TRELLIS BEAM BRIDGES
INNOVATIVE SOLUTIONS FOR HIGHLY SKEWED FLYOVERS

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Introduction:

Modern urban interchanges in some instances require complex geometry to achieve optional functionality. The Calgary Trail/Gateway boulevard interchange at Anthony Henday Drive in Edmonton is a "Systems" interchange. (see Fig. 1) Four of the many flyovers at this interchange have underpassing roadways with curved horizontal alignments. Structure ES (Eastbound – Southbound) and structure NW (Northbound - Westbound) are flyovers over Calgary Trail southbound, which has an 800m Radius at ES and tangent section at NW. Structure NW is on a 600m Radius and 4.8% superelevation. Structures E1 and W3 are carrying Anthony Henday Drive mainline over Anthony Henday Northbound Westbound, which is on a 400 radius and 5.7% superelevation at this location. Structures E1, W3 an ES have to accommodate future widening on one side.

This paper describes the design challenges and solutions arrived at, taking in account safety, economy, functionality and aesthetics.

Issues and Constraints:

The structures are at varying and high angles of skew. On structures E1 and W3, the skew varies from about 50° at the south end to about 80° at the north end. On structure ES, the skew varies from about 70° at the east end to 80° at the west. On structure NW, the skew is about 62°. In conventional design, such high skew angles, combined with high superelevations will require much longer spans than the perpendicular width of the underpassing roadways. For example, Structures ES would require a minimum span of about 110m and structure NW, a span of 64m (these spans account for the stopping right distance requirements as well.) Such long spans would require deep girders, thus increasing the grade difference, which in turn increases the bridge length and cost. Furthermore, future widening has to take place over live traffic and girder erection will be very difficult because of lack of access.

These challenges were met by the "Trellis beam concept".

Trellis Beam Concept:

The 'Trellis Beam' concept is the structural arrangement wherein the main girders are perpendicular to the underpassing roadway, thus resulting in the least span and shallowest superstructure depth. The deck slab is cast to the required roadway width of the flyover. (see Fig. 2 structures E1 and W3 Plan and Fig. 3, section 3). The roadway above could be easily widened in the future by casting additional deck slab, for which the stay-in-place formwork could be supported on the trellis beams, or precast slabs could be used. Therefore traffic disruption is minimized. There are no piers adjacent to the roadway, further improving safety.

Description of Structures:

The trellis beams are supported on integral abutments.

Structures E1 and W3: The trellis beams span 40m between the centerlines of the integral abutments, which are supported on a line of steel H piles. (HP 310X94) Both eastbound and westbound Anthony Henday mainline are supported on the same series of trellis beams, and allow for future widening on the median side. The trellis beams are placed radially at 6m spacing or 8m spacing. The trellis beams are sloped to be parallel to the cross fall of the deck slab, thus minimizing the grade difference. There are no expansion joints except for the west end of the deck slabs of structure W3. This end of the bridge is supported by a 'box' abutment and is independent of the integral abutments. The earth pressures at the integral abutments are balanced by each other. The head slopes are 'terraced' by two intermediate retaining walls and planted with hardy native vegetation (Virginia Creepers).

Structure NW: (See fig 4 (plan) and Fig 5 (sections)). This structure is on a 600m radius curve and 4.8% superelevation. The 13.4m roadway width allows for the additional clear width required on the inside of the curve to obtain the required stopping sight distance. The 2.4m deep trellis beams are sloped at 2% and the difference in the deck slope and the beam slope is made up by concrete haunch. The trellis beams at the ends are cantilevered to carry the deck slab. The structure is under a high voltage powerline and therefore, reducing the depth of the super structure is important. There is an underground high pressure gas pipeline at the south end and the box abutment spans across this right of way. The details of the box abutment are shown in Fig.6. (South Box Abutment Plan).

Structure ES: This is the longest of the four structures (244m long), (see Fig. 7 & 8). The flyover is on a tangent section. It was originally intended that only two lanes would be constructed initially with additional two lanes in the future when the east-leg of the Anthony Henday Drive is built. However, before the design was completed, Alberta Transportation decided the east leg will be built in a year or two, and four lane bridge was designed. The trellis beams span 44m between supports and the beams at ends are cantilevered to a maximum length of 13.8m. The soffit of the trellis beams are sloped parallel to the cross fall of the roadway below, at 4.7%. The deck slab in superelevated at 2% in the opposite direction. Therefore, haunch sections are required above the beams. (see Fig. 9).

All the trellis beams have the same narrow trapezoidal cross section, varying in width from 600mm at bottom to 1000mm at underside of top flange and 1300mm flange width.

The main objective of increasing the trellis beam spacing from a normal 3m to 6m and using narrow cross section is to reduce the visual impact allowing more light and openness under the structure. For the same reasons 44m spans were used instead of the minimum required span of about 22m using vertical wall abutments at the edges of the underpassing roadway. Underbridge lighting is provided at each beam, to be used in case the "flickering" effect (whereby the shadow cast by the beams alternating with the light between the beams) becomes distracting. The 5m wide swale at one side of the underpassing roadway provides room for snow storage and required clearance for sight distance.
Each beam is post-tensioned with 6 tendons each with 19- 15mm diameter strands (see Fig. 10). The deck slab thickness is 300mm for 6m beam spacing and 365mm for 8m beam spacing. There was a concern about the effects of the electromagnetic fields from the high voltage power lines on the post-tensioning steel. An FIP report ("Report on Prestressing steel: 6. The Iinfluence of the Stray Electrical Currents on the Durability of the Prestressed Concrete Structure", Federation Internationale De La Precontrainte – December 1980) indicates that alternating current does not have a significant effect whereas DC current requires more investigation.

Box abutments consisting of trapezoidal beams with cross-section similar to that of the trellis beams are used to support the bridge deck at both ends.

Analysis and Design:

The final element analysis program SAP2000 was used to analyse the structures. The grillege model was used to analyse the structure in three dimensions. Temperature and concrete shrinkage effects are particularly important in this unused structural arrangement. The Trellis beans in structures ES and NW are not connected to each other along their depth but only at the top by the deck slab and at the bottom by the abutment beam. This arrangement, and the narrow width of the trellis beams allows for the volume change movements on the trellis beams.

To minimize the effects of the deck slab concrete shrinkage, 2m wide closure strips were used (see Fig. 11).

The integral abutments support the trellis beams and are in turn supported by steel H piles spaced at about 1.0m at each beam. The piles are subjected to significant lateral earth pressure because of the difference in height of backfill at both sides of the abutment beam. Therefore, the top of the piles are connected to the abutment beams by using steel studs to transfer bending moments and reduce rotations. (see Fig. 12) The steel piles also act as shear keys to improve slope stability.

Construction:

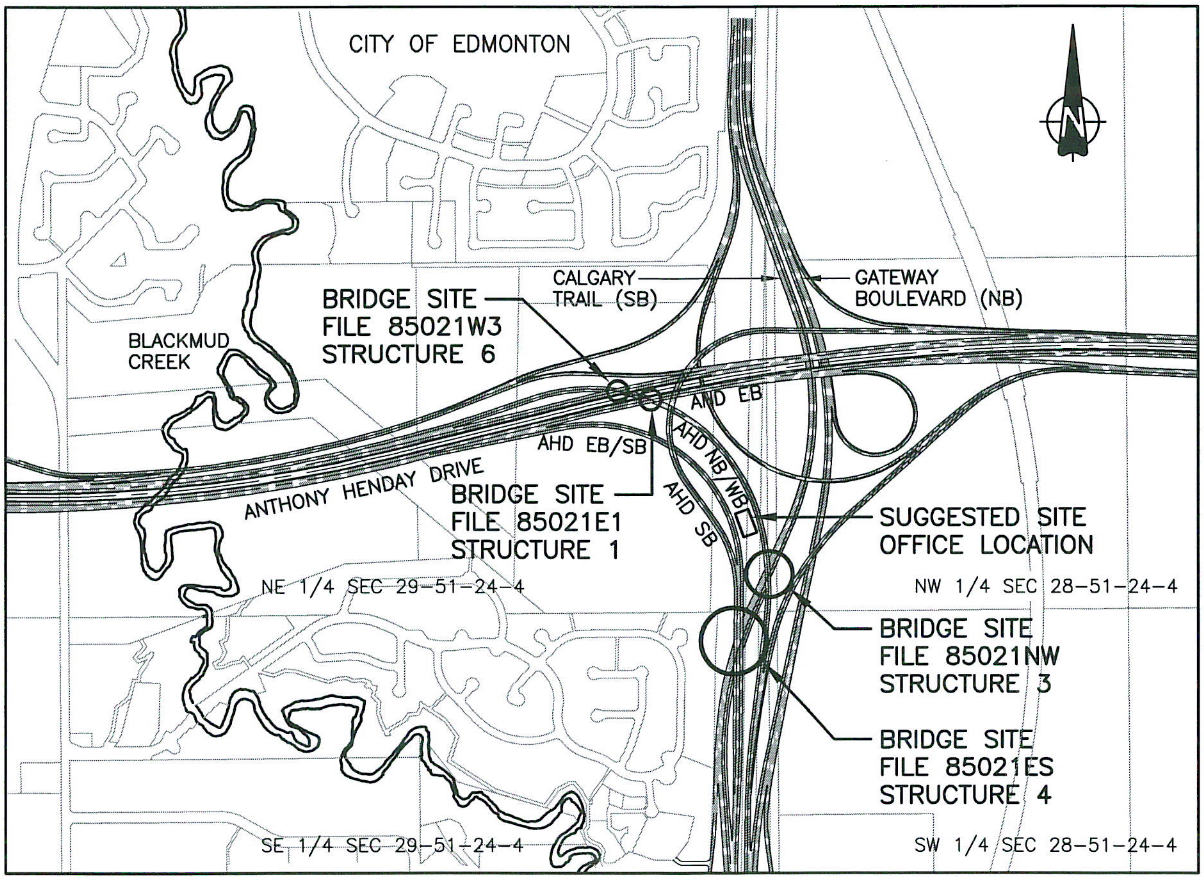
Figures 13 through 20 show the structures under different stages of construction.

- Figure 13 shows the piles with studs welded on to them. In order to confirm the vertical load capacity of the piles, Pile Drive Analyser (PDA) testing was performed on 28 piles. Dynamic monitoring with PDA Consists in measuring the force and velocity induced in the pile by the impact of the pile hammer, by installing gages at the pile head (see Fig. 14). Equivalent static capacity derived from Analysis using PDA results show that the piles have adequate capacity (ultimate capacity of 2200 kN) at the end of initial driving and significant capacity increase (due to set up) with time, (about 500 kN in two weeks).

A mockup of the trellis beam was constructed, Fig. 15). Steel forms were specified to obtain a smooth and consistent finish. Foam filler was used to form the voids. Rebar cages with post tension ducts in them were prefabricated in sections in the shop, (Fig.16). Typical Trellis beam after removal of forms is shown in Fig 17). This photo also shows the shallow height of the shoring enabled by specifying that the excavation for roadway be deferred until the completion of the bridge structure. Fig. 18 shows status of the construction of structures ES and NW 8 months after the start of construction. Fig. 19 shows the status of structures E1 and W3. The structures are substantially complete. Fig 20 shows and elevation view of structure ES.

Acknowledgements:

The 'A' Team consisting of UMA Engineering, Associated Engineering and AMEC are the consultants for the project. The Construction Contractor is Graham Construction. Support provided by Alberta Infrastructure and Transportation, the Owner, is gratefully acknowledged.



SITE MAP

FIGURE 1

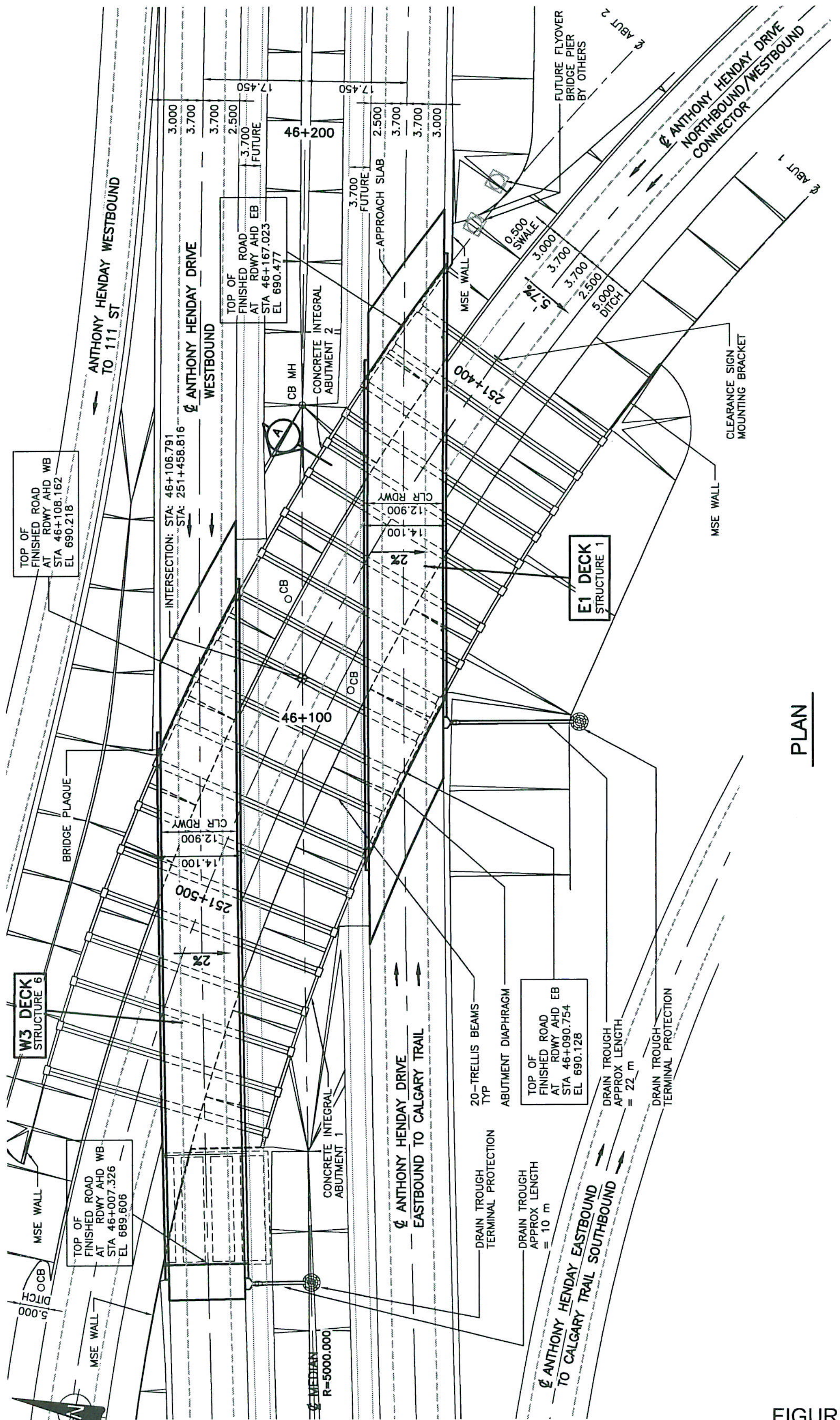
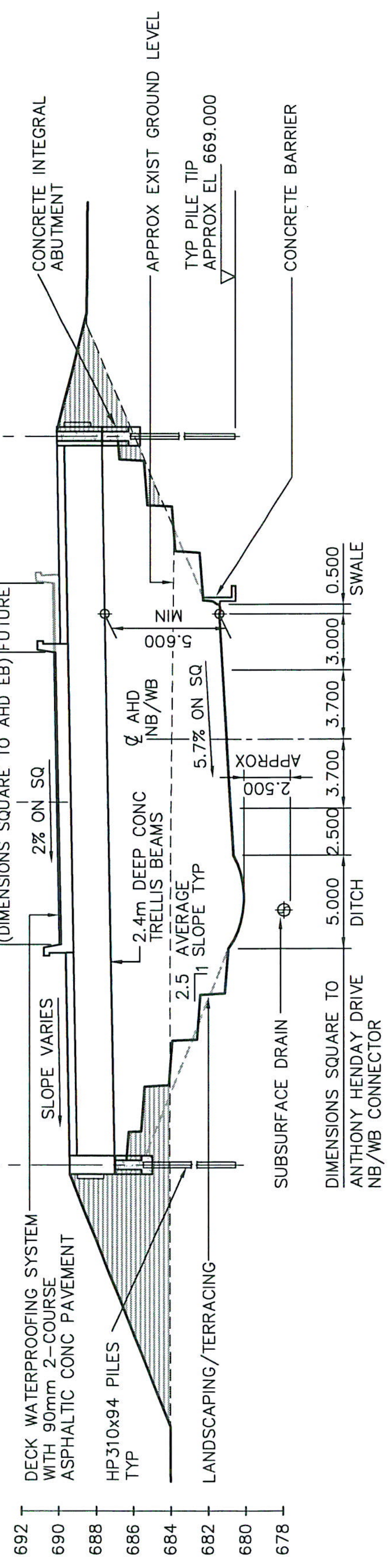

PLAN
ANTHONY HENDAY WESTBOUND TO 111 ST
℄ ANTHONY HENDAY DRIVE WESTBOUND
℄ ANTHONY HENDAY DRIVE EASTBOUND TO CALGARY TRAIL
℄ ANTHONY HENDAY DRIVE NORTHBOUND/WESTBOUND CONNECTOR
℄ ANTHONY HENDAY EASTBOUND TO CALGARY TRAIL SOUTHBOUND
W3 DECK STRUCTURE 6
E1 DECK STRUCTURE 1
TOP OF FINISHED ROAD AT RDWY AHD WB STA 46+108.162 EL 690.218
TOP OF FINISHED ROAD AT RDWY AHD EB STA 46+167.023 EL 690.477
TOP OF FINISHED ROAD AT RDWY AHD EB STA 46+090.754 EL 690.128
TOP OF FINISHED ROAD AT RDWY AHD WB STA 46+007.326 EL 689.606
INTERSECTION: STA: 46+106.791 STA: 251+458.816
CONCRETE INTEGRAL ABUTMENT 1
CONCRETE INTEGRAL ABUTMENT 2
APPROACH SLAB
20-TRELLIS BEAMS TYP
ABUTMENT DIAPHRAGM
DRAIN TROUGH TERMINAL PROTECTION
DRAIN TROUGH APPROX LENGTH = 10 m
DRAIN TROUGH APPROX LENGTH = 22 m
BRIDGE PLAQUE
MSE WALL
CLEARANCE SIGN MOUNTING BRACKET
FUTURE FLYOVER BRIDGE PIER BY OTHERS
℄ ABUT 1
℄ ABUT 2
℄ MEDIAN R=5000.000
CB MH
46+100
46+200
251+400
251+500
12.900 CLR RDWY
14.100
17.450
0.500 SWALE
5.000 DITCH
3.700 FUTURE

FIGURE 2



℄ ABUT 1
℄ ABUT 2
℄ RDWY AHD EB
DECK WATERPROOFING SYSTEM WITH 90mm 2-COURSE ASPHALTIC CONC PAVEMENT
HP310x94 PILES TYP
LANDSCAPING/TERRACING
SLOPE VARIES
6.700
6.200
3.700
(DIMENSIONS SQUARE TO AHD EB)
FUTURE
2% ON SQ
2.4m DEEP CONC TRELLIS BEAMS
2.5
1
AVERAGE SLOPE TYP
℄ AHD NB/WB
5.7% ON SQ
2.500
APPROX
5.600 MIN
SUBSURFACE DRAIN
DIMENSIONS SQUARE TO ANTHONY HENDAY DRIVE NB/WB CONNECTOR
5.000
2.500
3.700
3.700
3.000
0.500
DITCH
SWALE
CONCRETE INTEGRAL ABUTMENT
APPROX EXIST GROUND LEVEL
TYP PILE TIP APPROX EL 669.000
CONCRETE BARRIER
692
690
688
686
684
682
680
678

FIGURE 3

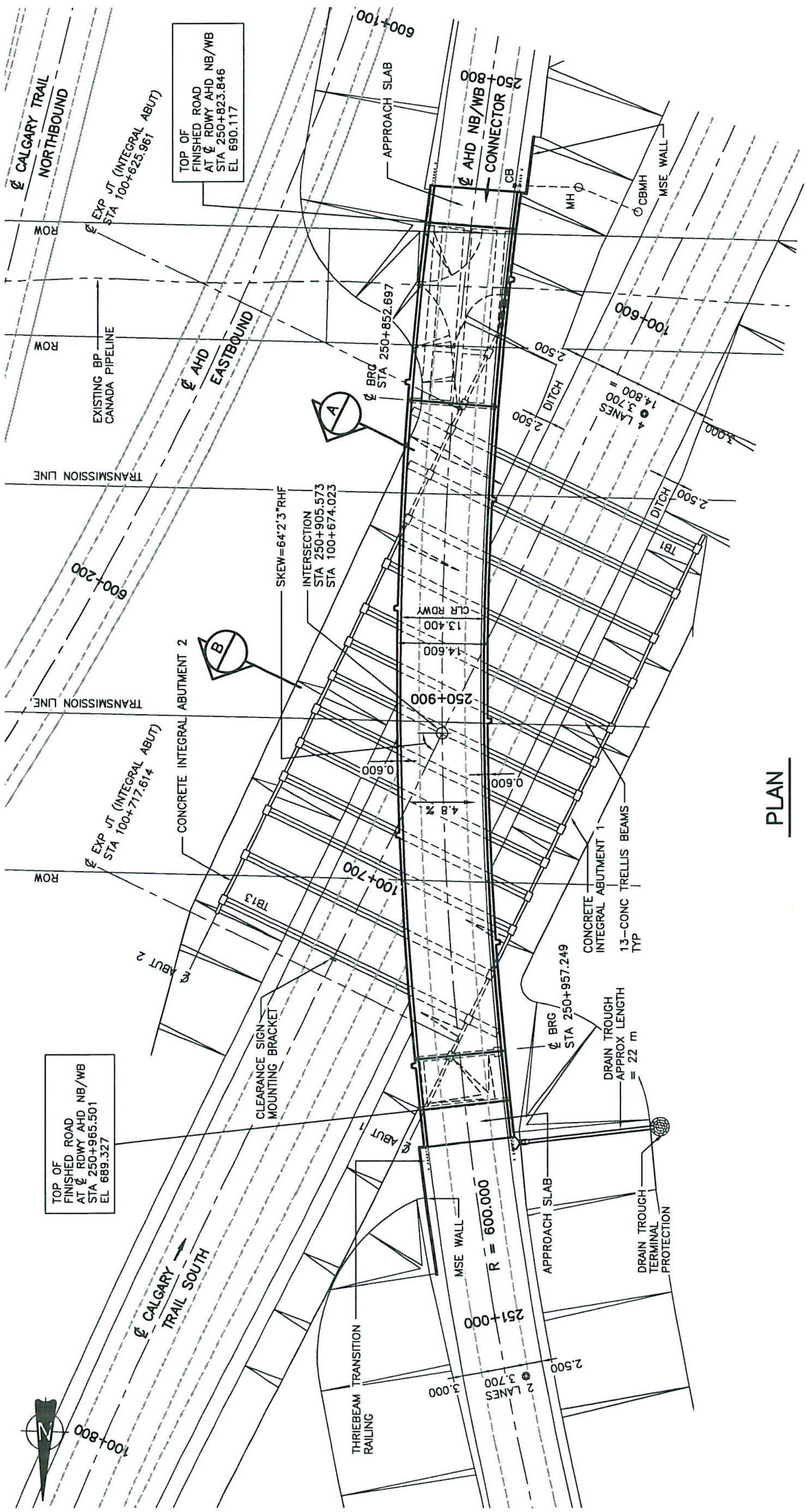
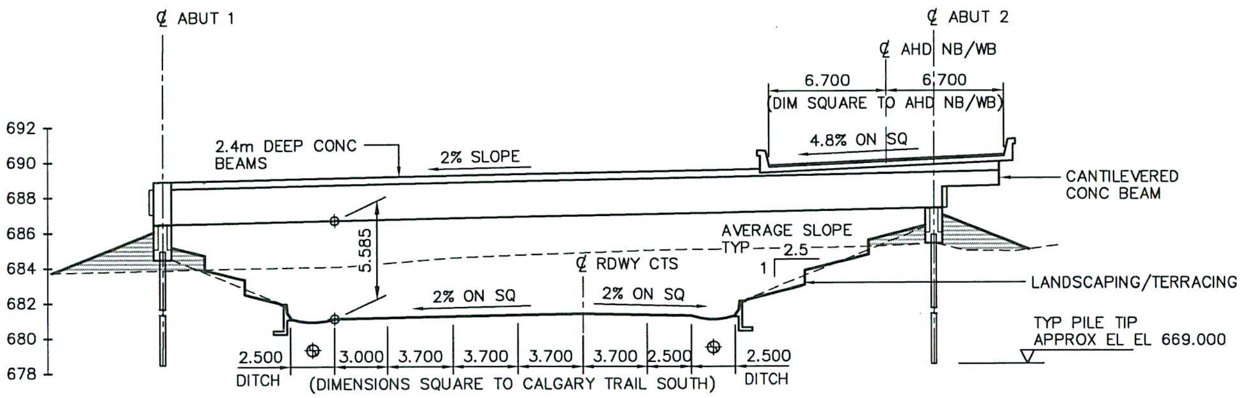
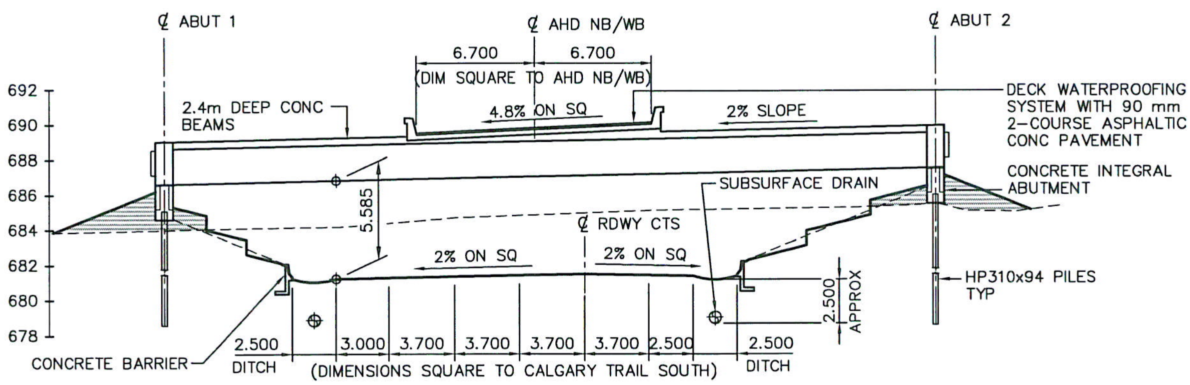

PLAN
℄ CALGARY TRAIL NORTHBOUND
℄ CALGARY TRAIL SOUTH
℄ AHD EASTBOUND
℄ AHD NB/WB CONNECTOR
TOP OF FINISHED ROAD AT ℄ RDWY AHD NB/WB STA 250+823.846 EL 690.117
TOP OF FINISHED ROAD AT ℄ RDWY AHD NB/WB STA 250+965.501 EL 689.327
℄ EXP JT (INTEGRAL ABUT) STA 100+625.961
℄ EXP JT (INTEGRAL ABUT) STA 100+717.614
EXISTING BP CANADA PIPELINE
TRANSMISSION LINE
ROW
APPROACH SLAB
MSE WALL
CB
MH
CBMH
℄ BRG STA 250+852.697
℄ BRG STA 250+957.249
SKEW=64°2'3"RHF
INTERSECTION STA 250+905.573 STA 100+674.023
CONCRETE INTEGRAL ABUTMENT 2
CONCRETE INTEGRAL ABUTMENT 1
13–CONC TRELLIS BEAMS TYP
TB1
TB13
CLR RDWY
13.400
14.600
0.600
4.8 %
DITCH
4 LANES @ 3.700 = 14.800
2 LANES @ 3.700
2.500
3.000
CLEARANCE SIGN MOUNTING BRACKET
DRAIN TROUGH APPROX LENGTH = 22 m
DRAIN TROUGH TERMINAL PROTECTION
THRIEBEAM TRANSITION RAILING
R = 600.000
600+100
600+200
250+800
250+900
251+000
100+600
100+700
100+800
℄ ABUT 2
℄ ABUT
N

FIGURE 4

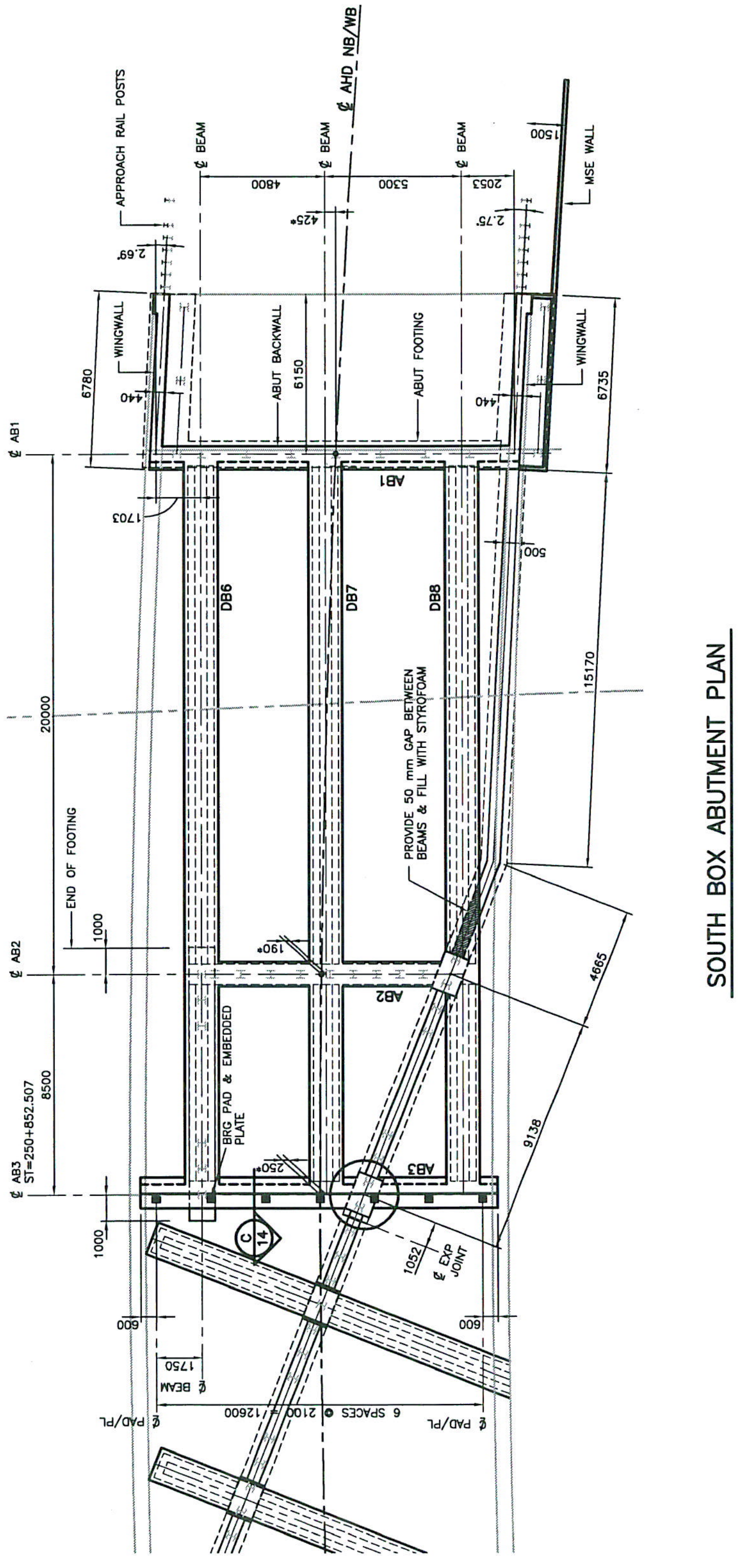


A SECTION



B SECTION

FIGURE 5



SOUTH BOX ABUTMENT PLAN
APPROACH RAIL POSTS
℄ AHD NB/WB
℄ BEAM
MSE WALL
WINGWALL
ABUT BACKWALL
ABUT FOOTING
END OF FOOTING
PROVIDE 50 mm GAP BETWEEN BEAMS & FILL WITH STYROFOAM
BRG PAD & EMBEDDED PLATE
℄ AB1
℄ AB2
℄ AB3
ST=250+852.507
DB6
DB7
DB8
AB1
AB2
AB3
℄ EXP JOINT
6 SPACES @ 2100 = 12600
℄ PAD/PL
20000
8500
15170
9138
4665
6780
6735
6150
4800
5300
2053
1500

FIGURE 6

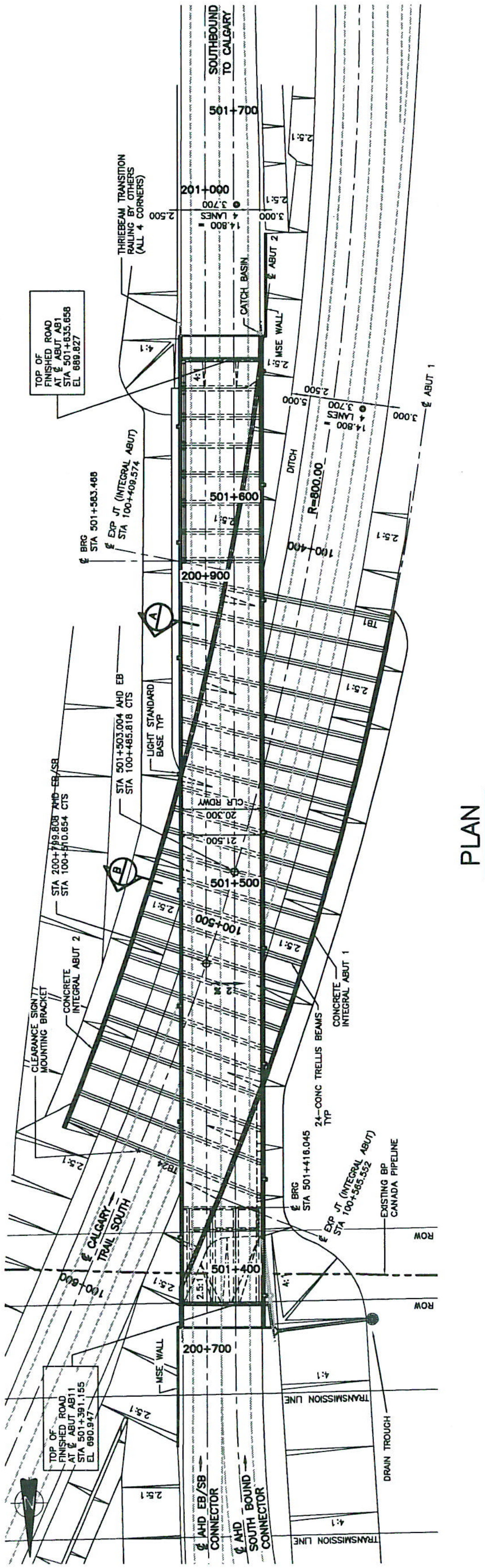
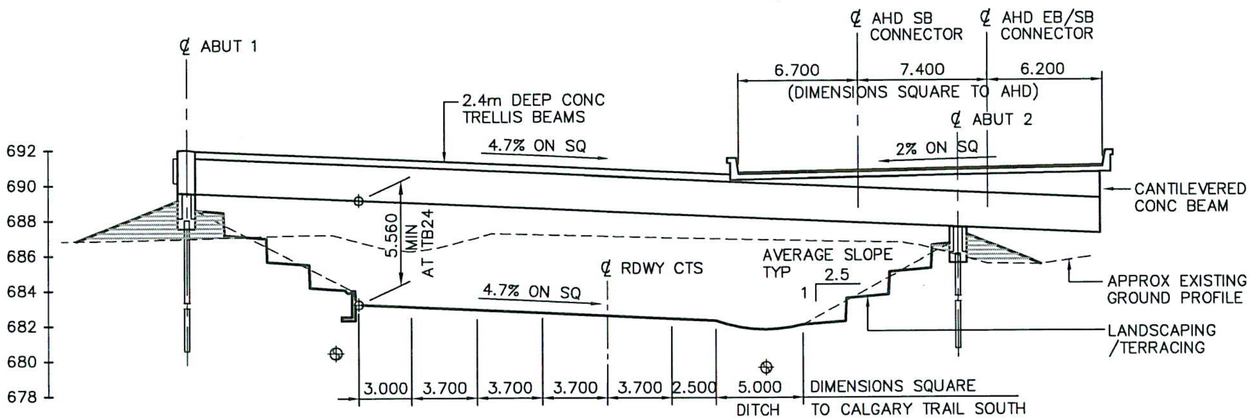

PLAN
SOUTHBOUND TO CALGARY
501+700
201+000
THRIEBEAM TRANSITION RAILING BY OTHERS (ALL 4 CORNERS)
TOP OF FINISHED ROAD AT ℄ ABUT AB1 STA 501+635.658 EL 689.827
CATCH BASIN
℄ ABUT 2
MSE WALL
℄ ABUT 1
DITCH
R=800.00
501+600
100+400
℄ BRG STA 501+583.488
℄ EXP JT (INTEGRAL ABUT) STA 100+409.574
200+900
STA 501+503.004 AHD EB
STA 100+485.818 CTS
LIGHT STANDARD BASE TYP
CLR ROWY
STA 200+799.808 AHD EB/SB
STA 100+510.654 CTS
501+500
100+500
CLEARANCE SIGN MOUNTING BRACKET
CONCRETE INTEGRAL ABUT 2
CONCRETE INTEGRAL ABUT 1
24-CONC TRELLIS BEAMS TYP
℄ BRG STA 501+416.045
℄ EXP JT (INTEGRAL ABUT) STA 100+585.552
EXISTING BP CANADA PIPELINE
℄ CALGARY TRAIL SOUTH
ROW
501+400
100+600
200+700
MSE WALL
TOP OF FINISHED ROAD AT ℄ ABUT AB11 STA 501+391.155 EL 690.947
TRANSMISSION LINE
DRAIN TROUGH
℄ AHD EB/SB CONNECTOR
℄ AHD SOUTH BOUND CONNECTOR

FIGURE 7



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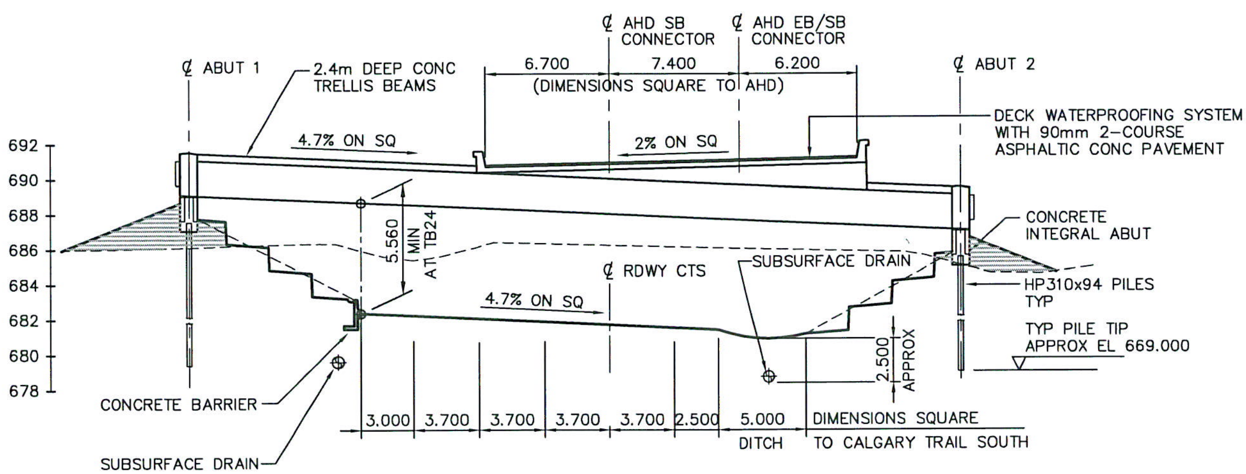
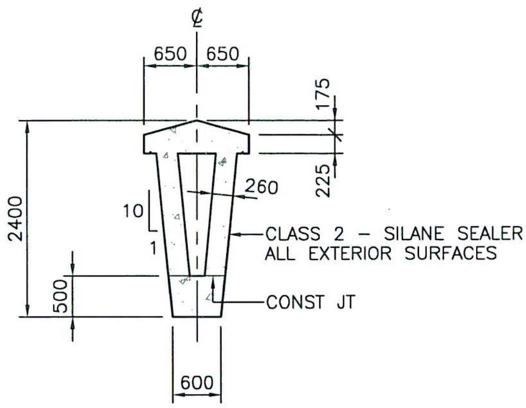
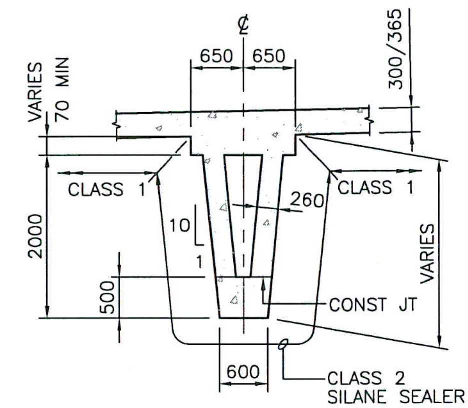


B SECTION

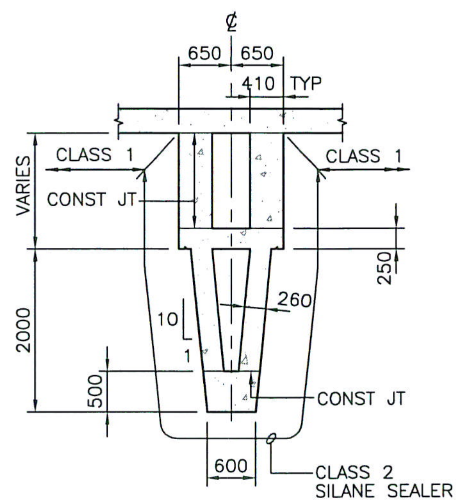
FIGURE 8



A BEAM SECTION

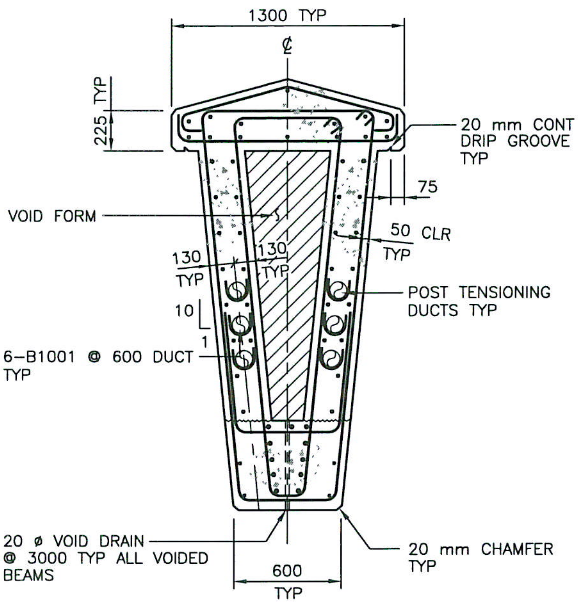


B BEAM SECTION UNDER DECK

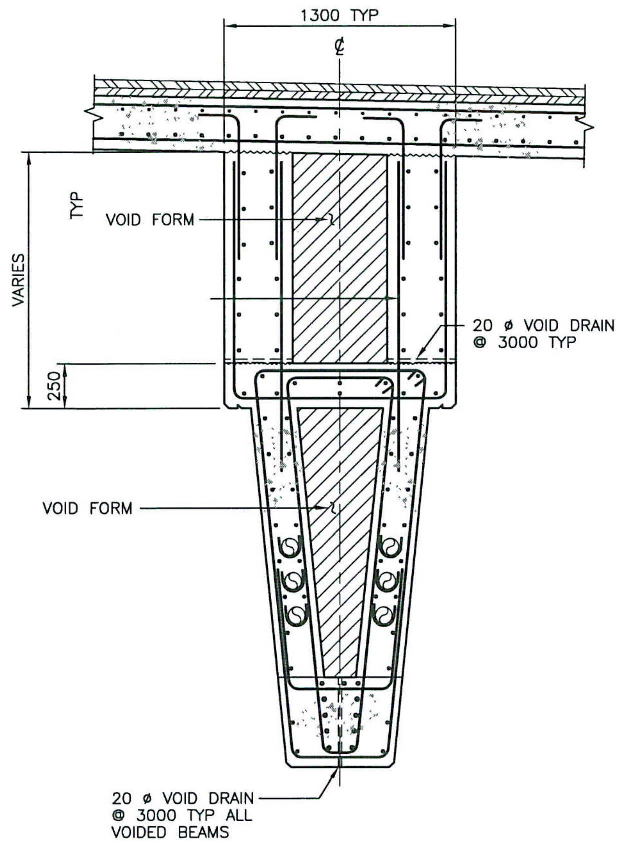


C BEAM SECTION AT HAUNCH

FIGURE 9



A SECTION



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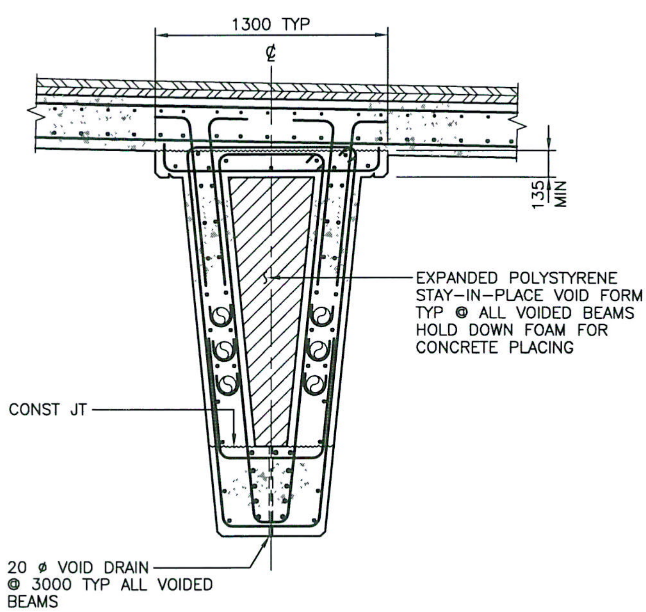
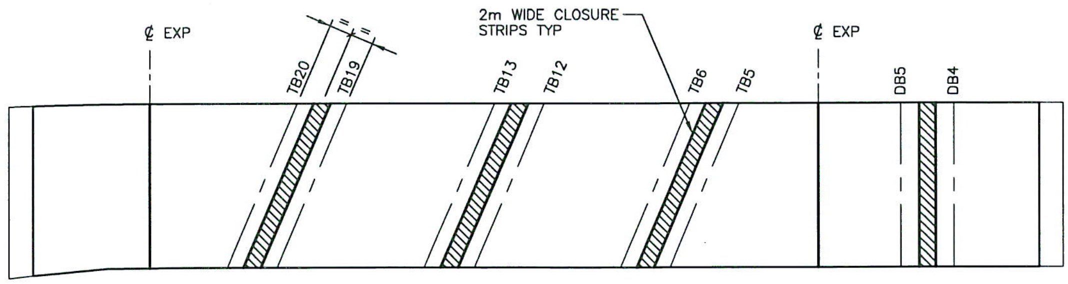


B SECTION

FIGURE 10

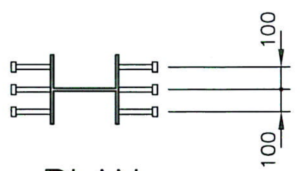


NOTE

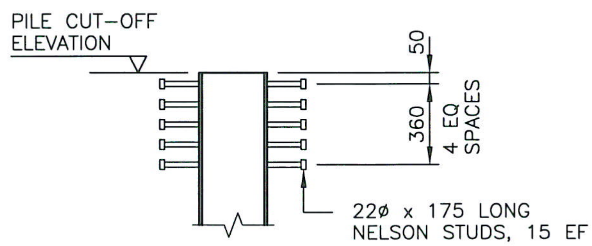
- CLOSURE STRIPS TO BE POURED 14 DAYS AFTER MAIN SECTIONS
- CURBS SHALL BE PLACED IN 3 m (MAX) SECTIONS IN ALTERNATING CHECKER BOARD PLACEMENT. THERE MUST BE A MINIMUM OF SEVEN (7) DAYS ELAPSED TIME BETWEEN THE PLACEMENT OF THE INFILL CURB POUR SECTIONS

DECK AND CURB PLACING SCHEDULE

FIGURE 11

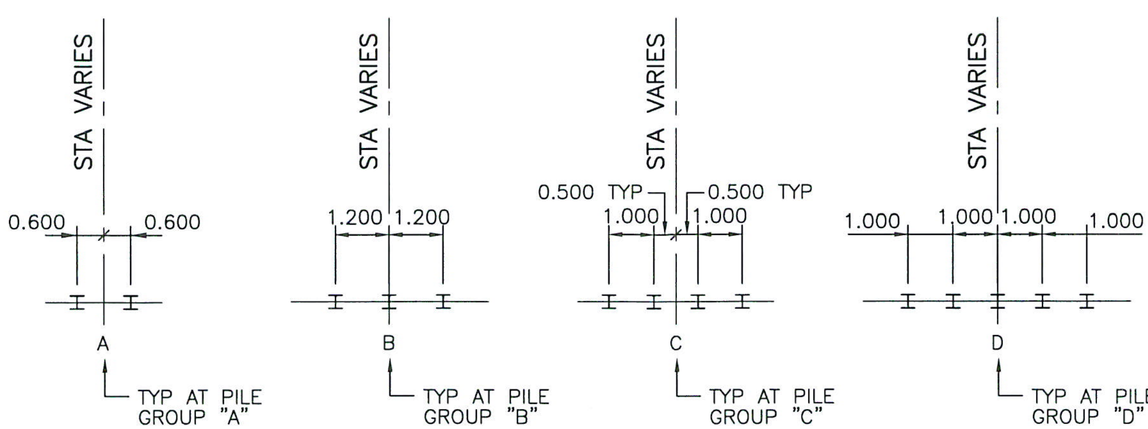


PLAN



ELEVATION

TYPICAL PILE HEAD DETAIL



PILE SPACING

FIGURE 12

FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

FIGURE 19

FIGURE 20