DESIGN OF HORSE-SHOE SHAPED CROSS PASSAGE FOR A TWIN TUNNEL SYSTEM

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Abstract - In this project we have designed a Cross-passage, which is a reinforced concrete structure built in between two tunnels. They are provided to serve two primary purposes namely, emergency escape and maintenance work. Due to lots of conjunctions, tunnels was constructed earlier in a location from Saidapet to Washermenpet and for that tunnels horseshoe shaped cross passages was designed and analyzed. It provides unique challenges when considering the 3D geometry, geotechnical behaviour and interaction between the internal tunnel structures and ground. It was realised that the ground conditions might be difficult so provision was made for geotechnical investigation and ground treatment through the main tunnel linings at each passage location. The observed behaviour of the cross passages during excavation was established. The analysis is concluded with a discussion of the importance of each mechanism to potential future design of cross passages.

Keywords- Cross-passage, tunnel linings, horseshoe shape, geotechnical, ground treatment.

1. INTRODUCTION

Twin bored tunnels are commonly used for a variety of road and tunnel projects throughout the world. A major component of these twin tunnel projects is the construction of transverse cross passages connecting the two tunnels for emergency egress purposes. The excavation of these cross passages involves large schedule and cost risk in tunnel construction, since they are often constructed towards the end of a project and involve difficult technical challenges in supporting the excavation face, excavation profile, and existing bored tunnel linings. Design of the cross passages therefore involves a combination of structural and geotechnical techniques to adequately support the ground.

Structural methods are used to enhance the capacity of the tunnel to resist the applied loading. Three aspects of cross passage design and construction require structural consideration: temporary support of excavations, permanent lining of the cross passage, and support of existing bored tunnel structures during construction. Temporary cross passage support typically involves a sprayed concrete lining, also known as a shotcrete lining, with additional reinforcement from steel fibres, steel mesh, or lattice girders as required. This lining is built up in stages behind the advance, involving multiple layers of shotcrete spraying to build a full thickness lining. Permanent lining design aspects include the cast-in-place concrete and rebar design, waterproofing design, and design of the connecting collar between the cross passage.

Support of existing tunnel structures requires consideration of the transfer of loads around the opening, including redistribution of hoop forces above the opening to neighbouring segments.

Recent developments with tunnel boring machine (TBM) technology have led to a vast majority of bored tunnels being constructed using precast segmental concrete linings installed behind the TBM as it progresses. This results in openings being cut from the segmental lining or specific opening segments being prepared in advance. Support for the tunnel therefore must include some combination of additional reinforcing placed into the segments, shear dowels (known as bicones) placed between ring to ring segment contacts, additional steel beams added to support the lintel and sill of the opening, and propping struts being added to transfer hoop forces across the opening.

Geotechnical methods are used to enhance the internal strength of the ground, reducing loads on the tunnel by encouraging redistribution of load into the ground mass. These methods of ground improvement include excavation dewatering, ground freezing, jet grouting, permeation grouting, the use of spiles or pipe canopies, and rock bolting.

These methods can help to reduce load on the tunnel linings mentioned above, but they are often particularly necessary for ensuring stability of the cross passage excavation face in soft ground. Since it is difficult to install structural support instantly after excavation, sufficient ground strength must be present to ensure stability until the lining can be installed.

Design of the structural and geotechnical methods used to accomplish cross passage excavation involve significant conservatism due to the risks involved and a lack of understanding of the load conditions and interactions between the many facets involved. Significant benefit can be gained by reducing the amount of support required for construction, but to do so, a better understanding of the development of loads during construction must be understood. The first step in this process is to evaluate field data from various projects, establish observed mechanisms driving the loading behaviour, and use this information to consider new aspects in the design process.

Passenger emergency evacuation design for cross-passage between running tunnels are constructed by either cut -and- cover or bored method.

Fig.1: A Typical Horse Shoe Shaped Cross Passage

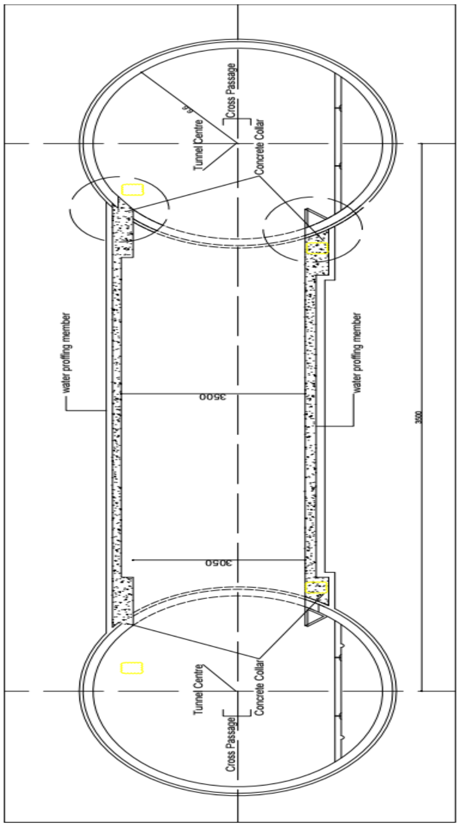

Fig. 2: Plan Layout

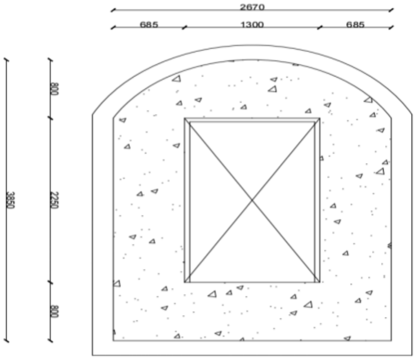

Fig. 3: Section A-A

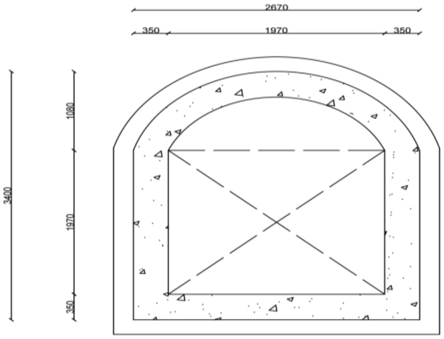

Fig. 4: Section B-B

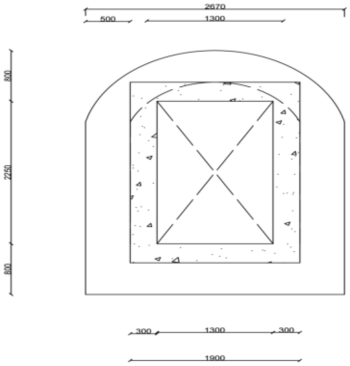

Fig. 5: Section C-C

2. PRESSURE DISTRIBUTION

Height of the tunnel structure (H_T) = 3.5m
Height of backfill over the tunnel (H_G) = 30m
Height of water table over the tunnel (H_W)= 13m
Dry unit weight of the soil (γ_s) = 18kN/m^3
Saturated unit weight of the soil (γ_{sat}) = 20kN/m^3
Buoyant unit weight of the soil (γ_{Sb}) = 10.19kN/m^3
At rest lateral earth pressure coefficient (R_o) = 0.8
(For saturated soil)
Magnitude of surcharge (F_s) = 23.94kN/m^2

(For cut and cover tunnel)
Vertical Earth pressure: = $\gamma_S (H_G-H_W) + \gamma_{Sb} (H_W)$
= 18(30-13) + 10.19x13
= 438.47kN/m^2
Horizontal Hydrostatic Pressure:
a = $\gamma_W H_W$
= 127.53kN/m^3
b = $\gamma_W (H_W + H_T)$
= 161.87kN/m^2
Horizontal Earth pressure:
a = $\gamma_S R_O(H_G-H_W) + \gamma_{Sb} R_O H_W$
= 18x0.8(30-13) + 10.190x0.8x13
= 350.8kN/m^2
b = $a + \gamma_{Sb} R_O H_T$
= 350.8 + (10.19x0.8x3.5)
= 379.332kN/m^2
Horizontal Surcharge Load:
= $F_S R_O$
= 23.94x0.8
= 19.152kN/m^2
Vertical Hydrostatical pressure (Buoyancy):
= $\gamma_W (H_W + H_T)$
= 161.87kN/m^2
Dead Load:
= $\gamma_W (H_W + H_T)$
= 9.81x (13 + 3.5)
= 161.87kN/m^2
Live Load:
= 10kN/m
Total Load:
w = Total vertical distributed load
w = 438.4+127.5+10+263.8
w = 840kN/m^2
w_u = 1259.836kN/m^2
w_u = 26ksi/ft^2

3. FLEXURAL DESIGN:

Width of section (b) = 0.30m, 11.81"
Wall thickness of the pipe (h)
= 0.250m, 10"
Effective depth (d) = 0.150m, 5.9"
Effective cover (Assume) (d')
= 50mm, 1.97"
Compressive strength of concrete (f_c')
= 27.5Mpa, 3.988ksi
Yield strength of reinforcement (f_c')
= 275.79Mpa, 40ksi
Inside diameter of the circular pipe (D_i)
= 3.5m, 137.78"
Flexure:
R = $(D_i + h)/2$
= (137.78 + 10)/2
= 73.9"

R/h = 73.9"/10
= 7.39"
The cross section parameter:
γ = (h-2d')/h
= (10-2(1.97))/10
= 0.6
K = (lateral uniform load/vertical uniform load)
w_u = [26ksf(1ft/12in)] x1in
= 2.17 k/in
n_{sp} = $w_u R/f_c' bh$
= (2.17x73.9)/ (3.988x11.81x10)
= 0.340
n_{cr} = $K w_u R/f_c' bh$
= 0.8 n_{sp}
= 0.8(0.340)
= 0.272
h/e_{sp} = [4/1-K][1/(R/h)]
= [4/(1-0.8)] [1/(7.39)]
= 2.706
h/e_{cr} = [4K/1-K][1/(R/h)]
= [4(0.8)/(1- (0.8)][1/(7.39)]
= 2.165
Non-dimensional moment:
m_{sp} = $(1-K)wR^2/4f_c' bh^2$
= 0.126
Reinforcing index:
ω = $A_s f_y / bhf_c'$
$A_s f_y$ = $gØd-N_u-\sqrt{g}(g(Ød)^2-N_u(2Ød-h)-2M_u$
g = $0.85\ bf_c'$
= 0.85x11.81x3.988
g = 40.03
Diagonal Tension:
= $M_u/V_u Ød$
= 8.0
diagonal tension Ø = 0.9
γ = 0.6
cos2Ɵ = 6Ø9/R
= (6x0.9x5.9)/73.9
= 0.43
Ɵ = 33°
N_u = $w_u R$ [(1+K) + (1-K) cos2Ɵ]/2
= 2.17x73.9 [(1+0.8) + (1-0.8) cos 66°
= 151.50kips
= 673.905Kn
M_u = wR^2 [(1-K)Cos2Ɵ/4]
= 2.17x73.9[(1-0.8) cos66°]/4
= 241 in-k
= 27.23kNm
For Flexure:
Ø = 1
For Shear:
Ø = 0.9
$A_s f_y$ = 216.85
Reinforcing index:

= 216.85/
(11.81x10x3.988)
ω = 0.46
$P_{\text{total required}}$:
= $\omega f_c' / f_y$
= 0.46(3.988 ksi/40 ksi)
= 0.0459
$A_{s\ (\text{total required})}$:
= pbh
= 0.0459 x (11.81in) (10in)
= 5.416in^2
A_s = 3494.38mm^2
For equal inner and outer cages:
$A_{so}=A_{si}$ = 5.416in^2/2
= 1748mm^2

4. LIMITS FOR FLEXURAL REINFORCEMENT:

Min A_{si} = 0.002x11.81x10
= 0.2362 < 2.71

Hence Ok
= 152.39mm^2
Min A_{so} = 0.015bh
= 0.015x11.81x10
= 0.1775 < 2.71

Hence Ok
(Or)
Min A_{si} = $(s_i+h^2)/65000$
= 0.336 < 2.71
Hence Ok
= 220mm^2
Min A_{so} = 0.75xA_{si}
= 162.645mm^2

5. LIMITS DUE TO COMPRESSION CONCRETE:

A_{sc} = $[(55000\ b\ Bf_c'\ Ø\ d) / [fy(87000+f_y)]\ [(0.75\ N_u)/f_y$
B = $0.85-0.05(f_c - 4000)/10000$
B = 0.85-0.05(3988- 4000)/10000
= 0.85 (0.65≤B≤0.85)
Hence Ok
N_u = w_uR
N_u is maximum when ϴ = 0°
N_u = 2.17x73.9
= 160.363 kips
= 160363 lbs
= 713.33 kN
A_{sc} = 2.557-(534.997/(40000)
= 2.54 in^2
A_{si} = A_{so} = 2.71 in^2
Modification is required
If ties are provided,A_{sc} may be increased by 0.75A_s'
= 0.75x2.71
= 2.033
A_{sc} = 2.033 + 2.54
= 4.573 in^2>2.71 in^2
A_{sc} = 2950.32mm^2

6. RADIAL TENSION

R_{rt} = t_{ru}/t_{rc}
t_{ru} = M_u-0.45 N_ud/bd r_s
r_s = $0.5\ (D_i + 2t_b)$
r_s = 0.5 [137.9 + 2(1)]
r_s = 69.95 in
r_s = 1776.73 mm
t_{rc} = $1.2\ (f_c')^{½}$
= $1.2\ (3988)^{½}$
t_c = 75.78
When ϴ= 0° and 180°
N_u = $w_uR[(1+K)+(1-K)\cos2ϴ]/2$
= 2.17x73.9 [(1.8) + 0.2(1)]/2
= 160.363 kips
= 160363 lbs
N_u = 713.33 kN
M_u = $wR^2\ [(1-K)\ \cos2ϴ]/4$
= $2.17x73.9^2\ [0.2(1)]/4$
= 592.54 kips-in
= 592539 lbs-in
M_u = 66.948 kNm
t_{ru} = M_u-0.45 N_ud/bd r_s
= [592539.8-0.45(160363x5.9)]/ (11.81x5.9x69.95)
t_{ru} = 34.217
R_{rt} = t_{ru}/t_{rc}
= 34.217/75.78
= 0.465
Similarily, when ϴ= 45◦ and 135◦
N_u = 144.3267 kips
N_u = 144326 lbs
N_u = 641.5 kN
M_u = 0
t_{ru} = 78.64 kN
R_{rt} = -1.04
Similarily, when ϴ= 90◦
N_u = 570.65 kN
M_u = -592539.8 kNm
t_{ru} = -191.45
R_{rt} = -2.52
Here taking the minimum R_{rt} value
ϴ= 0◦,R_{rt}= o.46<1.0 Hence Ok
Approxiamate solution for R_{rt}
R_{rt} = $A_{si}\ f_y/16\ r_s(f_c')^{½}$
R_{rt} = 1.533

Table 1: Radial Tension Analysis

θ	M_u	N_u	t_{ru}	R_{rt}
0°	592539.8	160363	34.217	0.465
45°	0	144326	-78.64	-1.04
90°	-592539.8	128288	-191.45	-2.52
135°	0	144326	-78.64	-1.04
180°	592639.8	160363	34.217	0.465

7. BASIC SHEAR STRENGH:

V_b = $[b\text{Ø}d(F_{vp}(f_c')^{1/2}\ (1.1+63B)F_d]/f_c\,f_h$
Here
F_{vp} = 1.00
F_d = Crack depth effect
F_d = $0.8+1.6/\text{Ø}d$
F_d = 1.10
F_c = Effect of curvature
F_c = $1+\text{Ø}d/2R$
= 1.035
F_n = Effect of thrust
V_u = $[wR\ (1\text{-}K)\ \sin 2\theta]/2$
= $2.17\text{x}73.9\ (0.2\sin 66^\circ]/2$
V_u = 14.65 kips
V_u = 14650 lbs
V_u = 65.166kN
N_u = 128.288kN
N_u/V_u = 128.288/14.65
N_u/V_u = 8.75
Since N_u/V_u lies between $u \leq N_u/V_u <$ infinity
F_n = 0.7
V_b = $11.81\text{x}0.9\text{x}\ (3988)^{1/2}[1.1+63p\ (1.11)]/\ (1.03\text{x}0.7)$
P = $P_{total}/2$
= 0.0459/2
P = 0.02292
V_b = 671.23x2.823/1.03x0.7
V_b = 2628.8716
V_b = 2.62 kips
V_b = 11.65kN
$V_b < V_u$ provide stirrups

8. STIRRUPS:

A_{vs} = $(1.1S/f_v\text{Ø}d)\ (V_uf_c\text{-}V_c)\ +A_{vr}$
S_{max} = $0.75\text{Ø}d$
= 0.75x0.9x5.9
= 3.98 in
S_{max} = 0.100m
V_{cmax} = $2b\text{Ø}d\ (f_c')^{1/2}$
= $2\text{x}11.81\text{x}0.9\text{x}5.9\text{x}\ (3988)^{1/2}$
A_{vr} = $1.1s(M_u\text{-}0.45N_u\text{Ø}d)/f_vr_s\text{Ø}d$
r_s = $D_i/2+t_b+d_b/2$
r_s = 69.95
A_{vr} = 0.02194
= 0.0676+002194
A_{vs} = 0.10 in^2
A_{vs} = 64.512 mm^2

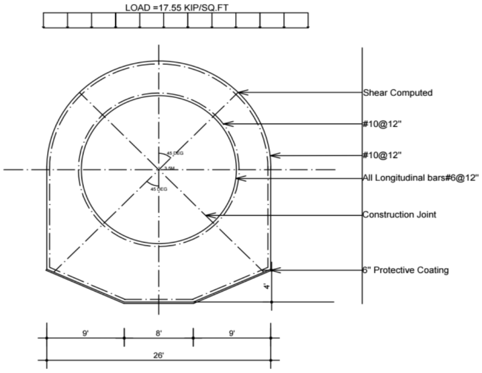

Fig. 8: Reinforcement Details

9. CONCLUSION

The standard horse shoe cross section has a semi circular top portion, which is the best shape for a cross passage but the horseshoe shape has been used in dozens of tunnels to allow for greater floor width, thereby facilitating the passage of equipment through the tunnel and allow more number of passengers. Design of Horse-shoe shaped cross passage for an twin tunnel system can be considered as an enthusiastic project. Specimen design for cross passage is manually done and enclosed with the report. Thus the cross passage was successfully designed and analyzed.

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