EXPRESS CONSTRUCTION OF PEDESTRIAN UNDERPASS USING CORRUGATED STEEL BOX CULVERT[1]

Ankur AGARWAL*

*) PSL Corrosion Control Services Limited, India

This paper deals with a new pedestrian underpass made from structural deep corrugated plates over a newly constructed airport access road for Mumbai International Airport, India. The underpass was constructed to cater for the demands of local establishments for crossing the highway. The steel bridge is founded on raft footing made of reinforced concrete. Its effective span is 4.10 m and clear height is 2.29 m. The entire underpass was constructed in just 20 days. The structural design and construction of the underpass is described in detail in this paper.

Key words: Pedestrian Underpass; Corrugated Steel Plates

1. INTRODUCTION

Mumbai International Airport Limited has recently built an access road to connect the international terminal to a highway for traffic decongestion. Just before opening the road to traffic the investor decided to construct an underpass crossing the highway to facilitate pedestrian traffic crossing the road, in response to the needs of local people. It was decided to construct an underground structure using deep corrugated steel plates due to its many advantages such as lightweight, environmental friendliness, cost-effectiveness, rapid construction, etc. [1], as an alternative to the RC culvert and not delaying the grand opening of the access road. The lower initial cost and long term maintenance cost works in favor of corrugated metal structures [2].

This paper deals with the design and construction of deep corrugated steel structure which was constructed at Mumbai International Airport Limited (MIAL). The structure was fabricated to shape with multiple pieces of corrugated steel plates jointed together by high strength bolts. The entire structure along with fixtures was heavily galvanized for corrosion protection. Currently we do not have formal technical specifications for the design of buried structures;

therefore, international standards have been adopted for the design and installation of the structure. It is shown that these structures can be conservatively designed using a frame analysis or using finite element analysis, modeling the beneficial effects of soil structure interaction. Comparisons are made between simple and rigorous analysis of the structure and then analyzed.

2. UNDERPASS DESCRIPTION

The structure under consideration is a deep corrugated box type structure, with a span of 4.1m and a rise of 1.8m. The length of the underpass is 36 m, and the top road is first-class highway designed with ten traffic lanes. The depth of soil cover varies from 700mm to 1m over the structure. A cross section of the box structure is presented in Fig. 1.
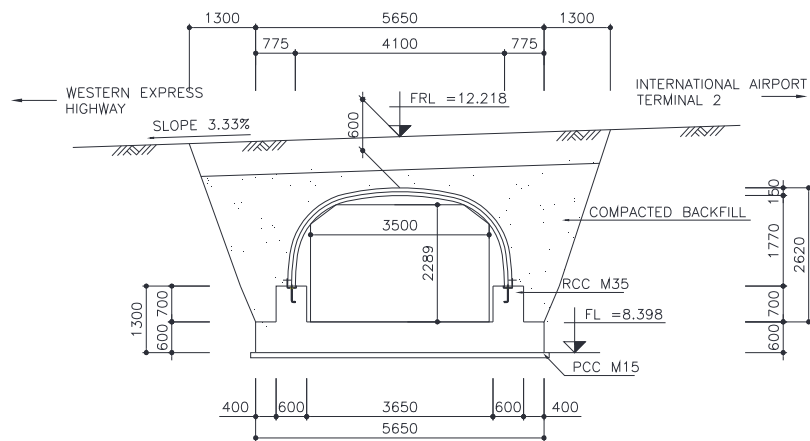
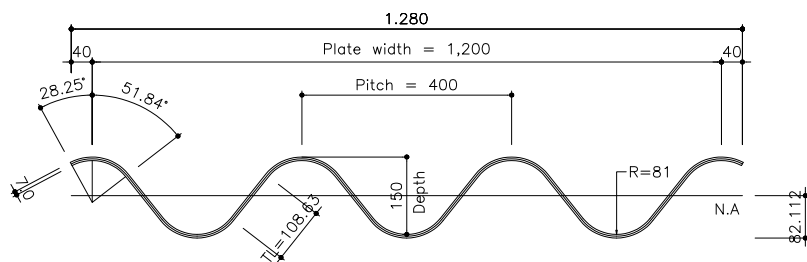Fig.1. Cross Section of the underpass

Fig.2. Profile of corrugated steel plate

The material of the corrugated steel plate is structural steel SS40 of 7mm thickness with yield strength and tensile strength of 275 MPa and 380 MPa,

respectively. The profile of the corrugated steel plate for the wall is 400 x 150 mm as shown in Fig.2. Crusher dust [3] is used as granular backfill and rigid pavement is made on top of the backfill. Backfilling is carried out symmetrically during the construction period.

3. DESIGN METHODOLOGY

3.1. Structural Design

The structural performance of buried corrugated steel structure depends on properties of both the structure and the surrounding soil as well as on the resulting interaction between the two. Detailed design specification for designing buried corrugated structures is given in American Association of State Highway and Transportation Officials (AASHTO) Bridge Design Specifications [4] and Canadian Highway Bridge Design Code (CHBDC) [5].

Buried Flexible Structures, owing to the interaction of structural steel plate with the surrounding soil, are able to carry a very large loading taking the advantage of arching [3]. That phenomenon is observed as a reduction of soil pressure on the top surface of the shell. Arching is a phenomenon of redistribution of shell loading as a result of occurrence of tangent stresses, which counteracts the displacement in soil mass.

The most suitable material for the backfill is well compacted granular material which can be assumed to have no time-dependent properties.

The profile used in the design is steel box section which is relatively flat at the top as compared to steel arch and requires large flexural capacity due to extreme geometry and shallow cover depths. The effect of thrusts is negligible as compared to that of flexure in case of box type culverts [6].

3.2. Model analysis

At the ultimate limit state, the factored crown and haunch moments shall not exceed the factored Plastic Moment capacity of the section. The Factored crown and haunch (shoulder) moments, M_{cf} and M_{hf}, induced by dead and live load is computed by the following equations:

$$M_{cf} = \alpha_D M_{cD} + \alpha_L M_{cL} \left(1 + DLA\right) \tag{1}$$

$$M_{hf} = \alpha_D M_{hD} + \alpha_L M_{hL} \left(1 + DLA\right) \tag{2}$$

Where, α_D and α_L are load factors for ultimate limit state (ULS) combination from CHBDC, M_{cD} and M_{hD} are the bending moments (kN-m/m) as a result of dead load (backfill weight and surcharge) and M_{cL} and M_{hL} are the bending moments (kN-m/m) as a result of live loading over the structure, and DLA is Dynamic Load Allowance [4,5].

The bending moments at crown and haunch location are calculated as per the

specifications given in Canadian Highway Bridge Design Code (CHBDC) & AASHTO code and Finite Element Analysis separately.

The unit weights of different materials used are summarized in table 1 below:

Table 1: Unit Weight of Material Used

Material	Unit Weight, kN/m3
Pavement Quality Concrete	24
Dry Lean Concrete	24
Wet Mix Macadam	23.5
Granular Soil	20
Crushed Rock	22

3.3.   Finite element analysis

A finite element analysis is also performed to compare the results with the numerical analysis. Using PENTAGON 3D FEM, 2-D and 3-D analyses are done to examine soil-steel structure behaviour under loading. Due to shallow cover of fill, the behaviour of buried structure becomes complex and depends entirely on soil-structure interaction [7].

The Corrugated steel plate is modelled as flat plate using the equivalent stiffness principle [8]. The moment of inertia and cross section of steel plate per unit length are 27021 mm4/mm and 9.640mm2/mm; its elastic modulus and unit weight are 2.1 x 10^5 MPa and 78.5 kN/m3. Shell4 element is utilized for corrugated steel plate unit and Hexa8 element is adopted for backfill and pavement layer. The backfill is modelled based on [9] which depends on the degree of backfill compaction. A combination of live load is taken using vehicle class A and Vehicle Class 70R. The finite element model is shown in Fig. 3.
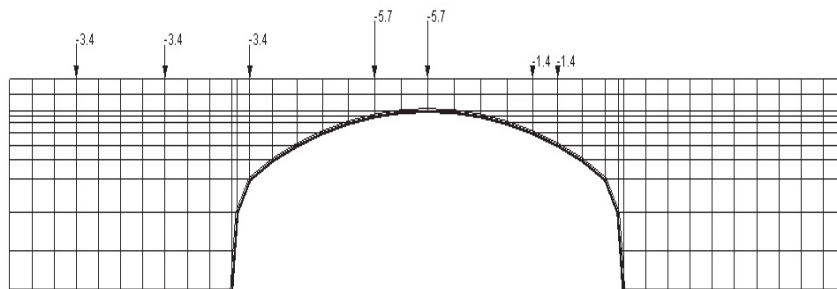

Fig. 3. Finite Element Analysis Model

The combined effects of bending moments and axial thrust arising from specified dead load and live load shall satisfy the following condition:

$$\left[\frac{P}{P_{pf}}\right]^2 + \left[\frac{M}{M_{pf}}\right] \leq 1.0 \qquad (3)$$

Where P_{pf} = factored compressive strength of corrugated steel section without buckling

M_{pf} — factored plastic capacity of the section

P — $T_D + T_L$, Axial Thrust due to dead load and live loads, respectively

M — Moment due to dead load and live loads

4. CONSTRUCTION TECHNIQUES

4.1. Installation of corrugated steel shell

Corrugated steel structures, owing to their strength, light weight and resistance to fracture, can be installed quickly, easily and with the least expensive equipment. The flexibility of steel shell permits unequal tolerance to settlement and dimensional changes that would sometimes cause failure in rigid structures [10].

The corrugated steel plates are manufactured in width-wise pieces of 1.2m and varying length and are assembled on-site using high strength bolts. The structure is bolted over the base channel already anchored and casted into the footing. Single rings are assembled off-site and moved to position via crane which is assembled to base channel and the previous ring. The torqueing is done properly and checked and verified at all locations to ensure stability of the metal shell.

The entire structure can be assembled off-site or on-site, depending on the site conditions. It is however useful for small span or length which is not the case here. Hence ring by ring assembly is adopted in this case, as shown in Fig. 4. It is important to maintain the design shape of the structure during plate assembly.

Fig. 4. Installation in progress

4.2. Backfilling and Compaction

As the corrugated steel shell is highly flexible, the backfilling process has considerable effect on moments, thrust and deflection of the structure. As the backfill is being placed by the sidewall, the structure experiences upward movement as a result of lateral pressures that the soil applies. The largest change in deflection, bending moment and thrust between lifts during backfilling occurs when the first layer over the crown is placed (Webb et al., 1998).

The backfilling process starts from the headwall towards the centre of the structure. The backfill is provided in layers of 200mm each and is compacted to minimum proctor density of 95%. The backfilling is done simultaneously on both sides of the corrugated steel structure so that no moment is induced in the shell due to uneven loading.

The backfilling is done parallel to the length of the structure till 3/4th of the rise is reached and then the backfilling is done perpendicularly to the structure. This is done to minimize the impact of the material placement and compaction methods on the structure. Fig. 5 shows the backfilling process from the end of headwall and commencing towards the centre of the structure. Fig. 6 shows the perpendicular compaction process on top of the structure. The pavement is made on top of the backfill after the compaction is completed up to the required height.

The deflection is measured at all stages of installation and backfilling to check and ensure the stability of the structure.

Fig. 5. Compaction Process

Fig. 6. Compaction

5. RESULTS AND DISCUSSIONS

5.1. Finite Element Analysis Interpretation

The flexural thrust and moment at crown and haunch is taken from the finite element analysis and compared with plastic moment capacity of the section. The effects of thrust was ignored as it did not cause much variation in the results. This is in accordance with the AASHTO and CHBDC codes.

5.2. Comparison between Theoretical and Analytical Results

The factored thrust and moments calculated by CHBDC and AASHTO equations is compared with Finite Element Analysis Results. The moment at crown and haunch is higher when calculated by AASHTO/ CHBDC code and the moment from finite element analysis is lower.
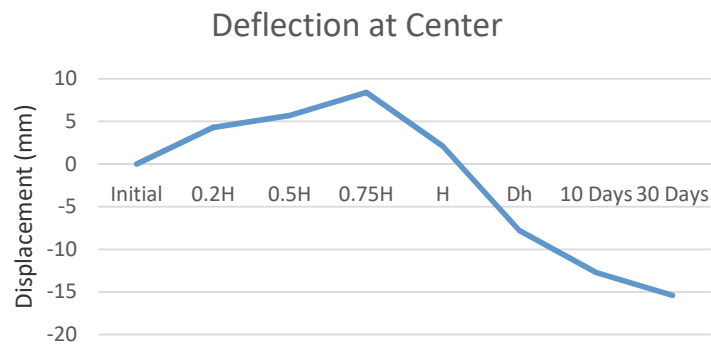
The estimated moment due to live load is higher than dead load moment as can be interpreted since the weight of structure is negligible. Thus the live load thrust and moments are the governing forces and moments in case of corrugated steel plate box structures with low soil cover.

Table 2: Bending Moment Values

Results	Unfactored Bending Moment			
	At Crown		At Haunch	
	DL	LL	DL	LL
CHBDC/ AASHTO	8.46	26.14	6.50	17.32
FEM Analysis	8.21	25.23	6.12	16.88

5.3. Deflection of the structure

The deflection at various construction stages is measured and plotted to check structure stability. It is observed that the crown moves vertically up during the initial placement of the backfill at sides and then progressively moves down when the backfill reaches the crown top. This is understandable as the structure will deflect upwards (peaking) at the initial stage. When the backfill is placed on top of the structure, the movement is downwards due to the weight of the backfill. The end result is the structure coming into the designed shape. The total deflection comes to be within 2% of the structure's span.

Deflection at Center

6. CONCLUSIONS

Deep corrugated steel plate structures prove to perform extremely well under normal traffic loads. Quick, easy and cheap construction together with very good bearing capacity of the structures can be an excellent alternative to traditional construction practices. These structures can be used as a bridge replacement where less construction time is required, allowing earlier project completion. Minimum maintenance and a longer life span with corrosion resistance make it optimum for usage as road and railway bridges and tunnels.

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