Design of the Underwood Road Ventilation Facility on WestConnex 1B
Sydney
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Abstract: The Underwood Road Ventilation Facility (URVF) is located at the western end of the WestConnex M4 East Project siting directly above the westbound carriageway and alongside the existing M4 eastbound carriageway. The ventilation structure is 23.8 metres by 15.8 metres in plan and 40 metres high and compromises of six internal shafts. Five of the shafts support fans, damper and attenuator equipment ranging from 15 tonnes to 55 tonnes. The remaining shaft provides access into the mechanical shafts. The URVF structure comprises of over 16 levels precast wall elements, weighing approximately 13 tonnes each, and a series of internal precast floor with reinforced topping slabs tied to the precast walls. The vertical and lateral loadings are transferred into the underlying cut and cover structure via a series of 2.5-metre deep by 1.5-metre wide reinforced concrete beams with up to nine layers of reinforcement. In the structural design of the URVF, a sensivity analysis was undertaken to assess the impact of the cut and cover structure under due to wind and earthquake loading. In addition, impacts of modelling the precast joints to simplify the precast dowel connections was also assessed. As with the rest of the cut and cover structure, the URVF has been designed for a two-hour hydrocarbon fire which is not currently addressed in Australian design codes. Hence this posed challenges in the concrete mix design, reinforcement detailing and fire protection of the wall dowel joints.

Keywords: WestConnex 1B, ventilation, precast, complex, fire

1. Introduction

The Underwood Road Ventilation Facility (‘URVF’) is the western ventilation structure for WestConnex Stage 1B and is located approximately 15 kilometres south west of the Sydney central business district. As the 40 metre high structure is in a built urban environment located directly above the western carriageway of the Homebush Bay Drive Cut and Cover, a precast structural system was adopted. The URVF comprises of precast wall and floor elements tied together with in-situ topping slabs and stainless-steel wall dowels to support equipment weights up to 55 tonnes. The URVF structure is illustrated in Figure 1 below.
Figure 1: URVF structure over Homebush Bay Drive Cut and Cover

This paper will explore the design process of this complex structure.

2. Underwood Road Ventilation Facility

The Underwood Road Ventilation Facility (‘URVF’) is the exhaust station located at the western end of WestConnex Stage 1B. With the constraints of the site and the construction program of the underlying cut and cover structure, a precast construction methodology was adopted in lieu of a cast in-situ reinforced concrete structure.

![URVF Isometric](image)

Figure 2 URVF Isometric

2.1 Building Geometry

The structure is 23.8 metres by 15.8 metres in plan and 40 metres high and compromises of six internal shafts with seven floor levels. Five of the shafts support exhaust fans, intake acoustic attenuators, discharge ductwork transitions, isolation dampers and discharge acoustic attenuator equipment ranging from 15 tonnes to 55 tonnes. The remaining shaft provides access into the mechanical shafts. Each fan assembly is located within an individual concrete shaft with maintenance access to each level via a set of common access stairs from Ground Level.

The configuration of the structure is shown in Figure 3 below.
The focus of this paper is on the structural design of the URVF building.

2.3 **Structural Framing System**

2.3.1 **Shaft Walls**

The shaft walls consist of 250mm thick, 2.5m high precast reinforced concrete panels. Three wall panel configurations, L-shaped, T-shaped or straight, are used to arrange the panels and provide alternating horizontal joint arrangements (connecting the panels top to bottom). The horizontal joint connection consisted of dowel bars grouted into the concrete panels. Vertical joint (connecting the panels side to side) are provided by dowel bars inserted in slots between the panels, which are grouted after placement. Penetrations are provided in the walls panels for services, operation and maintenance requirements.

2.3.2 **Basement Level – B01**

At the basement level, shaft walls are supported on deep concrete in-situ transfer beams (2500mm deep by 1200mm wide) tied into the westbound cut and cover tunnel structure. These transfer beams also support the steel grillage for the intake noise attenuator and any associated equipment loads.
2.3.3  **Ground Entry Level – L00**

At ground level there is a precast composite slab in the access shaft. This is the lowest level served by the steel stair that gives access up the shaft.

![Figure 5 Ground Floor Framing](image)

2.3.4  **Service Entry Level – L01**

The service entry level above ground floor consists of a steel platform with access to other maintenance platforms in each ventilation shaft.

![Figure 6 Service Entry Framing Plan](image)

2.3.5  **Fan Level - L02**

The fan floor level is a composite precast RC floor with in-situ topping slabs with an overall thickness of 450 mm. Temporary support angles are provided to assist with installing the precast floor panels during construction.

A circular penetration is required through the centre of each shaft to accommodate for air flow into the exhaust fans. This will be formed with a steel bell-mouth to provide a smooth air passage.
2.3.6 **Duct Transition – L03**

The Duct Transition level consists of a combination of precast beams and in-situ topping around the vent shaft perimeter to support the duct transition.
2.3.7 **Attenuator Level – L04**

The attenuator level consists of a combination of precast beams and in-situ topping around the vent shaft perimeter. Temporary support angles will also be provided to assist with installing the precast beams during construction. A grillage of steel beams is provided to support each discharge attenuator module on four sides.
2.3.8 **Damper Level – L04**

The Damper level is located above the discharge attenuators and consists of a precast corbel supporting steel beams for the Dampers.
2.3.9 Roof - L05

At the roof there is a composite slab in the access shaft at the top of the steel stair. This is positioned below the parapet level to allow the stairs to terminate with a conventional doorway. The centre part of the slab will be infilled with a precast roof.

2.4 Design Loadings

The structure has been designed for the following loads:

2.4.1 Ventilation and Mechanical Equipment

The URVF building has been designed for the following loads:

- Intake attenuators at Basement Level B01 - Total of 5 intake noise attenuators with an individual maximum weight of 55 tonnes
- Fans at Level 02 – Total of 5 axial ventilation fans with an individual maximum weight of 22.5 tonnes and extra allowance of 6 tonnes for fan motor removal during maintenance
- Duct transitions at Level 03 - Total of 5 ductwork transition pieces with an individual maximum weight of 21 tonnes.
- Discharge attenuators between Level 03 and Level 04 - Total of 5 discharge noise attenuators with an individual maximum weight of 55 tonnes
- Dampers at Level 04 - Total of 5 motorised isolation dampers with an individual maximum weight of 5.64 tonnes positioned above the slab

In addition to the mechanical equipment loading, the structure has been designed to support monorail loads directly under the Discharge Attenuator level and the Service Entry level 05, which will be used during maintenance and replacement of these equipment. Furthermore, positive and negative air pressures induced due to active ventilation fans were considered for the design of this structure – this was +1.6kPa (pressure) and -1.9kPa (suction) respectively.
2.4.2 Earthquake Loading

Earthquake loads were considered in accordance with AS 1170.4[1]; seismic effects were quantified based on an Importance Level of 4 and Earthquake Design Category 3 for the URVF building.

2.4.3 Wind Loading

Wind loads were considered in accordance with AS 1170.2[2]; wind effects were quantified based on an Importance Level of 4 and Terrain Category 3 for the URVF building.

2.5 Design Criteria

2.5.1 Design Life

All structural elements of the URVF building are designed for a 50-year design life except for the following:

- Access stairs, walkways and platforms – 20-year design life, and
- Structural steelwork – 25-year design life

The concrete exposure classification considered was based on the project-wide durability report; this was in accordance with AS 5100.5 [3], which varied from B1+ to B1.

Steel members that form support systems for mechanical equipment (attenuator and damper support frames) have a 25-year design life in conjunction with the required design life of the mechanical equipment.

2.5.2 Design Codes

The URVF building has been designed for a 50-year design life and to a BCA Importance Factor of 4 with post-disaster functionality under the requirements of AS/NZS 1170.0[4]. The structure has been designed to the loadings required under AS/NZS 1170.1[5], AS/NZS 1170.2[2] and AS 1170.4[1].

To meet the project design life requirements, all concrete elements have been designed to comply with AS 5100.5 [3], RMS D&C Specification B80 [6] and with AS 3850.2[7] for precast concrete elements. The minimum concrete strength adopted was 40 MPa for in-situ elements and 50 MPa for precast elements.

Structural steel elements were designed to comply with AS 4100 [8] or AS/NZS 4600 [9] and RMS D&C Specification B240[10] and B241[11]. Project design life requirements of steel elements were met by specifying all steelwork to be hot-dip galvanised to AS 4680 [12] with a minimum zinc coating rate of 800g/m².

2.5.3 Fire Design

All structural elements of the URVF building are designed for a fire resistance period (FRP) of 240/240/240 to cellulosic fire and 120/120/120 to hydrocarbon fire except for the following:

- Walls and floors of access shaft – FRP of 0/0/0
- Access stair, all walkways and platforms – FRP of 0/0/0
- Steel members supporting attenuators and dampers – Structural adequacy at 450°C for 120 minutes
For concrete elements, appropriate covers and section sizes were considered in accordance with AS 3600[13] for four-hour cellulosic fire resistance. However, resistance against hydrocarbon fire is not currently addressed in Australian design codes. The main reference for this came from a special hydrocarbon fire report produced to address hydrocarbon fire loads for designing cut and cover structures. As a result, concrete elements requiring two-hour hydrocarbon fire resistance were specified to have a minimum dosage of 1.5kg/m$^3$ of polypropylene fibre within the concrete mix. In addition, spalling and temperature effects within the concrete cover zone and on critical reinforcement bars were also considered respectively.

Steel members supporting attenuators and dampers were designed for the above-mentioned fire case using Section 12 of AS 4100[8]; reduced yield stress and modulus of elasticity values at 450°C were considered in the design. Bolted connections are protected from elevated temperature effects using fire-rated polymeric bolt caps.

2.6  **Interface with Cut and Cover structure**

The ventilation shaft walls are supported on a series of deep reinforced concrete beams in the cut and cover structure with spans up to 20 metres.

![Figure 15 URVF Structure Transfer beams](image)

In order to design the transfer beams and shaft walls, a series of sensitivity studies were undertaken to design both key elements by considering differing boundary restraints and element stiffness. These studies included modelling gap elements in the walls precast wall to replicate the vertical and horizontal dowels.
3. Key Design Considerations

3.1 Mechanical and Ventilation Operation and Maintenance Requirements

To ensure maintenance and replacement of the ventilation equipment can occur throughout the life of the structure, the following provisions have been made:

- Monorails at Discharge Attenuator level and the Service Entry Level 05
- Cast-in pulling eyes in walls at various locations
- Temporary loading platforms
- Total of five (5) large openings with removable precast wall panels (apx. 5m by 5m) above Fan Level 02

3.2 Crane support on transfer beams

With limited space on site to accommodate the tower crane to lift the precast concrete elements into place, the transfer beams in the cut and cover structure were designed to support a tower crane located in the access service shaft.

3.3 Precast joint design

The horizontal precast joint connection consists of vertical dowel bars grouted into the concrete panels within a corrugated steel sleeve. Vertical dowels were designed to transfer horizontal shear forces between the precast panels resulting from lateral design loads (wind or earthquake). Vertical precast joints connect the precast panels side-to-side; two panels are tied together with horizontal dowel bars inserted in slots between the panels, which are grouted after placement.
To ensure these precast joints and dowel bars are not structurally compromised in a fire event, all joints are specified to be covered over with a special vermiculite-based fire-resistant material. On this basis, the outermost concrete surface affected by 2 hours of hydrocarbon fire can be kept below 250°C (per the manufacturer’s fire test results).

3.4 **Design of precast wall to floor connections**

The design for each floor comprised of the following two stages:
• Temporary stage – during the temporary stage, the precast concrete panel or edge beam is supported by a series of temporary steel angles.

• Permanent case – in the permanent case, the in-situ reinforced concrete topping and precast panel/beam act as one composite section to support the final design loads. The load is transferred into the precast walls via a series of cast-in ferrules and scabbled edge rebates.

![Typical Precast Panel](image)

**Figure 20 Typical Precast Panel**

![Typical Precast Panel Connection to Wall](image)

**Figure 21 Typical Precast Panel Connection to Wall**

### 3.5 Innovative strategies

In the design of the URVF building, the following strategies were adopted in collaboration with the contractor:

• Prefabrication of beam reinforcement cages – Given the constrained site and limited crane time, the beam reinforcement cages were detailed to be fabricated off site. Once installed, splices bars are installed to comply with the detailing requirements of AS 5100.5 [3]

• Concrete pouring sequence of topping slabs – To ensure constructability and safety
Figure 22: Typical Topping Slab Pouring Sequence

4. Conclusions

The Underwood Road Ventilation Facility is a complex structure currently under construction in the inner west of Sydney. The design of the structure required complex structural engineering analysis to design a precast concrete structure to support significant equipment loads and comply with stringent fire performance requirements.

5. Acknowledgement

The design of this structure has been delivered by the AECOM Arcadis JV in collaboration with our client: CPB Contractors, John Holland and Samsung C&T JV. The other key members of the design team are HASSEL (architect), NDY (mechanical and electrical designer), PSM (geotechnical engineer) and McMillen Jacobs Associates (tunneling engineer).

6. References

[6] Roads and Maritime Services (RMS) QA Specification B80 Concrete Works for Bridges