DECEMBER 2018
LEIGHTON CONTRACTORS (ASIA) LIMITED

HUNG HOM STATION EXTENSION

SHATIN TO CENTRAL LINE PROJECT

FINDINGS OF THE INDEPENDENT STRUCTURAL ASSESSMENT OF THE EWL SLAB TO DIAPHRAGM WALL CONNECTION

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CONTENTS

APPENDICES

1 Executive Summary

COWI have undertaken an independent structural analysis and assessment of the connection of the east west line slab to diaphragm walls for Hung Hom Station. The structural analysis and assessment being undertaken for the purposes of the Commission of Inquiry into the Diaphragm Wall and Platform Slab Construction Works at the Hung Hom Station Extension under the Shatin to Central Line Project.

The structural analysis and assessment has been undertaken for three sections; two sections located in Area C (Section 1 gridlines 41 to 46 and Section 2 gridlines 24 to 30) and a single section in Area B (Section 3 gridlines 16 to 19).

The connection Design as Constructed has been assessed at the Ultimate Limit State for the moments and forces determined from a structural analysis of the slab. The structural analysis has been undertaken using a similar methodology and approach to that used for the Original Design.

The findings of the structural analysis and assessment show that the connection Design As Constructed meets the requirements of the Design Standards applied to the Project. The findings of the Assessment are summarised below.

- The maximum Connection bending moment utilisation is less than 40%.
- The maximum Connection shear force utilisation is 74% but this occurs at a panel with a void which has reduced capacity. Elsewhere the peak utilisation is 51%.
- Reinforcement surplus to the requirements of the Design Standards has been provided in the connection. The percentage of surplus reinforcement ranges from 12% to 101% across the sections assessed.

2 Introduction and Scope of the Assessment

COWI UK Limited (COWI) have been instructed by the solicitors for Leighton Contractors (Asia) Limited (LCAL) to undertake an independent structural analysis and assessment of section utilisation of the east west line slab to diaphragm wall connection at Hung Hom Station and prepare a report for the Commission of Inquiry into the Diaphragm Wall and Platform Slab Construction Works at the Hung Hom Station Extension under the Shatin to Central Line Project.

We understand that investigations are underway into the diaphragm walls and platforms slabs that are the subject of our assessment. In this context, we reserve the right to supplement or amend this report, including if new information emerges that would be relevant to our assessment.

The scope of the structural analysis and assessment, the Assessment, is set out below:

> Develop structural models and perform structural analyses of particular locations of the east west line slab to determine the permanent design effects in the connections between the east west line slab and diaphragm walls, the Connection.

> Determine the connection capacity based on drawings provided by LCAL for both the Design As Constructed and the Original Design. The Original Design is the design at commencement of the project as accepted by the Buildings Department of the Government of Hong Kong.

> Determine the Connection utilisation for both the Design As Constructed and the Original Design at the Ultimate Limit State.

COWI have assessed the following locations as directed by LCAL:

> Section 1 - Gridlines 41 to 46 (Area C)

> Section 2 - Gridlines 24 to 30 (Area C)

> Section 3 - Gridlines 16 to 19 (Area B)

We understand that the above Sections were selected on the basis that these may be of interest to the Commission of Inquiry:

> Section 1 - Inclusive of the location of NCR 157

> Section 2 - The area with more substantial soffit repairs

- Section 3 - Location where the line of the west diaphragm wall changes resulting in the longest span between diaphragm walls

3 Background

Hung Hom Station Extension Project forms part of the Shatin to Central Link (SCL) Project, a strategic railway project connecting existing railway lines. The works at Hung Hom Station require the construction of two new railway lines, the east west line (EWL) and the north south line (NSL). The EWL is directly above the NSL. Both lines being constructed below the existing elevated podium structure which supports the existing station concourse and road network. As a consequence of constructing beneath an existing elevated structure a number of existing piled columns supporting the structures above were underpinned and the loads transferred to the new structural slabs.

The structural configuration comprises diaphragm walls referred to as east side and west side walls to which the EWL slab and NSL slabs are connected. The entire structure is constructed of reinforced concrete. The diaphragm walls typically being 1.2m thick, the EWL slab 3.0m thick and the NSL slab 2.0m thick. The EWL slab has a variety of openings and/or voids within the depth of the slab. These openings and voids are provided for a number of different purposes including services, ventilation, movement of people within the confines of the station, temporary openings for construction purposes some of which are temporary enlargements of permanent openings.

The structure was constructed by top down construction techniques, meaning that following installation of the diaphragm walls, the EWL slab was constructed first then excavation down to and construction of the NSL slab.

The main parties to the above works and their role are:

Organisation	**Role**
MTR Corporation	Client and Project Manager
Leighton Contractors (Asia) Limited	Contractor
Atkins	Design Consultant

The focus of this report is the structural connection between the EWL slab and the east and west diaphragm walls.

4 Basis of the Assessment

4.1 Reference Information

The Assessment has been based on the following documents and drawings relating to the design and construction details made available by LCAL. A detailed list of the pertinent information used in the Assessment is presented below.

Table 4.1.1 Original Design Reports

Document Deliverable No.	**Title**	**Revision / Issue Date**
TWD-004C1	Design Report for HUH Station Primary Structure Primary Slabs For Temporary Loadcases Area C (Grid 22 - 40) BD Consultation Document Volumes 1 to 4	C1/03 March 2016
TWD-094A	Design Report for HUH Station Primary Structure and Excavation & Lateral Support: Area B BD Consultation Document HUH-3 Volumes 1 to 3	A/29 June 2015
PWD-059A3	Discussion on Design Amendment Works D-Wall	A3/9 July 2015

Table 4.1.2 Various including Setting Out of Diaphragm Walls, Loading Plans, Existing Column Loadings, Openings and Construction Sequence.

Document	**Title**	**Revision / Issue Date**
1112/W/HUH/ATK/C01/208	EWL TRACK LAYOUT TEMPORARY CONSTRUCTION REQUIREMENTS (SHEET 3 OF 5)	B/27 Nov 15
1112/W/HUH/ATK/C01/209	EWL TRACK LAYOUT TEMPORARY CONSTRUCTION REQUIREMENTS (SHEET 4 OF 5)	B/27 Nov 15
1112/W/HUH/ATK/C01/210	EWL TRACK LAYOUT TEMPORARY CONSTRUCTION REQUIREMENTS (SHEET 5 OF 5)	C/06 May 16
1112/W/HUH/ATK/C02/005	EWL TRACK LEVEL LOADING PLAN	B/06 May 2016

Document	Title	Revision / Issue Date
1112/W/HUH/ATK/C02/006	EWL PLATFORM LEVEL LOADING PLAN	A/08 Mar 2013
1112/W/HUH/ATK/C02/010	EWL OTE ROOF LEVEL LOADING PLAN SHEET 1	A/08 Mar 2013
1112/W/HUH/ATK/C02/011	EWL OTE ROOF LEVEL LOADING PLAN SHEET 2	B/04 Sep 2017
1112/W/HUH/ATK/C10/F34	GENERAL ARRANGEMENT PLAN EWL PLATFORM LEVEL SHEET F34	D/04 Sep 2017
1112/W/HUH/ATK/C10/F35	GENERAL ARRANGEMENT PLAN EWL PLATFORM LEVEL SHEET F35	D/04 Sep 2017
1112/W/HUH/ATK/C10/F36	GENERAL ARRANGEMENT PLAN EWL PLATFORM LEVEL SHEET F36	C/04 Sep 2017
1112/W/HUH/ATK/C10/F38	GENERAL ARRANGEMENT PLAN EWL PLATFORM LEVEL SHEET F38	C/04 Sep 2017
1112/W/HUH/ATK/C10/A34	GENERAL ARRANGEMENT PLAN NSL TRACK LEVEL SHEET A34	E/04 Sep 2017
1112/W/HUH/ATK/C10/A38	GENERAL ARRANGEMENT PLAN NSL TRACK LEVEL SHEET A38	E/04 Sep 2017
1112/W/HUH/ATK/C10/B34	GENERAL ARRANGEMENT PLAN NSL PLATFORM LEVEL SHEET B34	E/04 Sep 2017
1112/W/HUH/ATK/C10/B35	GENERAL ARRANGEMENT PLAN NSL PLATFORM LEVEL SHEET B35	D/06 May 2016
1112/W/HUH/ATK/C10/B36	GENERAL ARRANGEMENT PLAN NSL PLATFORM LEVEL SHEET B36	C/06 May 2016
1112/W/HUH/ATK/C10/B38	GENERAL ARRANGEMENT PLAN NSL PLATFORM LEVEL SHEET B38	E/04 Sep 2017
1112/W/HUH/ATK/C10/C34	GENERAL ARRANGEMENT PLAN NSL PLATFORM MEZZANINE LEVEL SHEET C34 (DAmS/1112/C/0476 Sheet No. 2/62 dated 21/09/16)	I/18 Oct 2016

Document	Title	Revision / Issue Date
1112/W/HUH/ATK/C10/C35	GENERAL ARRANGEMENT PLAN NSL PLATFORM MEZZANINE LEVEL SHEET C35	D/04 Sep 2017
1112/W/HUH/ATK/C10/C36	GENERAL ARRANGEMENT PLAN NSL PLATFORM MEZZANINE LEVEL SHEET C36	D/04 Sep 2017
1112/W/HUH/ATK/C10/C38	GENERAL ARRANGEMENT PLAN NSL PLATFORM MEZZANINE LEVEL SHEET C38 (STAMPED CHECK PRINT)	E1/ Stamp Date 07 Oct 2016
1112/W/HUH/ATK/T25/013	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 2 MONTHS 7 to 12 SHEET 1 of 2	J/04 Feb 2015
1112/W/HUH/ATK/T25/014	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 2 MONTHS 7 to 12 SHEET 2 of 2	F/12 Mar 2014
1112/W/HUH/ATK/T25/015	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 3 MONTHS 13 to 18 SHEET 1 of 2	J/04 Feb 2015
1112/W/HUH/ATK/T25/016	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 3 MONTHS 13 to 18 SHEET 2 of 2	F/12 Mar 2014
1112/W/HUH/ATK/T25/017	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 4 MONTHS 19 to 24 SHEET 1 of 2	J/04 Feb 2015
1112/W/HUH/ATK/T25/018	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 4 MONTHS 19 to 24 SHEET 2 of 2	F/12 Mar 2014
1112/W/HUH/ATK/T25/019	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 5 MONTHS 25 to 30 SHEET 1 of 2	I/12 Mar 2014
1112/W/HUH/ATK/T25/020	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPINING STAGE 5 MONTHS 25 to 30 SHEET 2 of 2	F/12 Mar 2014

Document	Title	Revision / Issue Date
1112/W/HUH/ATK/T25/021	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPININING STAGE 6 MONTHS 31 to 48 SHEET 1 of 2	I/12 Mar 2014
1112/W/HUH/ATK/T25/022	CONSTRUCTION SEQUENCE FOR D-WALL AND UNDERPININING STAGE 6MONTHS 31 to 48 SHEET 2 of 2	F/12 Mar 2014
1112/W/HUH/ATK/C11/025	UNDERPINNING FOR AREA B & C COLUMN LOADING SCHEDULE	B/16 Jun 2015
1112/W/HUH/ATK/C17/003	PERMANENT DIAPHRAGM WALL AND BARRETTE LAYOUT PLAN (SHEET 3 OF 5)	C/06 May 2016
1112/W/HUH/ATK/C17/004	PERMANENT DIAPHRAGM WALL AND BARRETTE LAYOUT PLAN (SHEET 4 OF 5)	C/06 May 2016
1112/W/HUH/ATK/C17/005	PERMANENT DIAPHRAGM WALL AND BARRETTE LAYOUT PLAN (SHEET 5 OF 5)	C/06 May 2016

Table 4.1.3 Original Design arrangements and construction details

Drawing No.	**Title**	**Revision / Issue Date**
1112/W/HUH/ATK/C10/121	SECTION 17	A/08 Mar 2013
1112/W/HUH/ATK/C10/122	SECTION 18	A/08 Mar 2013
1112/W/HUH/ATK/C10/123	SECTION 19	A/08 Mar 2013
1112/W/HUH/ATK/C10/129	SECTION 25	A/08 Mar 2013
1112/W/HUH/ATK/C10/130	SECTION 26	A/08 Mar 2013
1112/W/HUH/ATK/C10/131	SECTION 27	A/08 Mar 2013
1112/W/HUH/ATK/C10/132	SECTION 28	A/08 Mar 2013
1112/W/HUH/ATK/C10/137	SECTION 33	A/08 Mar 2013
1112/W/HUH/ATK/C10/138	SECTION 34	A/08 Mar 2013
1112/W/HUH/ATK/C10/139	SECTION 35	A/08 Mar 2013
1112/W/HUH/ATK/C10/164	SECTION 51 (SHEET 4 OF 9)	A/08 Mar 2013
1112/W/HUH/ATK/C10/165	SECTION 51 (SHEET 5 OF 9)	A/08 Mar 2013
1112/W/HUH/ATK/C10/166	SECTION 51 (SHEET 6 OF 9)	A/08 Mar 2013
1112/W/HUH/ATK/C10/168	SECTION 51 (SHEET 8 OF 9)	A/08 Mar 2013
1112/W/HUH/ATK/C10/173	SECTION 55	A/08 Mar 2013
1112/W/HUH/ATK/C10/E34	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E34	A/08 Mar 2013
1112/W/HUH/ATK/C10/E35	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E35	A/08 Mar 2013
1112/W/HUH/ATK/C10/E36	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E36	A/08 Mar 2013
1112/W/HUH/ATK/C10/E38	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E38	A/08 Mar 2013

Drawing No.	Title	Revision / Issue Date
1112/W/000/ATK/C11/051	TYPICAL WATERPROOFING DETAILS SHEET 2	A/08 Mar 13
1112/B/HUH/ATK/C12/018	MISCELLANEOUS RC DETAILS FOR STATION SHEET 7	E/03 Mar 17
1112/W/HUH/ATK/C12/063	EWL TRACK LEVEL SHEAR REINFORCEMENT PLAN SHEET 3	A/08 Mar 2013
1112/W/HUH/ATK/C12/064	EWL TRACK LEVEL SHEAR REINFORCEMENT PLAN SHEET 4	A/08 Mar 2013
1112/W/HUH/ATK/C12/065	EWL TRACK LEVEL SHEAR REINFORCEMENT PLAN SHEET 5	A/08 Mar 2013
1112/W/HUH/ATK/C12/156	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E34	A/08 Mar 2013
1112/W/HUH/ATK/C12/157	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E35	A/08 Mar 2013
1112/W/HUH/ATK/C12/158	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E36	A/08 Mar 2013
1112/W/HUH/ATK/C12/160	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E38	A/08 Mar 2013
1112/W/HUH/ATK/C12/179	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E34	A/08 Mar 2013
1112/W/HUH/ATK/C12/180	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E35	A/08 Mar 2013
1112/W/HUH/ATK/C12/181	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E36	A/08 Mar 2013
1112/W/HUH/ATK/C12/183	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E38	A/08 Mar 2013
1112/W/HUH/ATK/C12/605	PERMANENT DIAPHRAGM WALL RC FOR PANELS TYPICAL DETAILS (SHEET 1 OF 2)	A/08 Mar 2013

Drawing No.	Title	Revision / Issue Date
1112/W/HUH/ATK/C12/606	PERMANENT DIAPHRAGM WALL RC FOR PANELS TYPICAL DETAILS (SHEET 2 OF 2)	A/08 Mar 2013

Table 4.1.4 Alterative Design arrangements and construction details

Drawing No.	Title	Revision / Issue Date
1112/W/HUH/ATK/C10/121	Section 17	D/04 Sep 17
1112/W/HUH/ATK/C10/122	Section 18	E/04 Sep 17
1112/W/HUH/ATK/C10/123	Section 19	E/04 Sep 17
1112/W/HUH/ATK/C10/128	Section 24	E/04 Sep 17
1112/W/HUH/ATK/C10/131	Section 27 (DAmS/1112/C/0476 Sheet No. 27/62 dated 21/09/16)	G/29 Jul 16
1112/W/HUH/ATK/C10/134	Section 30 (DAmS/1112/C/0476 Sheet No. 28/62 dated 21/09/16)	G/30 Oct 15
1112/W/HUH/ATK/C10/164	Section 51 (Sheet 4 of 9) - Longitudinal	D/04 Sep 17
1112/W/HUH/ATK/C10/165	Section 51 (Sheet 5 of 9) (DAmS/1112/C/0476 Sheet No. 29/62 dated 21/09/16)	F/04 Nov 16
1112/W/HUH/ATK/C10/166	Section 51 (Sheet 6 of 9)	E/04 Sep 17
1112/B/HUH/ATK/C10/168	SECTION 51 (SHEET 8 of 9)	E/04 Sep 17
1112/W/HUH/ATK/C10/E34	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E34	E/04 Sep 17
1112/W/HUH/ATK/C10/E35	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E35	F/04 Sep 17
1112/W/HUH/ATK/C10/E36	GENERAL ARRANGEMENT PLAN EWL TRACK LEVEL SHEET E36	E/04 Sep 17

Drawing No.	Title	Revision / Issue Date
1112/B/HUH/ATK/C10/E38	GENERAL ARRANGEMENT PLAN - EWL TRACK LEVEL SHEET E38	D/04 Sep 17
1112/W/000/LCA/C11/051	TYPICAL WATERPROOFING DETAILS SHEET 2	J/21 Oct 14
1112/W/HUH/ATK/C12/063	EWL TRACK LEVEL SHEAR REINFROCEMENT ARRANGEMENT PLAN SHEET 3	C/27 Nov 15
1112/W/HUH/ATK/C12/064	EWL TRACK LEVEL SHEAR REINFROCEMENT ARRANGEMENT PLAN SHEET 4	B/27 Nov 15
1112/B/HUH/ATK/C12/065	EWL TRACK LEVEL SHEAR REINFORCEMENT ARRANGEMENT PLAN SHEET 5	D/04 Sep 17
1112/B/HUH/LCA/C12/027	DIAPHRAGM WALL MODIFICATION PLAN SHEET 1 OF 2	A/27 Aug 18
1112/B/HUH/LCA/C12/028	DIAPHRAGM WALL MODIFICATION PLAN SHEET 2 OF 2	A/27 Aug 18
1112/B/HUH/LCA/C12/746	MISCELLANEOUS RC DETAILS FOR STATION SHEET 6	F/27 Aug 18
1112/B/HUH/LCA/C12/747	MISCELLANEOUS RC DETAILS FOR STATION SHEET 7	E/27 Aug 18
1112/B/HUH/LCA/C12/757	RC DETAILS FOR PANELS TYPICAL DETAILS (SHEET 1 OF 2)	C/27 Aug 18
1112/B/HUH/LCA/C12/770	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E35	E/27 Aug 18
1112/B/HUH/LCA/C12/771	EWL TRACK LEVEL R.C. DETAIL OF SLAB BOTTOM STEEL AREA E36	E/27 Aug 18
1112/B/HUH/LCA/C12/773	EWL TRACK LEVEL R.C. DETAIL OF SLAB - BOTTOM STEEL - AREA E38	C/27 Aug 18
1112/B/HUH/LCA/C12/775	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E35	F/27 Aug 18

Drawing No.	Title	Revision / Issue Date
1112/B/HUH/LCA/C12/776	EWL TRACK LEVEL R.C. DETAIL OF SLAB TOP STEEL AREA E36	E/27 Aug 18
1112/B/HUH/LCA/C12/778	EWL TRACK LEVEL R.C. DETAIL OF SLAB - TOP STEEL - AREA E38	D/27 Aug 18
1112/B/HUH/LCA/C12/817	PERMANENT DIAPHRAGM WALL RC FOR PANELS TYPICAL DETAILS (SHEET 1 OF 2)	A/27 Aug 18
1112/B/HUH/LCA/C12/818	PERMANENT DIAPHRAGM WALL RC FOR PANELS TYPICAL DETAILS (SHEET 2 OF 2)	A/27 Aug 18
1112/B/HUH/LCA/C12/819	COUPLER & BEND-OUT BAR SCHEDULE FOR AREA B	A/27 Aug 18
1112/B/HUH/LCA/C12/833	COUPLER SCHEDULE FOR AREA C SHEET 1	E/27 Aug 18
1112/B/HUH/LCA/C12/834	COUPLER SCHEDULE FOR AREA C SHEET 2	C/27 Aug 18
1112/B/HUH/LCA/C12/852	EWL TRACK LEVEL BOTTOM STEEL - AREA E34 R.C. DETAIL OF SLAB	C/27 Aug 18
1112/B/HUH/LCA/C12/853	EWL TRACK LEVEL TOP STEEL - AREA E34 R.C. DETAIL OF SLAB	E/02 Nov 18

4.2 Design Standards

The Assessment of the Connection has been undertaken on the basis of the following standards, the Design Standards, referenced in the Original Design Reports:

- Code of Practice for Structural Use of Concrete 2004 (Second Edition) published by the Hong Kong Buildings Department, referred to as the CoP.

- MTR Corporation Limited New Works Design Standards Manual Section 4 Civil Engineering (Revision A4 dated 15 April 2009)

4.3 Structural Configuration

The details described in the following sub sections relate to the EWL slab and the Connection to the diaphragm walls.

In the following sub sections the term "main reinforcement" refers to that reinforcement which is used for the design of bending moments and shear forces in the direction of span of the EWL slab, i.e. from diaphragm wall to diaphragm wall.

Where the descriptions use the terms "Area B" or "Area C" this shall be taken to refer to the sections under consideration in these areas as noted in Section 2 of this report.

4.3.1 Original Design

The Connection in the Original Design, the design at commencement of the project, is detailed as follows:

- Diaphragm walls to be constructed to top of slab level such that a vertical construction joint is formed between the face of the diaphragm wall and the EWL slab.

- Whilst the overall depth of the EWL slab is 3.0m there are locations where services voids are present within the depth of the slab. At the voids the total structural depth of slab reduces by 0.8m to 1.0m.

- The vertical reinforcement in the diaphragm wall laps to L bars which become the starter bars for the top and bottom layers of the EWL slab reinforcement. The starter bars are provided with couplers in the horizontal plane for connection to the EWL reinforcement. Couplers are mechanical splices formed of steel which connect two separate reinforcement bars to create a continuous bar.

- A shear key to be formed within the Connection on the excavation side and achieved by forming a recess in the face of the diaphragm wall which would be filled with concrete as part of the EWL slab pour. The depth of recess (distance perpendicular to the face) and height varies depending on the thickness of slab and location. Typically for a structural depth of 3m the shear key depth ranges from 245mm to 470mm and the height 1100mm to 1900mm.

- EWL slab to diaphragm wall Connection main reinforcement. Excluding the locations of voids within the depth the slab the main reinforcement typically comprises T40 bars at 150mm centres. In Area B there are also locations that incorporate; T25 with T40 bars at 150mm centres, T50 at 175 centres and T50 with T25 bars at 175mm centres and 150mm centres respectively. The number of layers of reinforcement typically two for the top of the slab and three at the bottom. At voids, both the upper and lower sections of slab are reinforced independently resulting in a greater number of layers in total.

The EWL slab midspan main reinforcement in the bottom layers is as follows:

- The main reinforcement in Area C is typically T40 at 150mm centres. The number of layers of main reinforcement is typically two. There is an additional bottom main reinforcement layer about gridline 43.

- The main reinforcement in Area B comprises T50 at 175mm centres and T40 at 150mm centres. Where T50 bars are present they are mostly in the first two layers. The number of layers of main reinforcement varies normally between two and four.

The EWL slab shear reinforcement is as follows:

- Selected areas of the EWL slab are also provided with shear link reinforcement, single leg stirrups, with the spacing and bar diameter varying depending on the particular location being reinforced. The sections in Area C have links which are T12 or T16 diameter spaced at between 150mm or 300mm in both main and transverse directions. In Area B the links are all T12 diameter, with a similar range of spacings to Area C.

4.3.2 Design As Constructed

The Connection in the Design As Constructed differs between east and west diaphragm walls.

The Design As Constructed for the Connection to the east diaphragm wall is detailed as follows.

- The diaphragm wall extends to top of slab level on the basis that a vertical construction joint would be formed between the face of the diaphragm wall and the EWL slab as with the Original Design.

- The uppermost sections of diaphragm wall are trimmed down below pile cut off level to expose the cast in reinforcement and couplers. Typically for the locations of interest the depth of section to be trimmed down being 200mm to 550mm and a greater depth at the location of air ducts. This trimming down being achieved by hydro demolition.

- The section of trimmed down diaphragm wall re-cast monolithically with the EWL slab.

- The reinforcement and couplers cast in with the diaphragm wall modified to varying degrees: from removal of couplers only to the complete removal of the top bars and the attached couplers. Where cast in bars and couplers are removed entirely, the top layers of main reinforcement through the Connection are anchored into the OTE slab on the non-excavation side.

- The bottom layers of the main reinforcement in the EWL slab connected to the diaphragm walls through reinforcement couplers in the horizontal plane cast in the diaphragm wall as in the Original Design.

- A shear key to be formed within the connection to the east wall as required by the Original Design. The shear key being formed on the excavation face by hydro demolition techniques which were also used to roughen the remaining surface of the construction joint above and below the shear key.

- EWL slab to diaphragm wall Connection main reinforcement. Excluding the locations of voids within the depth the slab the main reinforcement typically comprises T40 bars at 150mm centres. The number of layers being typically two for the top of the slab and three at the bottom. In Area B there are three locations where the number of top reinforcement layers increase to a total of three or four. At voids both the upper and lower sections of slab are reinforced independently resulting in a greater number of layers in total. All main reinforcement continues to the face of the diaphragm walls.

The Design As Constructed for the Connection to the west side diaphragm wall is detailed as follows:

- Diaphragm wall pile cut off level approximately 1.0m above the soffit of the EWL slab.

- The remaining two metres of diaphragm wall to be cast monolithically with the EWL slab. Hydro demolition techniques were used to roughen the surface of the construction joint.

- The bottom layers of the main reinforcement in the EWL slab connected to the diaphragm walls through reinforcement couplers in the horizontal plane cast in the diaphragm wall as in the Original Design.

- The main top reinforcement is anchored by either extending the bars into the OTE slab or by means of L bars which return down the non-excavation side (OTE side) of the EWL slab.

- EWL slab to diaphragm wall Connection main reinforcement. Outwith the locations of voids within the depth the slab the main reinforcement typically comprises T40 bars at 150mm centres. The number of layers being typically two for the top of the slab and three at the bottom. At voids both the upper and lower sections of slab are reinforced independently resulting in a greater number of layers. All main reinforcement continues to the face of the diaphragm walls.

The Design As Constructed for the EWL slab midspan main reinforcement is as follows:

- The main bottom reinforcement in Area C is typically T40 at 150mm centres. The number of layers of main reinforcement varies between two to five. The lesser number of layers tending to be associated with sections of slab that are discontinuous i.e. that have a significant opening present.

- The main bottom reinforcement in Area B comprises T50 and T40 at 150mm centres. Where T50 bars are present they are generally in the first two layers. The number of layers of main reinforcement varies normally between two to four but there is one isolated section with a fifth layer. The greatest number of layers typically coincides with the location of columns on gridlines 17 and 19 and also the T50 reinforcement.

The Design As Constructed for the EWL slab shear reinforcement is as follows:

- Selected areas of the EWL slab are also provided with shear link reinforcement, single leg stirrups, with the spacing and bar diameter varying depending on the particular location reinforced. The sections in Area C have links which are T12 or T16 diameter spaced at between 150mm or 300mm in both main and transverse directions. In Area B the links are all T12 diameter, with a similar range of spacings to Area C.

5 Assessment Approach

5.1 Original Design Methodology

The Original Design reports (Table 4.1.1) and in particular the reports for Area C detail the methodology used to determine the design load effects in the Connection between the EWL slab and diaphragm wall. The comments below relate to Area C.

The methodology can be summarised as follows:

- Soil Structure Interaction Analyses to determine; diaphragm wall to EWL slab Connection stiffness and load effects imparted on the Connection as a consequence of the construction sequence. Analyses undertaken using a 2D analysis of typical cross sections through the structure. Vertical loading on the EWL slab or due to self-weight of the slab is considered in the Structural Analyses.

- Structural Analyses of the EWL slab to determine design effects in the slab and at the Connection with the diaphragm wall due to all vertical loading on the EWL slab and to determine effects in the slab due to moments applied at the Connection derived from the Soil Structure Interaction Analyses. The Structural Analyses undertaken using a 2D finite element analysis of the EWL slab in plan in its entirety.

- Calculation of the structural capacity of the Connection in accordance with the Design Standards (Section 4.2).

COWI have reviewed the methodology and our main observations are as follows.

- The Structural Analyses of the EWL slab takes account of the presence of openings and various walls and columns over the length of the structure all of which will affect load distribution through the slab and therefore the distribution of design effects in both the EWL slab and the Connection.

- Soil structure interaction has been addressed in a manner which provides the necessary information without the need for complex 3D models of the slab and walls in their entirety.

In our opinion the method adopted for the design at Area C presents a reasonable and appropriate approach to determine design effects in the Connection and their distribution over the extent of the structure.

For Area B a similar methodology has been adopted for the Original Design with the following main exceptions relevant to this Assessment.

- The EWL slabs self-weight is included in the Soil Structure Interaction Analyses model of construction sequence.

- Approach to support conditions in the Structural Analyses model differ from Area C.

- Application of moments from the Soil Structure Interaction Analyses to the Structural Analyses models differ from Area C.

On the basis of our observations noted above COWI have opted to adopt a consistent approach for the Assessment of the Connection based on the approach taken for the Original Design in Area C. Whilst we have noted differences in approach at Area B we have not considered these in detail as we consider the methodology we are adopting as a reasonable and appropriate approach for this Assessment.

5.2 Assessment Methodology

As noted in Section 5.1 COWI have opted to adopt a consistent approach for the independent structural analysis and assessment of the Connection similar to the analysis and calculation of Section Capacity, the structural capacity of the slab calculated on a metre strip basis, performed for the purposes of the Original Design for Area C.

The main points to note from COWI's approach are:

1. COWI have undertaken Structural Analyses of the slab using the computer analysis software S-Frame.

2. COWI's analyses use a finite element structural model comprising of shell elements.

3. Separate models have been developed for each section (refer to Section 2.0 of this report) rather than modelling the entire slab. The extents are shown in Table 5.2.1 below. The diaphragm walls comprise "hit" and "miss" panels. The hit panels (prefixed by EH or WH) represent diaphragm walls founded in rock, miss panels (prefixed by EM or WM) are founded above rockhead.

Table 5.2.1: Model extents in terms of gridline and diaphragm walls.

Section	Gridline	Area	Wall Panel Ref. Range	
			East Side	West Side
1	41 to 46	C	EM98 to EH108	WH114 to WH128
2	24 to 30	C	EM62 to EH74	WM64 to WH81
3	16 to 19	B	EH40 to EH49	WM40A to WH49

Note – The extents of individual panels are not consistent with gridlines and as such partial panels may be modelled at these locations.

4 Support conditions in the models generally mirror the approach in the Original Design report for Area C.

5 In all COWI models, rotational and vertical supports have not been applied at locations in the EWL slab where voids are present and these voids continue through the diaphragm wall, such as the voids for the air ducts. The reason for this approach is that at these locations there is limited connectivity between the slab and the diaphragm wall. As such this approach is considered representative of the actual situation.

6 The models represent only portions of the EWL slab. At the limits of these models boundary conditions have been applied to mimic the fact that the slab continues beyond. These boundary conditions provide horizontal support with the slab free to displace vertically. The boundary conditions and limits of the models mean that results at the extremity of the models may not be realistic as peak stresses are developed locally and as such these results should be treated with caution. However for the purposes of reporting these utilisations are included.

7 Loading applied to the models has been based on the cases and combinations presented in the design reports. The following loadings have been reviewed or taken directly from the design reports.

7.1 Uniformly distributed loading on the platforms, track or similar and existing column loadings have been taken from the design reports in Table 4.1.1 and verified with the drawings listed in Table 4.1.2 in Section 4.1.

7.2 Stair loading, escalator loads and loads from internal walls have been taken from the design reports in Table 4.1.1 of Section 4.1.

7.3 Train loading has been based on the information in the design reports and verified by our own calculation.

8 The permanent design effects in the Connection have been determined from the sum of three analyses COWI has undertaken for each location in combination with the bending moments taken from the Original Design Soil Structure Interaction Analyses. The three analyses were as follows.

- Self-weight analysis with the slab supported by the diaphragm walls only producing bending moments and shear forces in the connection.
- Permanent load analysis with all internal walls and columns in place producing bending moments and shear forces in the connection.
- Analysis with moments applied from soil structure interaction output to determine additional shear forces.

9 Independent Soil Structure Interaction Analyses of the construction sequence have not been undertaken by COWI. In the Assessment COWI have used the output from the Design reports as follows:

9.1 For the models in Area C the modelling parameters and design effects derived from Soil Structure Interaction Analyses have been taken directly from the Original Design reports.

9.2 For the model in Area B we have adopted similar modelling parameters to Area C for the aspects deriving from the Soil Structure Interaction Analyses. The reason for this is twofold, firstly the parameters we required could not be clearly identified from the Area B design report and secondly based on our findings for Area C noted above that these parameters are not a significant factor for determining the critical utilisation of the connection.

10 COWI have undertaken a sensitivity analysis to determine the sensitivity of the results of the Assessment to the parameters taken from the Original Design Reports. The sensitivity analysis found the following.

10.1 A 100% increase in rotational stiffness increases the total design bending moment by typically 15%. This is due to the moment from the Soil Structure Interaction Analyses being the dominant moment. Given that the maximum Design As Constructed utilisation of the Connection in bending does not exceed 37% the results are not sensitive to this parameter.

10.2 A 100% increase in rotational stiffness results in less than 1% change in vertical shear force. A negligible change in the shear.

11 The COWI models have used the geometry and position of the diaphragm walls shown on drawings and as such do not consider the final as constructed position of the walls. We have assumed the walls have been built within tolerance.

12 COWI have calculated bending moment utilisation at the face of the diaphragm wall. The net bending moment at the face of the diaphragm wall is a hogging bending moment i.e. tension on the top face of the slab. The tension reinforcement for hogging bending moments is the main reinforcement in the top of the slab.

13 COWI have calculated shear force utilisations at two locations. Firstly at the face of the diaphragm wall and secondly at d from the face of the diaphragm wall, approximately 2800mm, d being the effective depth of the tension reinforcement in the section. The utilisations presented in this report have been derived on the following basis.

13.1 The reason for considering shear force utilisation at d from the face is that this is the limit of influence of the main reinforcement at the Connection on Section Capacity. This is due to the CoP requirement for main reinforcement considered in the calculation of shear capacity having to extend at least d beyond the section being considered (Clause 6.1.2.5(c)).

13.2 The area of longitudinal reinforcement considered in the calculation of the shear capacity due to the concrete has considered only the layers of main reinforcement that continue through the Connection.

13.3 Additional reinforcement present due to lapping bars has not been considered in the calculation on the basis that effective reinforcement has to extend at least a distance equivalent to d beyond the section considered (Clause 6.1.2.5(c) of the CoP), a distance which is greater than the specified lap lengths.

13.4 At d from the face of the support, the net bending moment varies between hogging bending moment (top main reinforcement in tension) and sagging bending moment (bottom main reinforcement in tension).

14 The scope of the review excluded review of bar bending schedules and actual lengths of bars. In the calculation of utilisation we have assumed that the reinforcement has been detailed and constructed in accordance with the Design Standards.

15 Shear enhancement has been considered in accordance with the requirements of the CoP as follows.

15.1 The calculation of shear utilisation at the face of the support considers shear enhancement in accordance with the CoP. At the face of the support, the CoP permits the allowable shear stress to be taken as equivalent to the ultimate shear capacity of the concrete. The full depth of section has been considered in this calculation on the basis that the construction joints at the diaphragm walls have been prepared by hydro demolition techniques to roughen the surface to increase bond strength and to provide aggregate interlock in accordance with Clause 10.3.10 of the CoP.

15.2 Shear enhancement has been applied at d from the face of the support. Shear enhancement applied at d doubles the contribution of the concrete shear capacity to the total Section Capacity.

16 The utilisations presented in this report are for the Ultimate Limit State (ULS) only.

17 At the face of the diaphragm wall utilisations have been calculated for strips of slab corresponding to the diaphragm wall panels, refer also to Table 5.2.1. These strips are considered to extend the full span of the slab and results at d from the face are calculated and reported on the same basis.

18 COWI have reviewed the detailing requirements of the CoP and in particular the following:

18.1 Clauses 6.1.2.5(g) and 8.4.1. Anchorage requirements for reinforcement to be considered effective.

18.2 Clause 9.3.1.1. Requirements for the minimum area of reinforcement.

18.3 Clause 9.3.1.3. Reinforcement at end supports.

a) End support of continuous slabs. Requirement for 50% of the calculated span reinforcement to be anchored into the support.

b) Negative moments arising due to partial fixity. Requirement for 50% of midspan bending reinforcement to be provided in the top layer at the support to limit cracking.

19 COWI have considered the implications of the detailing changes in the connection explained in the design report reference PWD-059A3 and are in agreement that acceptable load paths exist through the connection. Notably the amended arrangement meets the requirements for anchorage of the EWL top reinforcement required by Clauses 8.4.1 and 9.3.1.3 of the CoP.

6 Assessment Findings

6.1 EWL Slab to Diaphragm Wall Connection ULS Utilisation

The Assessment found the section utilisation ranges presented in the following tables (6.1.1, 6.1.2, 6.1.3 and 6.1.4) for each section considering the Design As Constructed arrangement at the Ultimate Limit State (ULS). The utilisations for the Original Design are provided in Appendix A of this report. Section utilisations are presented in the form of a percentage of the Section Capacity, for example a 100% utilisation would represent a section at the limit of its capacity at the ULS which includes all partial factors for loading and materials in accordance with the CoP.

The bending moment utilisations presented below are for hogging bending moment at the connection. Hogging bending moments generate tension in the top face of the EWL slab at the connection. The analyses found that any sagging bending moments at the connection are negated by the addition of the hogging bending moments from the Soil Structure Interaction Analyses summarised in the Original Design report.

The bending moment utilisations in Table 6.1.1 are indicative of the utilisations of the top main reinforcement.

Table 6.1.1 Hogging bending moment range of utilisation at face of the diaphragm wall

Section	**Gridline**	**Wall Side**	**Hogging Bending Moment Range of % Utilisation** **Design As Constructed**
1	41 to 46	East	21 to 35 Note 1
		West	15 to 21
2	24 to 30	East	19 to 37
		West	20 to 36
3	16 to 19	East	*8 to 17* Note 2
		West	*5 to 18* Note 2

Notes:
1. Excluding panel EH108 at the limit of the model. This panel is affected by the boundary conditions.
2. Bending moment utilisations in Section 3 are based on our interpretation of how the findings of the Soil Structure Interaction Analyses, which for Area B are presented in a different manner to Area C, have been applied to structural models in the Original Design. Our interpretation may differ from others.

Table 6.1.2 Shear Force range of utilisation at face of the diaphragm wall

Section	Gridline	Wall Side	Shear Force at Face of the Diaphragm Wall Range of % Utilisation Design As Constructed
1	41 to 46	East	14 to 51 Note 1/2
		West	20 to 49
2	24 to 30	East	7 to 43
		West	5 to 29
3	16 to 19	East	20 to 23
		West	6 to 34

Notes:
1. Single panel EH101 has a utilisation of approximately 1%. This is due to the presence of a void, the associated support condition assumptions noted in Section 5.2 (sub item nos. 3to 5) and the fact that adjacent panels are also wall panels which are not found in rock and therefore in the model have no vertical support.
2. Panel EM102 has a utilisation of 74%. EM102 is a location where the slab has a void that extends through the diaphragm wall and as such capacity has been based on the lower section of slab which is 1330mm thick.

The Section Capacity at d from the face of the diaphragm wall is the sum of two components; the shear capacity of the concrete section considering the main reinforcement and the shear capacity of the link reinforcement. The contribution to the total section capacity which derives from consideration of the main reinforcement is typically:

- For Section 1 and Section 2 a contribution of between 37% and 38% for the majority of diaphragm wall panels.
- For Section 3 the contribution is approximately 37% for the majority of diaphragm wall panels.

Table 6.1.3 Shear Force range of utilisation at d from the face of the diaphragm wall for hogging bending moments

Section	Gridline	Wall Side	Shear Force at d from the Face of the Diaphragm Wall Range of % Utilisation Design As Constructed
1	41 to 46	East	32 to 55 Notes 1/2
		West	14 to 39
2	24 to 30	East	11 to 34
		West	13 to 32
3	16 to 19	East	*No hogging moments*
		West	16 to 47

Notes:
1. Panel EH101 has a utilisation of approximately 8%. This is due to the presence of a void, the associated support condition assumptions noted in Section 5.2 (sub item nos. 3 to 5) and the fact that adjacent panels are also miss panels that have no vertical support.
2. Panel EM102 has a utilisation of 93%. EM102 is a location where the slab has a void that extends through the diaphragm wall and as such capacity has been based on lower section of slab which is 1330mm thick.

Table 6.1.4 Shear Force range of utilisation at d from the face of the diaphragm wall for sagging bending moments

Section	Gridline	Wall Side	Shear Force at d from the Face of the Diaphragm Wall Range of % Utilisation Design As Constructed
1	41 to 46	East	16 to 80 Notes 1/2/3/4
		West	19 to 52 Notes 5/6
2	24 to 30	East	11 to 44 Note 7
		West	16 to 24
3	16 to 19	East	33 to 40
		West	20 to 31

Notes:

1. The utilisation of 80% occurs at Panel EH103. A utilisation of 85% was found at EH99 near the extremity of the model but this utilisation may be influenced by the boundary conditions of the model.
2. Panel EM102 has a utilisation of 93%. EM102 is a location where the slab has a void that extends through the diaphragm wall and as such capacity has been based on lower section of slab which is 1330mm thick.
3. Panel EH108 has a utilisation of 99%. However this panel is at the extremity of the model and is not considered realistic.
4. Excluding the two panels (EH99 & EH108) which are or may be affected by boundary conditions, a total of six east wall panels have utilisations greater than 50%. This equates to approximately 42% of the number of east diaphragm wall panels.
5. Panel WH127 has a utilisation of 86%. This is a conservative estimate as immediately adjacent to this panel is a hidden beam which has additional capacity. A more complex analysis would be required to estimate a more accurate utilisation.
6. Panel WH128 has a utilisation of 161%. However this shear is at the extremity of the model and not considered realistic.
7. Panel EM72 has a utilisation of 76%. EM72 is a location where the slab has a void that extends through the diaphragm wall and as such capacity has been based on lower section of slab which is 1200mm thick.

6.2 Reinforcement at End Supports for the Design As Constructed

The CoP requires a percentage of top and bottom main reinforcement to be provided at end supports. The percentage of reinforcement at supports in each of the top (Aspt) and bottom (Aspb) layers requires to be at least 50% of the main reinforcement area required at midspan (Asm). We have reviewed the maximum midspan bending moment for each section and calculated the area of main reinforcement required for comparison to the area provided at the support. The findings of this review are summarised in Tables 6.2.1 and 6.2.2 below. Note that the area of reinforcement required at midspan, Asm, noted in the table below is calculated from the peak moment derived from the analyses.

The percentage of main reinforcement at the Connection exceeds the minimum requirements of the CoP, Clause 9.3.1.3.

Table 6.2.1 End support of continuous slab bottom main reinforcement

Section	**Gridline**	**Area of Reinforcement**		**% Area Surplus to CoP Requirement** Note 6
		A_{sm} (mm²/m) Note 1	**A_{spb} (mm²/m)** Notes 2/3	
1	41 to 46	11,112 Note 4	13,232 Note 5	+70%
2	24 to 30	16,667	10,312 Note 5	+12%
3	16 to 19	24,213	26,915	+61%

Notes:
1. Asm is the area of reinforcement required at midspan.
2. Minimum area based on worst case of two layers of T40 reinforcement bars at 150mm centres.
3. Aspb is the area of bottom main reinforcement provided at the Connection to the diaphragm wall.
4. Excludes a local concentration between two significant openings. Note that in the Original Design these two openings were combined into a single opening.
5. Average area of two diaphragm wall panels to coincide with location of midspan moment.
6. Calculation as follows. 50% being the Area required by the CoP.

$$\%\ Area\ Surplus = \left[\frac{Aspb}{Asm} * 100\right]\% - 50\%$$

Table 6.2.2 Partial Fixity top main reinforcement

Section	Gridline	Area of Reinforcement		% Area Surplus to CoP Requirement Note 6
		A_{sm} (mm²/m) Note 1	A_{spt} (mm²/m) Notes 2/3	
1	41 to 46	11,112 Note 4	16,755	+101%
2	24 to 30	16,667	16,755	+55%
3	16 to 19	24,213	16,755	+20%

Notes:
1. Asm is the area of reinforcement required at midspan
2. Minimum area based on worst case of two layers of T40 reinforcement bars at 150mm centres.
3. Aspt is the area of top main reinforcement provided at the Connection to the diaphragm wall.
4. Excludes a local concentration between two significant openings. Note that these openings were combined in the analysis model for Original Design.
6. Calculation as follows. 50% being the Area required by the CoP.

$$\%\ Area\ Surplus = \left[\frac{Aspt}{Asm} * 100\right]\% - 50\%$$

7 Summary of Findings

The Assessment of the Connection between the EWL slab and diaphragm wall has demonstrated the following.

Bending Moment Utilisation.

- The Connection has a low utilisation due to bending moment. The utilisations do not exceed 37% in any of the Sections considered.

- At Section 1 the upper bound range of utilisations are greater at the east wall in comparison to the west wall. At Section 1 and Section 2 the upper bound utilisations are similar between east and west walls.

Shear Utilisation at the face of the diaphragm wall.

- With exception to sections where voids extend through the diaphragm wall the Connection generally has a low utilisation due to shear force taking into account the benefits of shear enhancement. The maximum utilisation does not exceed 51%.

- At a diaphragm wall panel where the EWL slab has a void within the depth of the slab that extends through the diaphragm wall a higher utilisation of 74% is developed.

Shear Utilisation at the effective depth, approximately 2800mm, from the face of the diaphragm wall at locations where hogging bending moments are developed.

- With exception to sections where voids extend through the diaphragm wall the EWL slab generally has a low utilisation due to shear force taking into account the benefits of shear enhancement. The maximum utilisation does not exceed 55%.

- At a diaphragm wall panel where the EWL slab has a void within the depth of the slab that extends through the diaphragm wall a higher utilisation of 93% is developed.

Shear Utilisation at the effective depth, approximately 2800mm, from the face of the diaphragm wall at locations where sagging bending moments are developed.

- With exception to sections where voids extend through the diaphragm wall the EWL slab generally has a low utilisation due to shear force taking into account the benefits of shear enhancement at the west wall in Section 1 and both walls for Section 2 and Section 3. The maximum utilisation at these locations not exceeding 52%.

- To the east wall in Section 1 the majority of panels have utilisations less than 50%. Six wall panels (approximately 42% of the number of east wall panels) have utilisations greater than 50% with a maximum utilisation of 80%.

- At a diaphragm wall panel where the slab has a void within the depth of the slab that extends through the diaphragm wall a higher utilisation of up to 93% is developed.

Detailing at the Connection, minimum reinforcement provisions of the Design Standards.

- The requirement of the CoP to provide 50% of the span reinforcement area at both top and bottom layers at the support has been met. We noted that the reinforcement provided exceeds the requirements; for top reinforcement by an additional 20% to 101%, and bottom reinforcement 12% to 70%. The greatest percentages being associated with Section 1.

8 Conclusions

COWI have undertaken an independent structural analysis and assessment of the connection of the EWL slab to diaphragm walls for Hung Hom Station. The structural analysis and assessment being undertaken for the purposes of the Commission of Inquiry into the Diaphragm Wall and Platform Slab Construction Works at the Hung Hom Station Extension under the Shatin to Central Line Project.

The structural analysis and assessment has been undertaken for three sections; two sections located in Area C (Section 1 gridlines 41 to 46 and Section 2 gridlines 24 to 30) and a single section in Area B (Section 3 gridlines 16 to 19).

As noted in Section 7 the findings of the structural analysis and assessment of the Design as Constructed have shown the following.

1. Bending moment utilisations in the Connection are low at all three sections, the maximum utilisation does not exceed 37%.

2. Shear force utilisations in the Connection are generally low, the maximum utilisation does not exceed 51%. The exception is at a location where a void is present in the EWL slab.

3. Shear force utilisation at d from the face of the diaphragm wall due to hogging bending moments are generally low, the maximum utilisation does not exceed 55%. The exception is at locations where a void is present in the EWL slab.

4. Shear force utilisation at d from the face of the diaphragm wall due to sagging bending moments are generally low. The maximum utilisation for the majority of the panels does not exceed 52%. In Section 1 approximately 42% of the east wall panels have utilisations that are greater than 52% up to a maximum utilisation of 80%. The exception is at locations where a void is present in the slab.

5. The reinforcement provided in the Connection exceeds the CoP's detailing requirements. The level of surplus reinforcement being greater at Section 2 and Section 3 than Section 1.

The above findings are summarised in the table below which continues overleaf.

Principle requirements of the Design Standards for the Design As Constructed	**Requirement Met (Yes/No)**
Connection Adequate for Bending Moment	Yes
Connection Adequate for Shear	Yes

Principle requirements of the Design Standards for the Design As Constructed	**Requirement Met (Yes/No)**
Slab adequate for Shear at d (approximately 2800mm) from face of diaphragm wall	Yes
Minimum area of reinforcement at the Connection	Yes