619	4619	0.37	842	141	678	305	67	-352	-12	-51	37	46	55	-147	-184	-279
200	0.0	34.25	4481	4562	4619	4619	0.37	842	141	678	305	67	-352	-12	-51	37	46	55	-147	-184	-279
201	8.2	29.01	3253	3299	3313	3313	0.64	945	191	818	318	67	-184	-7	-28	24	30	40	-93	-116	-185
202	16.4	24.93	2444	2448	2447	2447	0.93	882	427	818	491	67	-62	-2	-11	46	57	77	-68	-85	-111
203	24.6	22.02	1908	1887	1908	1908	1.14	752	723	771	704	67	21	1	2	77	96	118	-54	-68	-83
204	32.8	20.27	1603	1567	1617	1617	1.27	600	1006	696	910	67	69	2	11	97	121	152	-42	-52	-68
205	41.0	19.69	1504	1464	1526	1526	1.31	529	1124	655	998	67	84	3	13	103	129	163	-38	-48	-53

Posttensioned Concrete Haunched Slab
Prototype S3:

TABLE IV.4

Service Check

K-9700
04-10-98

	Wrk.Str. HS-20				Wrk.Str. HS-25				Srv I & III HL-93				Ld Rtng for HS-20			
	Ft: 0 psi				Ft: -214 psi				Ft: -214 psi				Ft: 0 psi			
	Fc: 2030 psi (0.4F'c)				Fc: 2030 psi (0.4F'c)				Fc: 3046 psi (0.6F'c)				Fc: 2030 psi (0.4F'c)			
	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+
Nd	<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->	
	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi
100	814	814	814	814	814	814	814	814	814	814	814	814	N/A	N/A	N/A	N/A
101	1125	512	616	1021	1231	406	594	1043	1325	436	590	1075	3.15	2.21	7.99	12.45
102	1295	354	427	1222	1468	181	382	1267	1633	222	376	1329	2.06	1.51	3.42	5.59
103	1324	339	235	1428	1530	133	169	1494	1750	163	160	1588	1.86	1.41	1.89	3.28
104	1309	347	96	1560	1524	132	7	1649	1781	141	-3	1773	1.84	1.40	1.27	2.33
105	1230	368	60	1538	1419	179	-42	1640	1658	177	-55	1785	2.06	1.49	1.15	2.20
106	1137	359	123	1373	1283	213	15	1481	1474	206	1	1633	2.53	1.61	1.28	2.52
107	1001	372	222	1151	1091	282	117	1256	1218	270	103	1404	3.86	2.03	1.53	3.10
108	889	348	333	904	932	305	237	1000	1025	273	214	1149	7.69	3.04	1.86	3.92
109	871	234	404	701	899	206	316	789	932	208	211	1031	11.30	3.08	2.14	4.76
110	774	209	296	687	798	185	200	783	821	190	98	1030	14.14	3.19	1.77	4.51
200	774	209	296	687	798	185	200	783	821	190	98	1030	14.14	3.19	1.77	4.51
201	905	231	482	654	927	209	398	738	963	202	282	988	13.94	3.66	2.43	5.09
202	1042	267	485	824	1098	211	401	908	1196	189	383	1035	5.42	2.19	2.45	4.62
203	1254	221	429	1046	1375	100	343	1132	1513	110	353	1226	2.61	1.46	2.25	3.88
204	1415	191	388	1218	1594	12	311	1295	1824	7	293	1414	1.86	1.27	2.26	3.63
205	1467	186	353	1300	1670	-17	277	1376	1937	-28	321	1415	1.69	1.23	2.17	3.42

P/T Concrete Haunched Slab
Prototype S3:

TABLE IV.4

Page 3
Strength Check

K-9700
04-10-98

Nd	Nr	Ni	N	B1
0.95	0.95	1.05	0.95	0.80

LRFD Strength I Check HL-93

Nd	dp mm (+)	dp mm (-)	c mm (+)	c mm (-)	a mm (+	a mm (-)	Fps MPa (+)	Fps MPa (-)	phi*Mn N-mm (+)	phi*Mn N-mm (-)	Res. Mom phi* Mn K-Ft (+)	Load. Mom. N.Sum Gm.Q K-Ft (+)		Res. Mom phi* Mn K-Ft (-)	Load. Mom. N.Sum Gm.Q K-Ft (-)	
100	250	250	164	164	139	139	1519	1519	4.2E+08	-4.2E+08	311	0	ok	-311	0	ok
101	314	186	170	154	145	131	1578	1429	5.9E+08	-2.7E+08	433	213	ok	-196	52	ok
102	363	137	174	142	148	121	1611	1320	7.2E+08	-1.6E+08	528	354	ok	-115	76	ok
103	390	110	175	133	149	113	1626	1231	7.9E+08	-1.0E+08	583	429	ok	-75	75	ok
104	399	104	176	130	149	111	1631	1206	8.2E+08	-9.0E+07	601	453	ok	-66	47	ok
105	390	131	175	140	149	119	1626	1302	7.9E+08	-1.4E+08	583	418	ok	-106	-6	ok
106	366	191	174	155	148	132	1612	1438	7.2E+08	-2.8E+08	535	334	ok	-204	-89	ok
107	320	289	171	168	145	143	1582	1558	6.0E+08	-5.2E+08	445	194	ok	-386	-198	ok
108	259	420	165	177	140	150	1529	1641	4.4E+08	-8.7E+08	328	23	ok	-643	-343	ok
109	183	583	153	183	130	156	1423	1697	2.6E+08	-1.3E+09	190	-156	ok	-974	-582	ok
110	113	757	134	187	114	159	1242	1732	1.1E+08	-1.8E+09	79	-334	ok	-1333	-889	ok
200	113	757	134	187	114	159	1242	1732	1.1E+08	-1.8E+09	79	-334	ok	-1333	-889	ok
201	195	542	156	182	132	154	1444	1685	2.9E+08	-1.2E+09	211	-121	ok	-889	-495	ok
202	283	350	167	173	142	147	1552	1603	5.1E+08	-6.8E+08	374	116	ok	-503	-197	ok
203	347	212	173	159	147	135	1601	1470	6.8E+08	-3.3E+08	498	305	ok	-241	-29	ok
204	387	128	175	139	149	118	1624	1292	7.8E+08	-1.4E+08	577	432	ok	-101	66	ok
205	399	101	176	129	149	109	1631	1194	8.2E+08	-8.5E+07	601	472	ok	-62	113	ok

TABLE IV.5

Posttensioned Concrete Haunched Slab
Prototype S4: 21.5m-28m-21.5m

Analysis per 600 mm width of slab

Span 1:	21.5 m	70.5 '	Dm:	550 mm	21.65 "	F'c:	35 MPa	Fu:	1860 MPa	Asp:	2.604 In ^2	(1680) mm^2
Span 2:	28.0 m	91.9 '	Dp:	950 mm	37.40 "	F'c:	5076 psi	Fu:	270 ksi	Dct D:	3.41 In	(87) mm
Span 3:	21.5 m	70.5 '	C1:		0.007					Sp:	600 mm	(23.62) in
Rdwy:	11.0 m	36 '	C2:		24.61 '					z:	0.750 In	(19) mm

< Geometry >							< BDS									> BTBM		< BDS	> BTBM		
			< Dct.Ded.>		< Full Sec. >								K/Ft->	0.018	0.076						
			< P/T+DL >		< SDL+LL >		P/T			DL Slb+	DL Slb+	P/T				L+I	L+I	L+I	L+I	L+I	L+I
		Slab	Sec.	Sec.	Sec.	Sec.	T/Sl.to	DL Slb+	DL Slb+	Rl+fws+	Rl+fws+	Sec.	Slab	Rail	FWS	HS-20	HS-25	HL-93	HS-20	HS-25	HL-93
Node	Dist.	Dpth.	Mod.	Mod.	Mod.	Mod.	CG Str.	Fn.Prs	Fn.Prs	Fn.Prs	Fn.Prs	Mom.	Mom.	Mom.	Mom.	Pos.M.	Pos.M.	Pos.M.	Neg.M.	Neg.M.	Neg.M.
	Ft	In	In^3	In^3	In^3	In^3	Ft	top - psi	bot - psi	top - psi	bot - psi	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft	K-Ft
			(St)	(Sb)	(St)	(Sb)					(Gm>)	1.25	1.25	1.25	1.50			1.75			1.75
100	0.0	21.65	1845	1845	1846	1846	0.90	811	811	811	811	0	0	0	0	0	0	0	0	0	0
101	7.1	21.65	1845	1822	1846	1846	1.15	651	980	736	895	9	71	2	11	62	77	94	-13	-16	-21
102	14.1	21.65	1833	1796	1846	1846	1.34	514	1129	651	992	18	117	4	17	102	127	156	-26	-32	-42
103	21.2	21.65	1823	1779	1846	1846	1.44	403	1253	566	1090	27	138	5	20	122	152	190	-38	-47	-63
104	28.2	21.75	1835	1789	1863	1863	1.48	354	1295	509	1140	36	133	5	19	129	161	204	-50	-63	-85
105	35.3	22.50	1975	1933	1994	1994	1.45	400	1197	514	1083	45	104	4	15	122	153	197	-63	-79	-106
106	42.3	24.00	2263	2232	2267	2267	1.35	516	983	558	941	54	48	2	6	107	134	173	-76	-95	-127
107	49.4	26.23	2712	2701	2709	2709	1.18	650	726	619	757	63	-36	-1	-6	80	100	131	-89	-111	-148
108	56.4	29.21	3336	3362	3360	3360	0.94	763	476	670	569	72	-151	-5	-21	47	59	85	-102	-127	-172
109	63.5	32.94	4191	4249	4271	4271	0.64	827	279	684	422	81	-300	-10	-41	38	48	61	-126	-157	-243
110	70.5	37.40	5351	5441	5507	5507	0.37	736	237	562	411	90	-488	-15	-65	42	53	65	-177	-221	-338
200	0.0	37.40	5351	5441	5507	5507	0.37	736	237	562	411	90	-488	-15	-65	42	53	65	-177	-221	-338
201	9.2	31.73	3898	3949	3964	3964	0.69	872	249	739	382	90	-256	-8	-36	29	36	48	-111	-139	-220
202	18.4	27.32	2937	2940	2939	2939	1.03	848	446	783	511	90	-87	-3	-13	55	69	90	-78	-98	-132
203	27.6	24.17	2300	2276	2301	2301	1.27	762	695	783	674	90	27	1	3	90	112	141	-63	-79	-99
204	36.7	22.28	1938	1897	1955	1955	1.42	656	923	754	825	90	93	3	13	112	140	181	-48	-60	-81
205	45.9	21.65	1819	1774	1846	1846	1.47	598	1030	722	906	90	114	4	15	119	149	193	-47	-59	-64

Posttensioned Concrete Haunched Slab
Prototype S4:

TABLE IV.5

Page 2
Service Check

K-9700
01-26-98

	Wrk.Str. HS-20				Wrk.Str. HS-25				Srv I & III HL-93				Ld Rtng for HS-20			
	Ft: 0 psi				Ft: -214 psi				Ft: -214 psi				Ft: 0 psi			
	Fc: 2030 psi (0.4F'c)				Fc: 2030 psi (0.4F'c)				Fc: 3046 psi (0.6F'c)				Fc: 2030 psi (0.4F'c)			
	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+	DL Slb+ Rl+fws+ Fn.Prs+
Nd	<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->		<--- Pos.Mom.--->		<--- Neg.Mom.--->	
	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi	top - psi	bot - psi
100	811	811	811	811	811	811	811	811	811	811	811	811	N/A	N/A	N/A	N/A
101	1136	495	652	979	1236	395	631	1000	1347	407	626	1032	3.23	2.24	8.84	13.64
102	1311	332	484	1159	1476	167	442	1201	1665	181	432	1266	2.09	1.50	3.91	6.24
103	1356	300	321	1335	1554	102	260	1396	1801	102	238	1500	1.85	1.38	2.31	3.85
104	1338	311	184	1465	1546	103	103	1546	1823	89	71	1688	1.83	1.37	1.57	2.74
105	1251	346	134	1463	1435	162	39	1558	1700	134	4	1721	2.06	1.47	1.35	2.49
106	1126	373	156	1343	1268	231	55	1444	1474	208	21	1613	2.59	1.66	1.39	2.71
107	973	403	226	1150	1062	314	127	1249	1199	293	95	1412	3.98	2.14	1.57	3.24
108	839	400	307	932	881	358	217	1022	974	326	179	1183	8.07	3.37	1.85	4.03
109	792	314	331	775	819	287	243	863	855	285	137	1105	12.48	3.91	1.94	4.56
110	654	319	176	797	677	296	80	893	703	298	-27	1148	15.90	4.45	1.46	4.20
200	654	319	176	797	677	296	80	893	703	298	-27	1148	15.90	4.45	1.46	4.20
201	826	295	402	719	848	273	318	803	884	266	206	1048	14.82	4.38	2.19	4.90
202	1008	286	463	831	1064	230	383	911	1150	217	352	1050	5.54	2.27	2.45	4.75
203	1250	207	453	1004	1367	90	371	1086	1518	86	370	1191	2.67	1.44	2.37	4.11
204	1442	137	460	1119	1614	-35	386	1193	1865	-64	356	1322	1.86	1.20	2.56	4.09
205	1496	132	415	1213	1690	-62	338	1290	1976	-97	389	1323	1.69	1.17	2.35	3.66

P/T Concrete Haunched Slab

Prototype S4:

TABLE IV.5

Page 3

Strength Check

K-9700

01-26-98

Nd	Nr	Ni	N	B1
0.95	0.95	1.05	0.95	0.80

LRFD Strength I Check HL-93

Nd	dp mm (+)	dp mm (-)	c mm (+)	c mm (-)	a mm (+	a mm (-)	Fps MPa (+)	Fps MPa (-)	phi*Mn N-mm (+)	phi*Mn N-mm (-)	Res. Mom phi* Mn K-Ft (+)	Load. Mom. N.Sum Gm.Q K-Ft (+)		Res. Mom phi* Mn K-Ft (-)	Load. Mom. N.Sum Gm.Q K-Ft (-)	
100	274	276	179	179	152	152	1520	1522	5.1E+08	-5.1E+08	374	0	ok	-376	0	ok
101	351	199	186	167	158	142	1583	1423	7.2E+08	-3.1E+08	532	269	ok	-226	78	ok
102	408	142	190	153	162	130	1617	1298	8.9E+08	-1.7E+08	656	449	ok	-123	119	ok
103	439	111	192	141	163	120	1632	1199	9.8E+08	-1.0E+08	723	546	ok	-76	126	ok
104	451	101	193	136	164	116	1638	1159	1.0E+09	-8.5E+07	749	573	ok	-62	92	ok
105	442	130	192	149	163	126	1634	1263	9.9E+08	-1.4E+08	729	531	ok	-104	27	ok
106	411	198	190	167	162	142	1619	1420	9.0E+08	-3.0E+08	663	420	ok	-224	-79	ok
107	360	307	187	182	159	155	1589	1550	7.5E+08	-6.0E+08	552	240	ok	-440	-224	ok
108	287	456	180	193	153	164	1532	1639	5.4E+08	-1.0E+09	399	12	ok	-759	-416	ok
109	195	642	167	200	142	170	1415	1698	3.0E+08	-1.6E+09	218	-229	ok	-1171	-734	ok
110	113	837	142	204	121	173	1205	1733	1.1E+08	-2.2E+09	78	-475	ok	-1612	-1145	ok
200	113	837	142	204	121	173	1205	1733	1.1E+08	-2.2E+09	78	-475	ok	-1612	-1145	ok
201	210	596	169	198	144	169	1440	1687	3.3E+08	-1.4E+09	247	-178	ok	-1069	-624	ok
202	314	380	183	188	156	160	1556	1602	6.2E+08	-8.1E+08	455	131	ok	-595	-238	ok
203	387	227	189	172	161	146	1606	1465	8.3E+08	-3.8E+08	610	379	ok	-279	-20	ok
204	433	133	192	150	163	127	1629	1274	9.6E+08	-1.5E+08	709	540	ok	-110	105	ok
205	448	102	192	137	164	116	1636	1162	1.0E+09	-8.6E+07	743	589	ok	-63	162	ok

IV.10 Transverse Post-tensioning:

Transverse post-tensioning of the slab was evaluated during the study phase for its need and design. A finite element analysis of the superstructure was performed to study the effect of transverse moments. It was discovered that under design truck live load transverse moments were produced in the order of 12% of longitudinal moments near midspan and 20% near piers.

The differential shrinkage phenomenon that occurs between the placement of concrete in piers (especially wall type piers) and superstructure slab can result in tensile stresses greater than modulus of rupture in the transverse direction near pier supports.

For these two primary structural considerations and for the purposes of confinement and distribution of longitudinal prestress forces, transverse post-tensioning is highly recommended. The required transverse post-tensioning is greater near the piers than near midspan regions.

The stress analysis and design calculation for transverse post-tensioning requirement is included in Part II, "Calculations."

V. PROTOTYPE DESIGN

V.1 Units:

Key design parameters such as span lengths, roadway widths, slab depths, P/T tendon spacing, etc. are chosen in hard metric units. Plan standards to be produced in Phase II will be developed using metric units. Most calculations in study phase were performed and presented in US customary units for ease in familiarity.

V.2 Span Lengths:

The post-tensioned concrete haunched slab standards are intended to provide effective slab span solution from the mid 60' range (upper limits of conventional reinforced concrete haunched slabs) to the low 90' range (precast/steel beam span range). Four (4) span arrangements were chosen to develop the plan standards:

Span No.1	15 m – 20 m – 15 m	(49.2'-65.6'-49.2')
Span No.2	17 m – 22 m – 17 m	(55.8'-72.2'-55.8')
Span No.3	19 m – 25 m – 19 m	(62.3'-82.0'-62.3')
Span No.4	21.5 m – 28 m – 21.5 m	(70.5'-91.9'-70.5')

The average interior span / end span ratio is about 1.31. The ratio chosen optimizes the design by yielding balanced design moments for end span and interior span.

V.3 Roadway Widths:

Five (5) roadway widths are chosen for the standards. The design lane width is 3.7 m (12'). All standards will be developed for two (2) traffic lanes with varying shoulder widths, from 0.6 m (2') to 3.0 m (10') depending on class of route and Average Daily Traffic counts (ADT). The five design roadway widths are:

8.6 m (28')
9.8 m (32')
11.0 m (36')
12.2 m (40')
13.4 m (44')

The 8.6 m & 9.8 m roadways are intended primarily for use by the Bureau of Local Projects on federally funded low volume local county and city roads. The 11.0 m, 12.2 m & 13.4 m roadways are intended for use on State Highways by Bureau of Design.

The slab will be sloped in the transverse direction from the crown at 1.60% slope towards the sides for drainage.

V.4 Traffic Barrier:

The traffic rail used in the design and plans is based on 300 mm wide Kansas Corral Rail (685 mm or 815 mm high) without curb. The assumed maximum dead load from the traffic barrier is 4.01 kN/m (0.275 K/Ft) per one side of barrier.

V.5 Future Wearing Surfacing:

The superimposed dead load includes provision for 1.2 kPa (25 psf) uniformly distributed load for future wearing surface.

V.6 Concrete:

The concrete strength assumed for the design is 35 MPa (5076 psi). Higher strength concrete does not appear to result in any significant gains in the performance of the bridge. Achieving higher early strengths to minimize shrinkage cracks at jacking is desirable. Detailed concrete specifications and additive mixes will be discussed more in detail in Phase II.

V.7 Longitudinal Post-tensioning:

Strands:

Two (2) post-tensioning systems are selected to be most efficient for this application – 13 mm (0.5") diameter & 15 mm (0.6") diameter Low-Lax, 1860 MPa (270 K) strands. Option will be given to the contractor to bid either 0.5" or 0.6" strands to allow competitive bidding by post-tension suppliers. The prototypes were analyzed for both systems.

P/T Ducts:

Plastic as well as Galvanized Semi-rigid Steel ducts were considered in the design. Light weight plastic ducts provide built-in rust protection and less frictional losses. However prior experience indicates instability and splice failures during installation and concrete placement using plastic ducts. Even though these problems can be overcome, Semi-rigid Galvanized Steel Duct is preferred due to its proven track record.

Tendon Layout:

After numerous trials, 600 mm (1.97') was determined to be the most feasible nominal P/T spacing. The 600 mm spacing also facilitates closer spacing near slab edges – for edge beam effect, fitting various roadway widths in best possible manner. The concrete cover for ducts assumed at low points (bottom of slab) is a minimum of 40 mm (1.5") and at high points (top of slab) 50 mm (2"). The CG-Strands will conform to a parabolic profile starting at CG-Slab at centerline abutment locations, following the specified low points near midspan and high points at pier as shown in Fig. V.1 and V.2.

Edge Beam Effect:

The slab edges are analyzed for "edge beam" effect using LRFD specifications. The LRFD specifications for edge beam analysis is better defined and less ambiguous than the current LFD specifications. The edge beam requirement indicates need for closer P/T tendon spacing near slab edges to provide required resistance for loads near slab edges. Fig. V.1 shows transverse spacing of longitudinal P/T tendons for the five roadway widths for all span arrangements.

Grouting:

The post-tensioned design is based on a bonded system (grouted). Special provisions will be prepared during Phase II of this project for the grout material and application procedure.

End Anchors:

Post-tension suppliers typically design the end anchors for the maximum jacking forces. The design slab depths and P/T tendon spacing and profile have taken into consideration the space requirements to accommodate end anchors expected to be furnished by most prevailing post-tension systems.

Longitudinal post-tensioning details for the four span arrangements are shown in Fig. V.2.

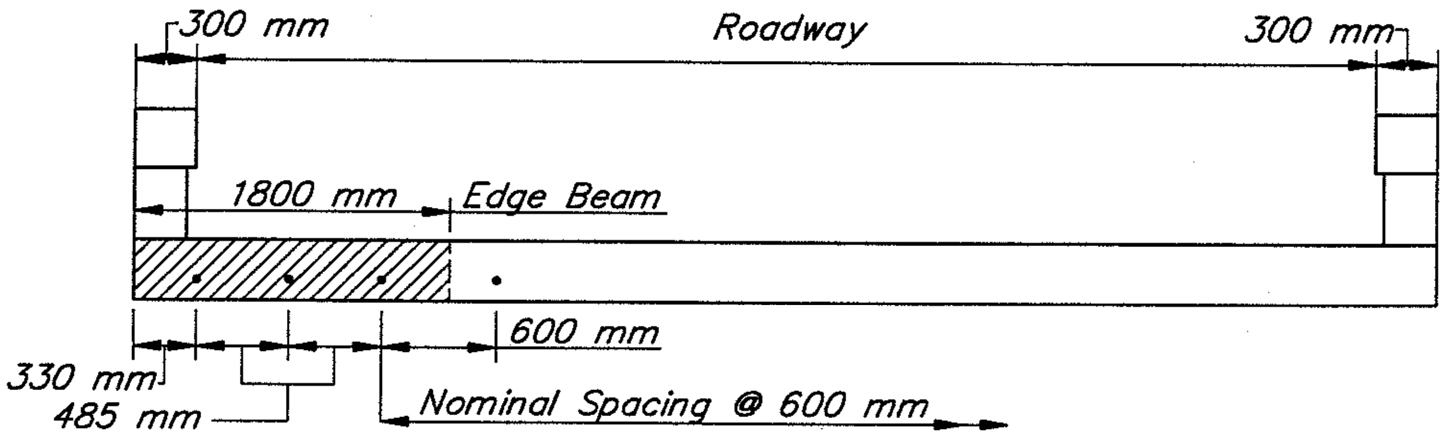
V.8 Transverse Post-tensioning:

Transverse post-tensioning will be provided by means of 4-15 mm (0.6") diameter strand system at spacings as shown in Fig. V.3. The closer spacing of transverse P/T tendon near the piers is to account for stresses caused by differential shrinkage between pier and superstructure slab and the higher percentage of transverse design moments near pier locations indicated by finite element analysis.

The transverse tendons will be placed along the centroid of the slab to avoid eccentricity in transverse post-tensioning. The duct for the transverse tendons can be a rectangular or elliptical semi-rigid galvanized metal or plastic type since the transverse post-tensioning is only secondary in nature. The duct will be grouted after stressing.

V.9 Design Calculations:

All design and analysis calculations for the design of prototypes including geometry, dead loads, live loads, load distribution etc. are included in Part II, "Calculations."



SPACING OF LONGITUDINAL P/T TENDONS

FIG. V.1

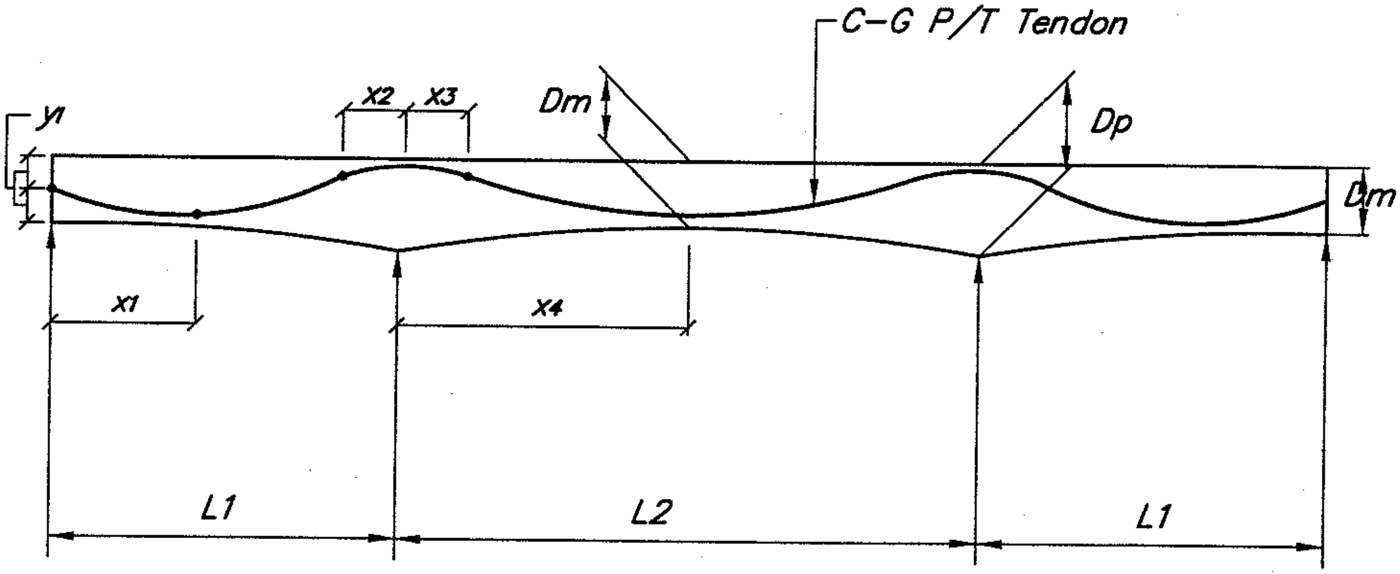
$y_1 = Dm/2$

$X1 = 40\%$ of $L1$

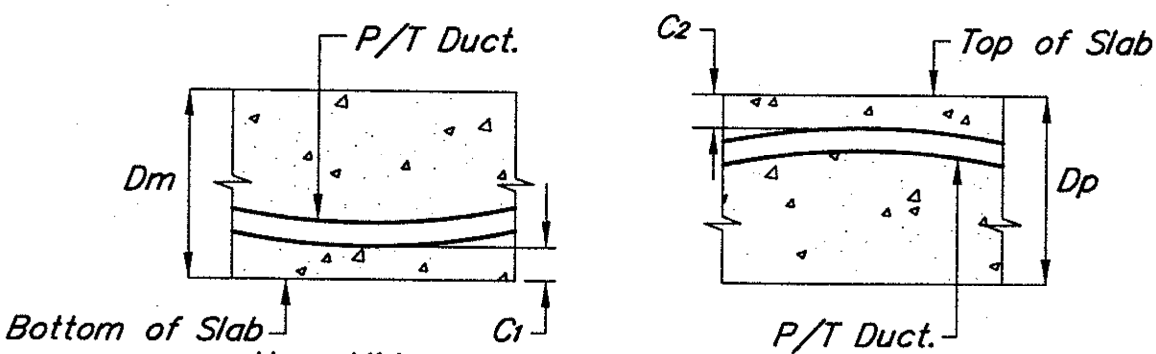
$X2 = 5\%$ of $L1$

$X3 = 5\%$ of $L2$

$X4 = 50\%$ of $L2$



Elevation



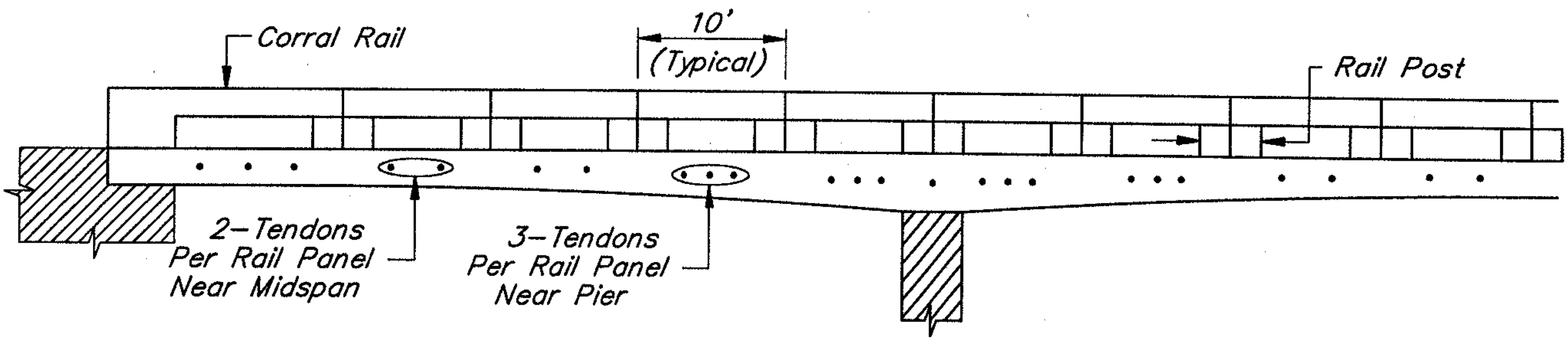
Near Midspan

@ Pier

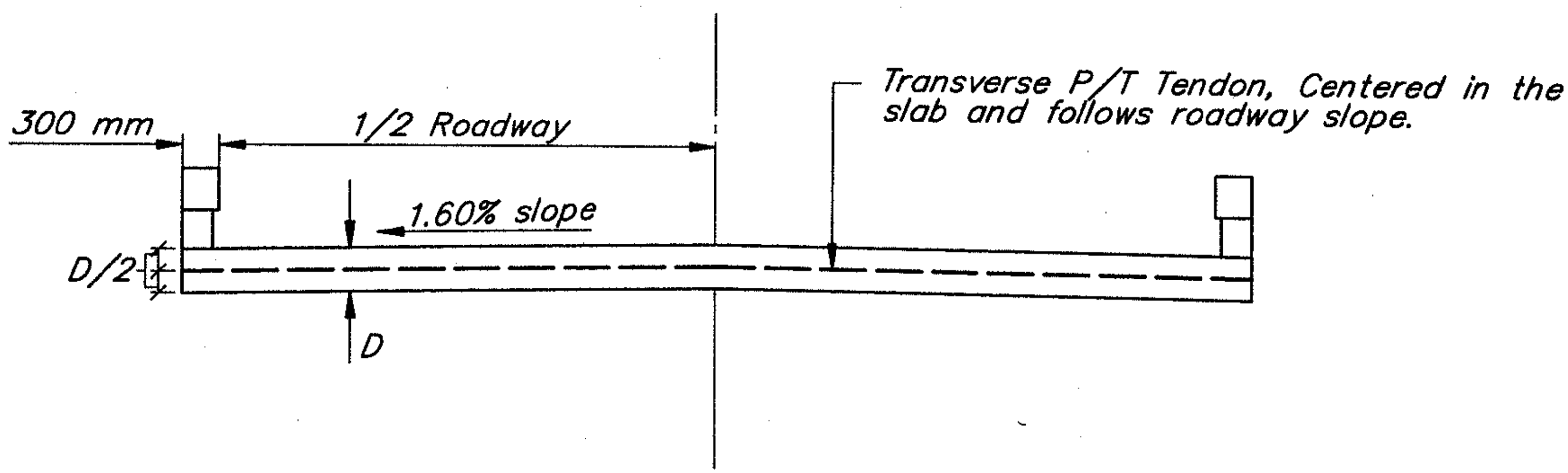
SPAN #	Dm mm	Dp mm	C_1 mm	C_2 mm	Spans m
No. 1	430	740	50	50	15–20–15
No. 2	460	780	40	50	17–22–17
No. 3	500	870	40	50	19–25–19
No. 4	550	950	40	50	21.5–28–21.5

Design Data

FIG. V.2



SPACING OF TRANSVERSE P/T TENDONS



SECTION

FIG. V.3

V.10 Mild Steel Reinforcement:

The purpose for placing mild steel reinforcement in the slab is to provide for temperature & shrinkage stresses. Additional mild steel may be required to facilitate supporting P/T ducts as well. This item will be presented in more detail during Phase II. Clearances for mild steel placement will be consistent with current practice for reinforced concrete slab standards, 65mm (2.5") at the top and 40mm (1.5") at the bottom.

VI. PRACTICAL CONSIDERATIONS

VI.1 Field Trip & Meetings:

The design group, including representatives from KDOT Bureau of Design, Bureau of Local Projects, Kansas State University, Sedgwick County and the Consultant visited three (3) post-tensioned slab sites to examine the condition of post-tensioned haunched slab bridges in service since 1989. A slide show was also presented to the group showing various stages of the construction.

A partnering meeting was organized including Contractors and Suppliers some of whom already had prior experience in construction of post-tensioned concrete bridges.

The purpose of these efforts was to receive valuable input from the construction industry to avoid potential pitfalls during fabrication, construction and inspection. Additional meetings are scheduled throughout the project, intended to achieve a very practical design.

VI.2 Lessons learned in the past:

- Minor hairline cracks in the longitudinal direction measuring about 6' wide at about 12' spacing was observed over the "wall" type piers in the 79'-102'-79' PCHS spans constructed in 1996. This is most likely due to differential shrinkage between pier and slab concrete as was confirmed by calculations (see Part II, "Calculations"). Traditionally, transverse P/T has been spaced uniformly over the entire span. As a result of this discovery, transverse P/T will be placed more over the piers than in the midspan area. This consideration has been addressed in Section V.

- Spacer frames at a minimum 1500mm interval rather than the customary 1/10th of the span will be required to assure stability of ducts during concrete placement.

- Mild steel reinforcement needs to be spaced in such a manner to facilitate providing support to P/T ducts and allow "walking" on the top reinforcement mat by construction workers – a unique problem of 'too little' mild steel!

- Higher early strength concrete and low water mix design (using additives such as superplasticizer) is recommended to minimize the curing time to achieve the required strength of concrete at jacking. Stressing the concrete as early as possible minimizes shrinkage cracks at the time of jacking.

- Use of plastic ducts for longitudinal tendons is to be avoided. Plastic ducts have problems maintaining correct profiles during hot days. Shifting of ducts and probable failure of duct splices are likely during the concrete placement. Until the suppliers of P/T develop acceptable improvements, it is best to avoid plastic ducts for longitudinal tendons. However, single piece plastic ducts with pre-installed strands are acceptable for transverse P/T.

VI.3 Simplicity and Duplication:

In order to make the PCHS a successful bridge solution, it is essential to design details as simple and practical as feasible with emphasis on duplication. The spacer frame details, P/T tendon spacing, end anchor blockouts and mild steel arrangement are examples of items where this concept will be very effective in minimizing cost and time. A deliberate attempt has been made throughout the study phase to achieve this goal in designing the prototypes.

VII. BASE MODEL VARIATION

VII.1 Frame action:

Even though the Base Model assumes pinned conditions at abutments, in reality the slab is monolithic with abutment beam. The top of the piers will be designed to be a pin-type connection with the slab; however, the relative stiffness of the pier may affect P/T stresses as the piers offer restraining forces in the longitudinal direction. The Base Model is expected to produce P/T requirements on the conservative side. Therefore, a check of the superstructure slab under the 'frame' action as described above is required especially to check top of slab stresses at the abutments.

A frame model of commonly encountered abutment and pier designs is shown in Fig VII.1. Analysis of the Base Model, modified to study the effect of the frame action, is carried out for all prototype designs.

From the results of the analysis, the net top and bottom slab stresses are found to be within allowable ranges and did not appear to govern the design.

VII.2 Construction Tolerances:

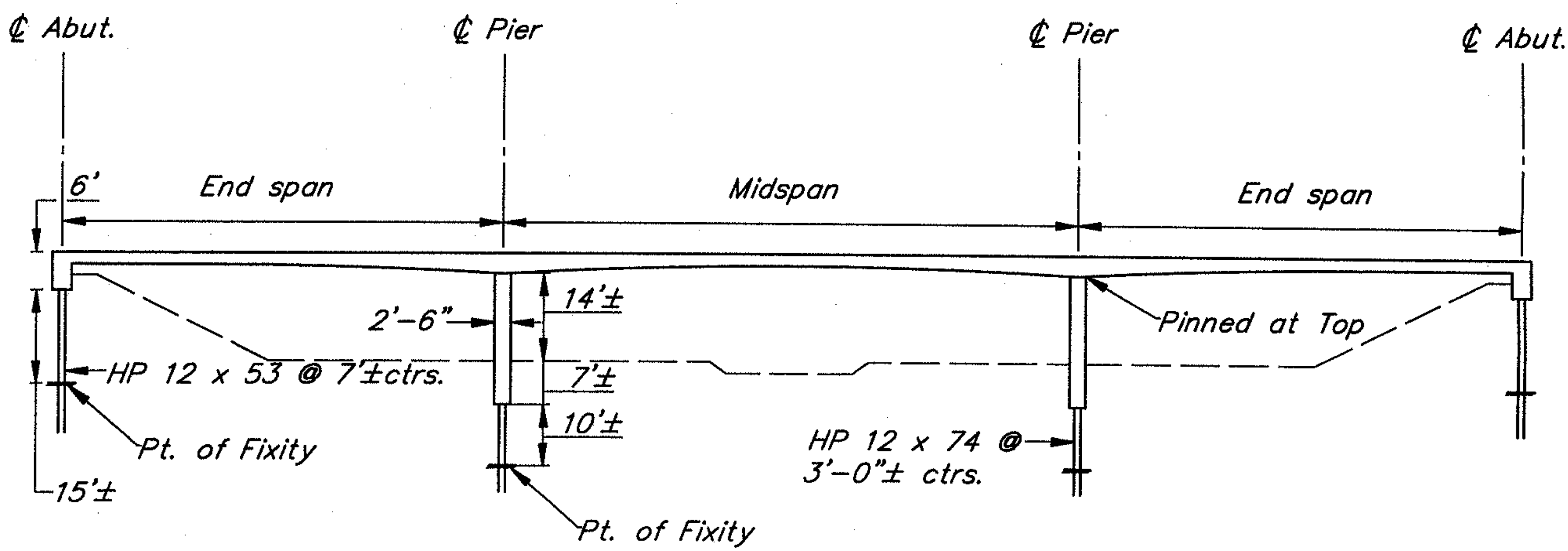
The placement of longitudinal P/T ducts and the forming of superstructure slab depth are critical items requiring a good degree of accuracy during construction. However anticipating probable deviations in the field, the Base Model is analyzed for several "scenarios" in slab depth and P/T tendon profile variation as shown below:

- Decrease in slab depth of about 0.5" or 13 mm (Tol.1)
- Increase in slab depth of about 1.0" or 25 mm (Tol.2)
- Decrease in P/T eccentricity of about 0.5" at critical points (Tol.3)
- Increase in P/T eccentricity of about 0.5" at critical points (Tol.4)
- Combination of decrease in slab depth and increase in P/T eccentricity (Tol. 5)
- Combination of increase in slab depth and decrease in P/T eccentricity (Tol.6)

The base model is modified for each of these scenarios to check the variation of flexural stresses. The increased tensile stresses were found to be within maximum allowable tensile stress for HS-25 or HL-93 load categories, 3 x Sqrt (F'c).

Although the design appears to be 'flexible' in accommodating such variations in the design parameters, the designers, constructors and inspectors are required to adopt a high degree of accuracy in controlling P/T tendons profile and slab depths.

VII.3 Future Deck Overlays:



ELEVATION

FRAME MODEL

FIG. VII.1

VII.3 Future Deck Overlays:

The Base Model was modified for yet another potential future condition. 1" (25 mm) may be milled and an 1.5" (40 mm) silica-fume overlay may be placed in the future as a maintenance measure. This condition increases dead load by 0.5" (13mm) and reduces the effective section by 1" (25 mm). The superstructure is analyzed for all loads using the reduced effective section.

The results of the analysis shows no significant increases in flexural stresses.

VII.4 Buoyancy:

Ordinarily reinforced concrete structures have sufficient dead load and reinforcing to overcome buoyant forces due to high water conditions. However post-tensioned slabs are somewhat light for the given span lengths and the uplift force due to buoyancy in combination with P/T forces is a concern for stresses in the top of slab near mid-span and bottom of slab near pier support.

The prototypes were checked for the case when the high water is just at the top of the slab. For this condition the slab was checked for loads including slab dead load, rail dead load, buoyant pressure, P/T forces and live load with reduced impact (impact reduced by 30% to account for slowing of vehicles during high water condition).

The stresses for the condition without live load were found to be within 3 x Sqrt (F'c). The stresses at the top of slab near mid-span of end spans were found to be slightly more than 6 x Sqrt (F'c) when live loads on remote spans cause additional uplift forces, a combination that may be considered as an 'extreme event.'

A summary of the results of the analysis for the Base Model variations is shown in table VII.1 through VII.4.

Table VII.1

Base Model Stress Variations

Prototype 1: 15m-20m-15m

Item	@ Abut. (Top) psi	@0.4 Ext. Span (Bot) psi	@0.4 Ext. Span (Top) psi	@0.5 Ext. Span (Top) psi	@Pier (Top) psi	@Pier (Bot) psi	@0.5 Int. Span (Bot) psi	@0.5 Int. Span (Top) psi
Final (DL+P/T+LL) (Base Model)	**679**	**-58**	**-73**	**-128**	**147**	**90**	**-95**	**144**
Base Run (BDS)	679	-76	-72	-123	155	90	-137	145
Frame Action	327	61	----	-2	167	----	-58	----
(Change)	*(-352)*	*(137)*		*(121)*	*(12)*		*(79)*	
Tol.5 (D-1/2",P+1/2")	759	-35	----	-204	221	----	-121	----
(Change)	*(80)*	*(41)*		*(-81)*	*(66)*		*(16)*	
Tol.7 (D-1/2",P-1/2")	764	-203	----	-67	93	----	-164	----
(Change)	*(85)*	*(-127)*		*(56)*	*(-62)*		*(-27)*	
Max. Variation	*(-352)*	*(-127)*	----	*(-81)*	*(-62)*	----	*(-27)*	----
Maximum Final (Fr.Act. & Tolerance)	**327**	**-185**	----	**-209**	**85**	----	**-122**	----
Future Mill & Overlay	----	-141	----	----	198	----	-113	----
(Change)		*(-65)*			*(43)*		*(24)*	
Maximum Final (Future Maintenance)	----	**-192**	----	----	**190**	----	**-71**	----
Buoyancy DL only	----	----	56	180		-194		180
(Change)			*(128)*	*(303)*		*(-284)*		*(35)*
Maximum Final (Buoyancy +DL)			**55**	**175**	----	**-194**	----	**179**
Buoyancy DL+LL			-379	-323	----	-311	----	-155
(Change)			*(-307)*	*(-200)*		*(-401)*		*(-300)*
Maximum Final (Buoyancy +DL+LL)	----	----	**-380**	**-328**	----	**-311**	----	**-156**

Maximum Allowable Tension : 6 x Sqrt (F'c) = **-427 psi**

KDOT Maximum : 3 x Sqrt (F'c) = **-214 psi**

Notation: - Tension

+ Compression

Live Load: Maximum of HS-25 or HL-93

Table VII.2

Base Model Stress Variations

Prototype 2: 17m-22m-17m

Item	**@ Abut.** (Top) psi	**@0.4 Ext. Span** (Bot) psi	**@0.4 Ext. Span** (Top) psi	**@0.5 Ext. Span** (Top) psi	**@Pier** (Top) psi	**@Pier** (Bot) psi	**@0.5 Int. Span** (Bot) psi	**@0.5 Int. Span** (Top) psi
Final (DL+P/T+LL) (Base Model)	**711**	**-43**	**-33**	**-87**	**81**	**134**	**-117**	**176**
Base Run (BDS)	711	-69	-32	-86	139	133	-152	174
Frame Action	370	68	----	25	151	----	-74	----
(Change)	*(-341)*	*(137)*		*(111)*	*(12)*		*(78)*	
Tol.5 (D-1/2",P+1/2")	789	-44	----	-148	157	----	-181	----
(Change)	*(78)*	*(25)*		*(-62)*	*(18)*		*(-29)*	
Tol.7 (D-1/2",P-1/2")	793	-190	----	-30	77	----	-178	----
(Change)	*(82)*	*(-121)*		*(56)*	*(-62)*		*(-26)*	
Max. Variation	*(-341)*	*(-121)*	----	*(-62)*	*(-62)*	----	*(-29)*	----
Maximum Final (Fr.Act. & Tolerance)	**370**	**-164**	----	**-149**	**19**	----	**-146**	----
Future Mill & Overlay	----	-120	----	----	186	----	-127	----
(Change)		*(-51)*			*(47)*		*(25)*	
Maximum Final (Future Maintenance)	----	**-94**	----	----	**128**	----	**-92**	----
Buoyancy DL only	----	----	-12	124		-213		219
(Change)			*(20)*	*(210)*		*(-346)*		*(45)*
Maximum Final (Buoyancy +DL)			**-13**	**123**	----	**-212**	----	**221**
Buoyancy DL+LL			-430	-364	----	-334	----	-144
(Change)			*(-398)*	*(-278)*		*(-467)*		*(-318)*
Maximum Final (Buoyancy +DL+LL)	----	----	**-431**	**-365**	----	**-333**	----	**-142**

Maximum Allowable Tension : 6 x Sqrt (F'c) = **-427** **psi**

KDOT Maximum : 3 x Sqrt (F'c) = **-214** **psi**

Notation: - Tension

+ Compression

Live Load: Maximum of HS-25 or HL-93

Table VII.3

Base Model Stress Variations

Prototype 3: 19m-25m-19m

Item	**@ Abut.** (Top) psi	**@0.4 Ext. Span** (Bot) psi	**@0.4 Ext. Span** (Top) psi	**@0.5 Ext. Span** (Top) psi	**@Pier** (Top) psi	**@Pier** (Bot) psi	**@0.5 Int. Span** (Bot) psi	**@0.5 Int. Span** (Top) psi
Final (DL+P/T+LL) (Base Model)	**814**	**132**	**-3**	**-55**	**98**	**185**	**-28**	**277**
Base Run (BDS)	814	99	7	-37	180	186	60	273
Frame Action	533	212	----	73	190	----	15	----
(Change)	*(-281)*	*(113)*		*(110)*	*(10)*		*(75)*	
Tol.5 (D-1/2",P+1/2")	895	161	----	-121	258	----	-22	----
(Change)	*(81)*	*(62)*		*(-84)*	*(78)*		*(38)*	
Tol.7 (D-1/2",P-1/2")	900	-18	----	23	127	----	-77	----
(Change)	*(86)*	*(-117)*		*(60)*	*(-53)*		*(-17)*	
Max. Variation	*(-281)*	*(-117)*	----	*(-84)*	*(-53)*	----	*(-17)*	----
Maximum Final (Fr.Act. & Tolerance)	**533**	**15**	----	**-139**	**45**	----	**-45**	----
Future Mill & Overlay	----	63	----	----	232	----	-18	----
(Change)		*(-36)*			*(52)*		*(-78)*	
Maximum Final (Future Maintenance)	----	**96**	----	----	**150**	----	**-106**	----
Buoyancy DL only	----	----	-15	148		-226		251
(Change)			*(-22)*	*(185)*		*(-412)*		*(-22)*
Maximum Final (Buoyancy +DL)			**-25**	**130**	----	**-227**	----	**255**
Buoyancy DL+LL			-431	-331	----	-341	----	-109
(Change)			*(-438)*	*(-294)*		*(-527)*		*(-382)*
Maximum Final (Buoyancy +DL+LL)	----	----	**-434**	**-349**	----	**-342**	----	**-105**

Maximum Allowable Tension : 6 x Sqrt (F'c) = **-427** **psi**

KDOT Maximum : 3 x Sqrt (F'c) = **-214** **psi**

Notation: - Tension

+ Compression

Live Load: Maximum of HS-25 or HL-93

Table VII.4

Base Model Stress Variations

Prototype 4: 21.5m-28m-21.5m

Item	**@ Abut.** (Top) psi	**@0.4 Ext. Span** (Bot) psi	**@0.4 Ext. Span** (Top) psi	**@0.5 Ext. Span** (Top) psi	**@Pier** (Top) psi	**@Pier** (Bot) psi	**@0.5 Int. Span** (Bot) psi	**@0.5 Int. Span** (Top) psi
Final (DL+P/T+LL) (Base Model)	**811**	**89**	**71**	**4**	**-27**	**296**	**-62**	**338**
Base Run (BDS)	811	68	101	37	65	296	-112	339
Frame Action	556	174	----	125	76	----	-51	----
(Change)	*(-255)*	*(106)*		*(88)*	*(11)*		*(61)*	
Tol.5 (D-1/2",P+1/2")	885	114	----	-29	109	----	-106	----
(Change)	*(74)*	*(46)*		*(-66)*	*(44)*		*(6)*	
Tol.7 (D-1/2",P-1/2")	888	-35	----	92	17	----	-126	----
(Change)	*(77)*	*(-103)*		*(55)*	*(-48)*		*(-15)*	
Max.Variation	*(-255)*	*(-103)*	----	*(-66)*	*(-48)*	----	*(-15)*	----
Maximum Final (Fr.Act. & Tolerance)	**556**	**-14**	----	**-62**	**-75**	----	**-77**	----
Future Mill & Overlay	----	44	----	----	115	----	-71	----
(Change)		*(-24)*			*(50)*		*(41)*	
Maximum Final (Future Maintenance)	----	**65**	----	----	**23**	----	**-21**	----
Buoyancy DL only	----	----	-30	127		-193		281
(Change)			*(--131)*	*(90)*		*(-489)*		*(-58)*
Maximum Final (Buoyancy +DL)			**-60**	**94**	----	**-193**	----	**280**
Buoyancy DL+LL			-416	-321	----	-303	----	-85
(Change)			*(-517)*	*(-358)*		*(-599)*		*(-424)*
Maximum Final (Buoyancy +DL+LL)	----	----	**-446**	**-354**	----	**-303**	----	**-86**

Maximum Allowable Tension : 6 x Sqrt (F'c) = **-427 psi**

KDOT Maximum : 3 x Sqrt (F'c) = **-214 psi**

Notation: - Tension
+ Compression

Live Load: Maximum of HS-25 or HL-93

VIII. SUBSTRUCTURE DESIGN

VIII.1 Special Consideration:

The design of abutments and piers in a continuous post-tensioned concrete slab bridge should consider the instantaneous elastic shortening that occurs upon applying longitudinal prestress force. Since the superstructure is tied to the substructure, the substructure in a post-tensioned concrete haunched slab bridge needs to be designed for the instantaneous elastic shortening due to axial component of prestress, and gradual thermal movement.

VIII.2 Abutment Design:

The prototype design calls for an integral abutment beam on single row of piles similar to RCHS design. The pile bent type abutment on single row of piles offers excellent flexibility to allow movement at the abutment as well as providing adequate resistance to loads. The elastic shortening at the abutment locations can be reasonably estimated using the following formula:

D(es-A)= (Pi x Lt)/(A x Ei), where

D(es-A))= Elastic Shortening at the abutments due to prestress

Pi = Total Prestress Force = 0.9xPjack
Lt = Total out-to-out bridge length
A = Cross Section of slab = W x Davg
W = Out-to-out width of slab
Davg = Average slab depth = Dmin + 1/3 of Haunch
Ei = Modulus of Concrete at the time of Initial Prestress

The abutment piles can generally be assumed to be fixed about 15' (4.6m) below the abutment beam. The top of piles can be assumed to be pinned for the purpose of this analysis as is normally done for integral abutment on single row of piles (3).

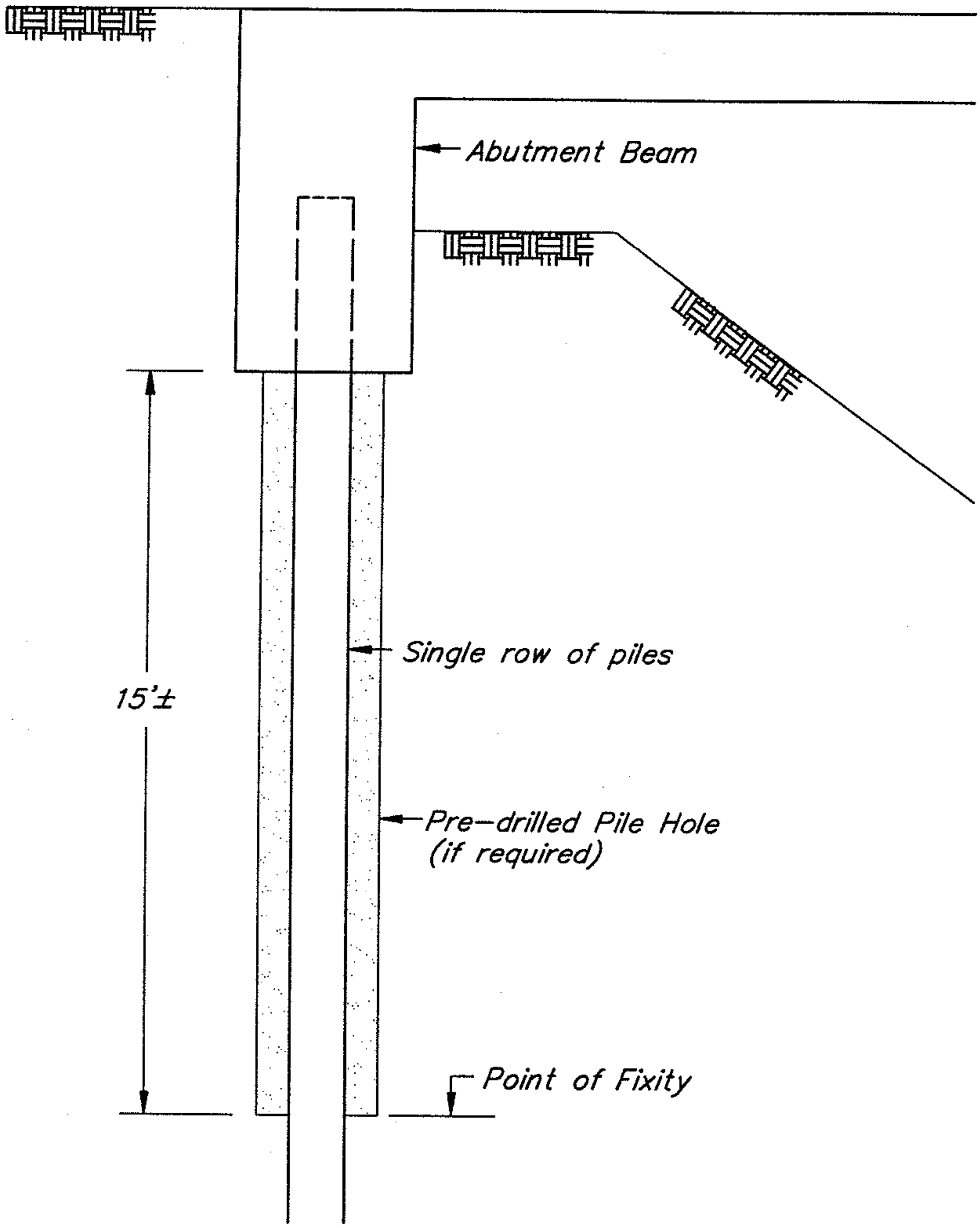
The elastic shortening movement at the abutment must be added to thermal movement in analyzing the abutment piles for various load combinations.

In the event stiff soil conditions are encountered at the site, abutment piles may need to be placed in pre-drilled pile holes of sufficient depth and backfilled with granular material to allow the required top of pile movement without exceeding allowable pile stresses.

A schematic of abutment design is shown in Fig. VIII.1.

VIII.3 Pier Design:

Three types of piers are normally used in conjunction with slab bridges. Type 1 is pile bent type with single row of piles encased in concrete wall. Type 2 is a pedestal type



ABUTMENT DESIGN

FIG. VIII.1

pier with column and footing; The footing may be placed on solid rock/shale (Type 2A) or pile group (Type 2B) depending on soil conditions. Type 3 is a drilled-shaft type pier with columns supported on drilled shafts.

Assuming the point of 'zero' movement at the center of bridge, the thermal movement as well as elastic shortening are not significant due to the close proximity of the pier from the point of 'zero' movement (unlike the abutments). However, calculations must be done to check the stresses in the piles and column due to the total movement at the top of the pier. Piers of these types, unless very short and socketted in solid rock, are generally flexible enough to allow this movement.

D(es-P) = (Pi x Lp)/(A x Ei), where

D(es-P) = Elastic Shortening at the pier

Lp = Distance between piers or the length of interior span

As in the case of abutments, the elastic shortening must be added to thermal movement in analyzing the pier for various load combinations.

The top of the pier must be designed to achieve a pinned condition at the top. The bottom of piles typically achieve fixity as shown in Fig. VIII.2.

Detailed substructure design and plans will be completed in Phase II.

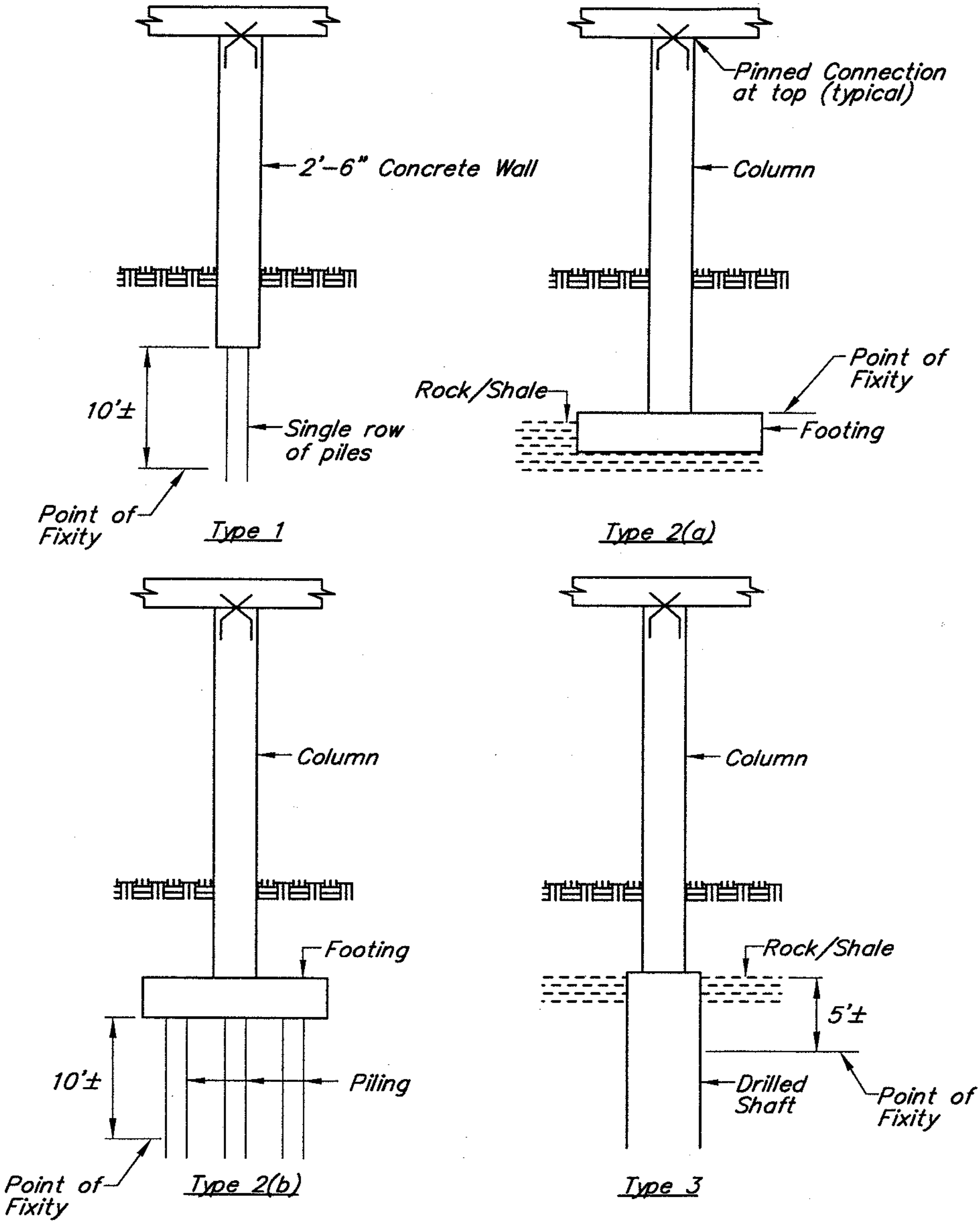

2'-6" Concrete Wall
10'±
Single row of piles
Point of Fixity
Type 1
Pinned Connection at top (typical)
Column
Point of Fixity
Rock/Shale
Footing
Type 2(a)
Column
Footing
10'±
Piling
Point of Fixity
Type 2(b)
Column
Rock/Shale
5'±
Drilled Shaft
Point of Fixity
Type 3

FIG. VIII.2

IX. GENERAL DISCUSSION

IX.1 Life-Cycle Cost:

The comparison of various bridge alternatives must evaluate a variety of long-term costs and the associated values over the entire life of a given structure, not just the initial construction cost.

For example post-tensioned concrete haunched slab bridges offer many indirect cost savings:

- In many instances, the profile grade of the approach roadway needs to be raised to achieve the required vertical clearance and horizontal opening below the superstructure. In the case of shallow-depth PCHS, this requirement is minimized; saving construction cost and right-of-way requirements, a distinct advantage in urban areas.

- The superstructure slab is entirely in a compressive state under all dead and prestress loads. Even under design live loads the tensile stresses in concrete are only about one half of allowable tensile stress, well below modulus of rupture. In effect, the superstructure is "crack-free" and more impervious to moisture penetration than a conventionally reinforced concrete deck. This makes PCHS more durable with a better performing deck.

IX.2 Initial Cost:

Estimated superstructure cost is shown in Table IX.1 for the prototypes, based on the limited historic data. The future costs of PCHS will depend on the extent of its application. With increasing application and standardization, prices should be competitive with other types of bridges.

IX.3 Skewes:

PCHS bridges can be skewed up to 30° without significant difficulties. The skewed PCHS design and details are beyond the scope of this project. However, as in the case of RCHS, skews can be accommodated with PCHS. Layout of transverse P/T tendons to avoid rail posts would be critical due to the skew, but can be done. Other design parameters such as slab depths and P/T forces would be the same as for non-skewed design.

A 30° skewed 62'-81'-62', 28' roadway PCHS span bridge was built in Sedgwick County in 1993.

TABLE IX.1

• ESTIMATED CONSTRUCTION COST

PROTOTYPE SPAN	SPANS	PROJECTED UNIT COST	ESTIMATED BRIDGE COST				
			ROADWAYS				
			8.6m	9.8m	11.0m	12.2m	13.4m
1	15m-20m-15m	$530/Sq.M.	$228,000	$260,000	$292,000	$323,000	$355,000
2	17m-22m-17m	$580/Sq.M.	$279,000	$318,000	$357,000	$396,000	$435,000
3	19m-25m-19m	$635/Sq.M.	$344,000	$392,000	$440,000	$488,000	$536,000
4	21.5m-28m-21.5m	$700/Sq.M.	$427,000	$427,000	$547,000	$606,000	$666,000

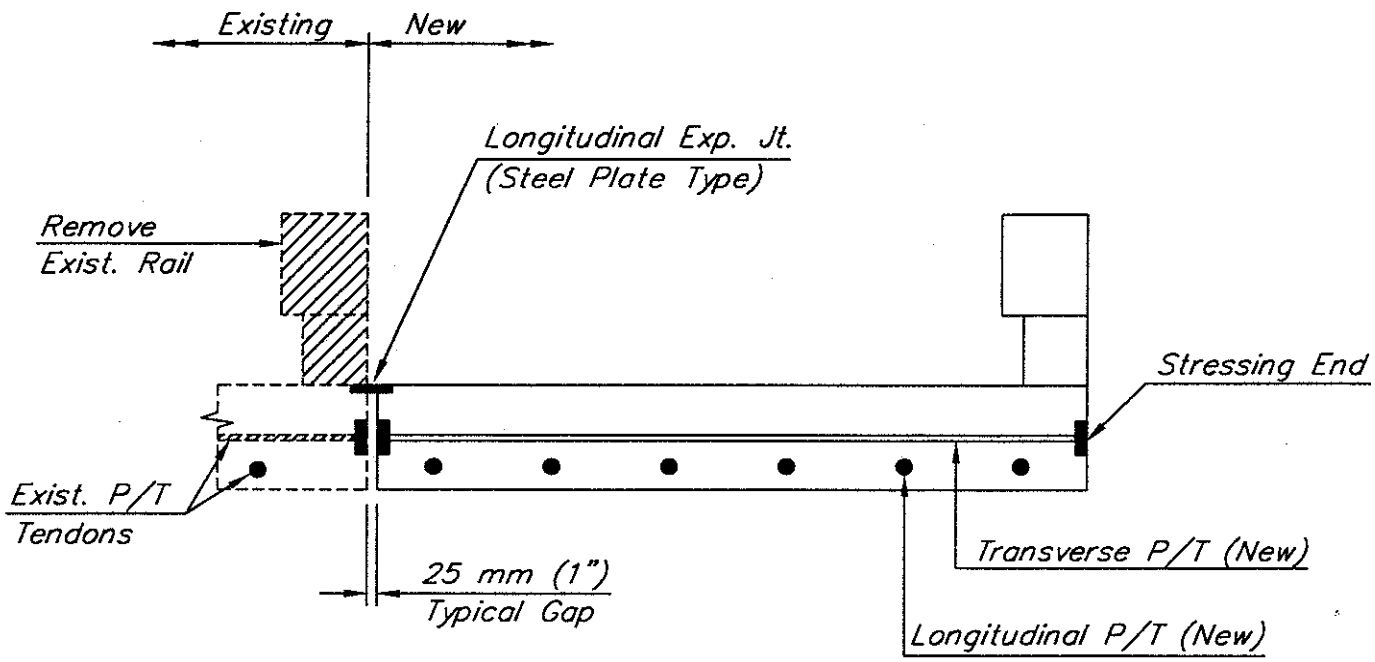
• **Projected for the year 1998**

IX.4 Future Widening:

Widening of a post-tensioned concrete superstructure is, in general, somewhat more complicated than conventionally reinforced concrete superstructures due to differential deflections between the existing and the new. One way to achieve this is to construct the portion immediately adjacent to the existing but structurally independent of the existing structure with a longitudinal expansion joint between the two portions. A steel expansion device is recommended for the longitudinal joint.

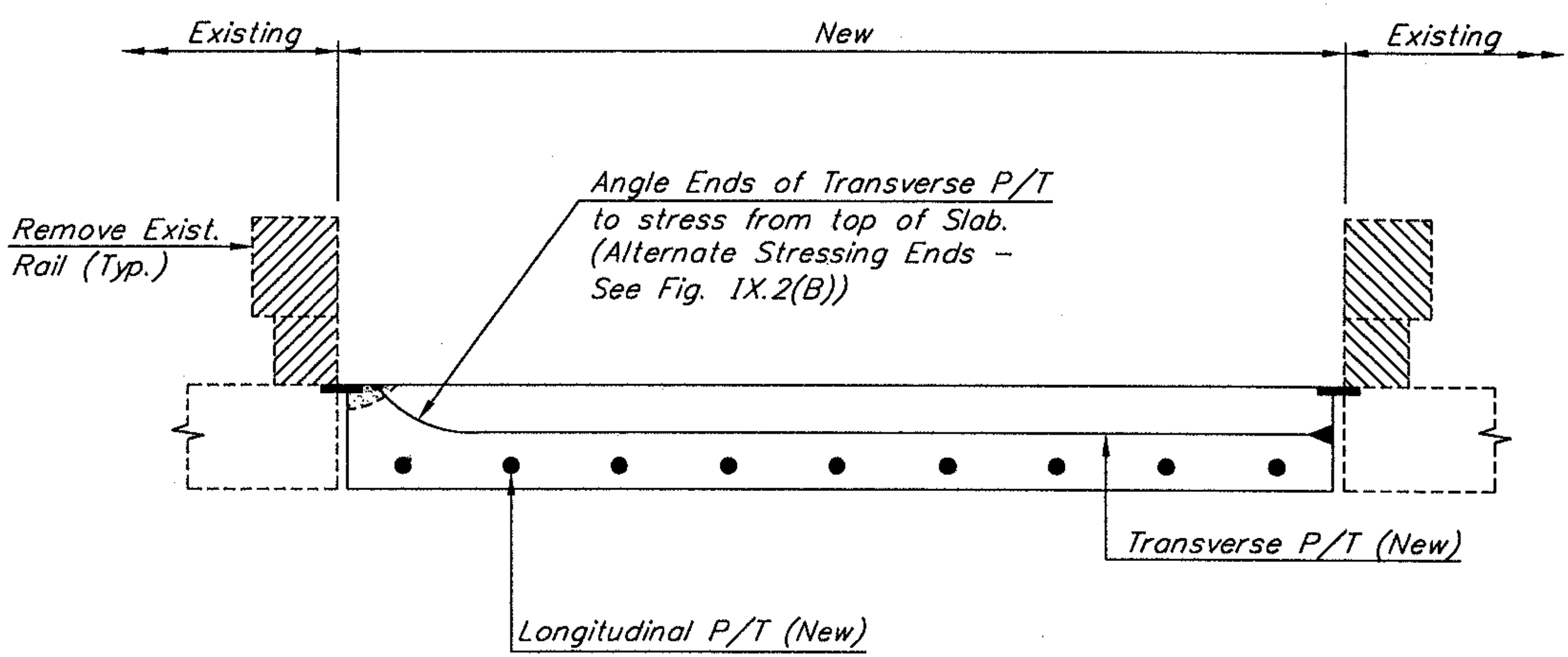
Typically, transverse post-tensioning of the new portion can be achieved by stressing at the free outside edge. However, this is difficult if the new portion is to be cast in the gap between twin bridges. In this case, the transverse P/T tendon can be anchored at an angle to come out at the top of slab rather than the side, thus allowing stressing to be done from the top side of the slab. Stressing ends can also be alternated at both ends of the new portion to maintain symmetry.

Conceptual schematics for P/T slab bridge widening are shown in Fig. IX.l and IX.2.



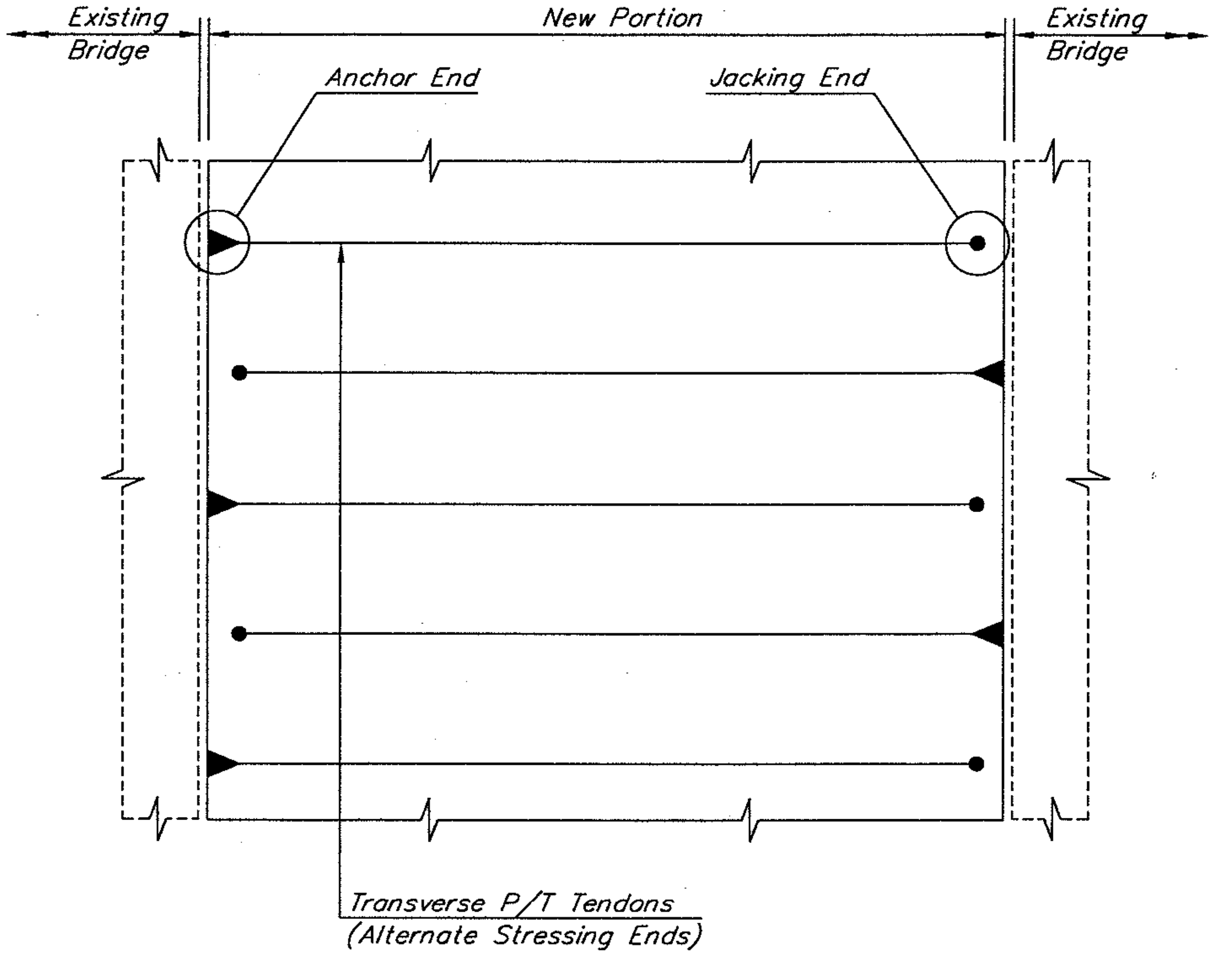
ROADWAY SECTION

FIG. IX.1



SECTION

FIG. IX.2(A)



PLAN

FIG. IX.2(B)

X. PEER REVIEW

X.1 Objective:

The goal of the peer review is to have an independent check of two prototypes (No. 2 & No. 4) for structural analysis as well as general review of the overall concept as reported in the study.

X.2 Review Performance

The independent review of the prototype designs was performed by Dr. Hani Melhem, Ph.D, Associate Professor of Civil Engineering at Kansas State University. Dr. Melhem specializes in structures with focus on Bridge Design. He is also the coordinator of the annual Bridge Design Workshop at Kansas State University.

X.3 Analysis Check:

Dr. Melhem has developed a computer program to analyze 3 span, non-prismatic, post-tensioned concrete bridge girders for AASHTO loads. Since the prototype design consisted of analyzing a 600 mm wide design strip, the KSU computer program served as an ideal check for the BDS software used to design the prototypes. However, the KSU software can only allow integer values for span lengths and single parabolic draping for P/T tendons within a span. Therefore, the selected prototypes had to be modified to run on KSU program. The same input data was run using BDS software and the results were compared.

The results of two independent analyses compared with excellent concurrence as shown in Table X.1. Thus it was concluded that the results of the BDS analysis for a given model were reliable by verification using KSU program.

Table X.1

Stresses in Top & Bottom of Slab : 17m-22m-17m

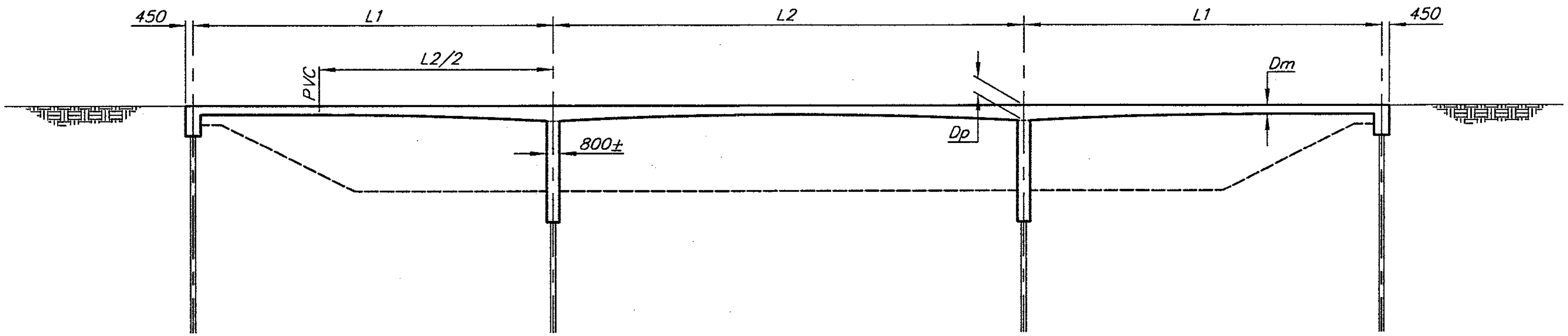
Load Combination	0.4 Span 1		Int. Support		0.5 Span 2	
	Top (psi)	Bot (psi)	Top (psi)	Bot (psi)	Top (psi)	Bot (psi)
DL Slab+SDL:						
BDS Software	810	-810	-948	948	646	-646
KSU Software	814	-814	-943	943	644	-644
Difference (psi)	*4*	*4*	*5*	*5*	*2*	*2*
Prestress (After Loss):						
BDS Software	-372	1930	1675	-749	-48	1566
KSU Software	-384	1961	1666	-752	-16	1511
Difference (psi)	*12*	*31*	*9*	*3*	*32*	*55*
Live Load (HS-20):						
BDS Software	1114	-1114	-484	484	1049	-1049
KSU Software	1123	-1123	-482	482	1049	-1049
Difference (psi)	*9*	*9*	*2*	*2*	*0*	*0*
Total (DL+P/S+LL):						
BDS Software	1552	6	243	683	1647	-129
KSU Software	1553	24	241	673	1677	-182
Difference (psi)	*1*	*18*	*2*	*10*	*30*	*53*
Cumulative Variance	*1%*	*2%*	*1%*	*1%*	*2%*	*3%*

Stresses in Top & Bottom of Slab : 21.5m-28m-21.5m

Load Combination	0.4 Span 1		Int. Support		0.5 Span 2	
	Top (psi)	Bot (psi)	Top (psi)	Bot (psi)	Top (psi)	Bot (psi)
DL Slab+SDL:						
BDS Software	964	-964	-1220	1220	885	-885
KSU Software	974	-974	-1215	1215	883	-883
Difference (psi)	*10*	*10*	*5*	*5*	*2*	*2*
Prestress (After Loss):						
BDS Software	-492	2199	1894	-887	-87	1732
KSU Software	-503	2214	1887	-891	-56	1677
Difference (psi)	*11*	*15*	*7*	*4*	*31*	*55*
Live Load (HS-20):						
BDS Software	990	-990	-466	466	942	-942
KSU Software	999	-999	-465	465	939	-939
Difference (psi)	*9*	*9*	*1*	*1*	*3*	*3*
Total (DL+P/S+LL):						
BDS Software	1462	245	208	799	1740	-95
KSU Software	1470	241	207	789	1766	-145
Difference (psi)	*8*	*4*	*1*	*10*	*26*	*50*
Cumulative Variance	*1%*	*1%*	*0%*	*1%*	*2%*	*3%*

REFERENCES

1. Standard Specifications for Highway Bridges, 16th Edition (1996), AASHTO.
2. LRFD Bridge Design Specification, 1st Edition (1994) (SI Units), AASHTO.
3. Design of Prestressed Concrete Structures, T.Y.Lin.
4. Post-tensioning Manual, 3rd Edition, Post-tenstioning Institute.



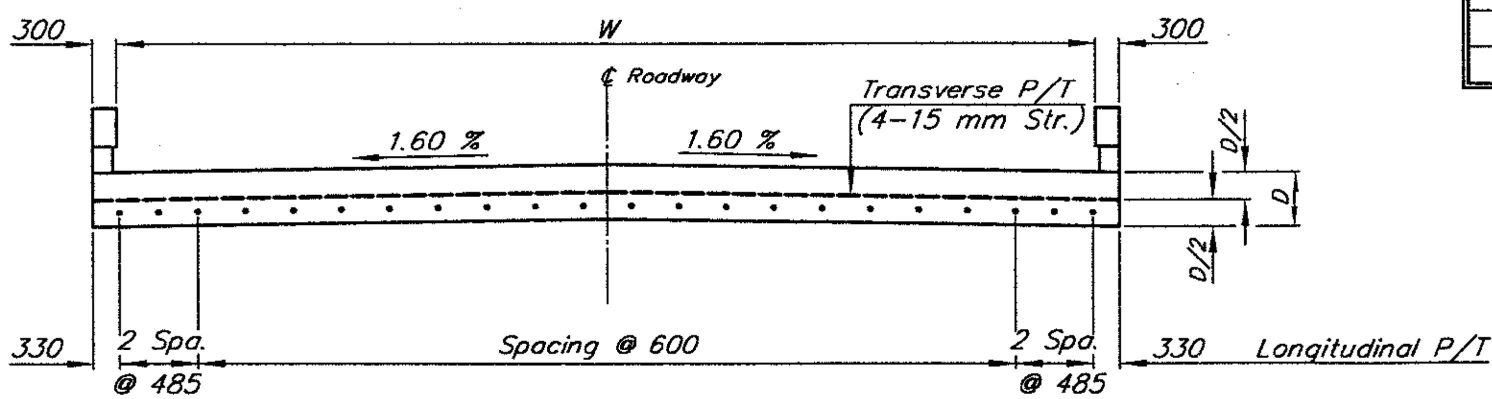
ELEVATION

MATERIAL PROPERTIES

Concrete F'c = 35 MPa. (5,076 PSI)
Prestress Steel Fu = 1 860 MPa (270 KSI)

GEOMETRIC DATA					LONGITUDINAL P/T DATA	
Proto Type	L1	L2	Dm	Dp	15 mm (0.6") Strand Number	13 mm (0.5") Strand Number
S1	15 000	20 000	430	740	8	12
S2	17 000	22 000	460	780	9	12
S3	19 000	25 000	500	870	11	16
S4	21 500	28 000	550	950	12	17

DESIGN INFORMATION



ROADWAY SECTION

W = 8 600
9 800
11 000
12 200
13 400

NOT FOR CONSTRUCTION

ALL UNITS ARE IN mm

KANSAS DEPARTMENT OF TRANSPORTATION

PROTOTYPE DATA

Booker ASSOCIATES INC. OF KANSAS
Wichita Kansas

SCALE — DATE — DWG. NO. —

SURV. PLOT CADD DES. DR. TR. CKD. APP.

SCALE 1"=10'