MTRCL Shatin to Central Link Contract 1112

Hung Hom Station & Stabling Sidings

Change of Details at Eastern Diaphragm Walls and Slabs

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Issuing office: Tony Gee and Partners (Asia) Ltd Suite 602, 6F Chinachem Century Tower 178 Gloucester Road Wanchai, Hong Kong	**Tel:**	+852 2377 2765
	Fax:	+852 2851 0460
	Email:	hongkong@tonygee.com

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1. INTRODUCTION

Leighton Contactors (Asia) Ltd ("LCAL") is constructing Contract SCL 1112, Hung Hom Station and Stabling Sidings, which forms part of the new Shatin to Central Link ("SCL") railway being constructed for the Mass Transit Railway Corporation Ltd ("MTRCL").

In respect of the diaphragm walls and platform slabs at the Hung Hom Station, a Commission of Inquiry ("COI") has been established to inquire into the facts and circumstances surrounding the steel reinforcement fixing works and any other works which raise concerns about public safety and to ascertain whether the works were executed in accordance with the Contract.

In addition, an investigation process is being undertaken to open up certain parts of the east west line platform slab at the intersection of the eastern diaphragm wall in order to test whether the steel reinforcement bars are properly connected to the couplers embedded in the diaphragm wall.

I have been engaged by O'Melveny and Myers, Counsel for LCAL, to provide my expert opinion on various structural engineering issues for the purposes of the COI.

This reports sets out my expert opinion on the relevant issues, which are:

- The changes that have occurred to the approved design of the station structure.
- The impact these changes had on the structural integrity and safety of the station structure.
- Whether or not these changes were required to be reported to the Buildings Department ("BD") prior to their implementation.
- Technical issues regarding these changes raised by witnesses appearing before the COI.
- Technical aspects of the results of the testing on the connections between the couplers and bars as part of the opening up process and whether these satisfy relevant standards and are safe.
- Comment on whether the station structure is safe, including in light of the results of the opening up process.

2. EXECUTIVE SUMMARY

In the course of construction by LCAL of MTRCL's original design of the SCL Contract 1112, some changes in the eastern diaphragm wall and connecting slabs reinforcement details were implemented in 2015 for the ease of practical construction. These changes were recorded and documented at the time and the relevant supervisory bodies were notified.

It has however been reported in the media that a significant quantity of reinforcement bar couplers in these walls were not included in the Works.

From my review of the construction drawings for the Contract it seems that this is the case, but the bar couplers were replaced by an alternative and superior detail using continuous reinforcement.

I have ascertained the following:

- That after the construction of the walls, Leighton constructed the connection between the platform slab and the eastern diaphragm wall using an improved detail that provided superior strength and robustness.

- The change of detail was compliant with all the relevant design codes used for the design of the station structure, and the resulting structure is now stronger and more robust than the original accepted detail.

- The structure continues to be a safe design suitable for its designed use.

These changes were part of the normal construction process and did not represent any significant or material change in the design of the structure. In fact the change had no impact on the overall stability of the station structure.

The witnesses from BD believe that these changes were major, affected the structural performance of the structure and carried substantial implications on structural safety and integrity. This is not the case for the reasons stated above.

By the 29th December 2018 twenty-four non-destructive tests have been carried out on the exposed bar couplers in the EWL slab at the Eastern Diaphragm Wall. Twenty-two of these tests have demonstrated that the length of threaded bar inside the couplers are greater than the minimum allowable threaded lengths.

There is a significant amount of structural redundancy in the design of the station box structure and such redundancy means that the limited amount of couplers with threaded lengths less than the minimum do not pose any concern for the overall structural safety and integrity of the station box structure.

3. INSTRUCTIONS

I have been retained by O'Melveny and Myers (Counsel for LCAL) to prepare a report indicating my opinion on the substitution of horizontal straight continuous bars instead of the as designed coupled bars at the tops of the diaphragm walls at the intersection of the EWL slab, eastern diaphragm wall and OTE slab.

I understand this report is to be provided to the COI into the Diaphragm Wall and Platform Slab Construction Works at the Hung Hom Station Extension.

I have been asked to address the following:

- Describe the changes that have occurred to the approved design of the station structure.
- Advise if these changes are acceptable and that the structures are safe.
- Advise if these changes were material, or were minor.
- Advise on whether these changes need to be accepted by BD prior to construction.
- Comment on technical points regarding these changes as raised by witnesses appearing before the COI.
- Comment on whether the connections between couplers and bars that have been tested as part of the opening up process satisfy relevant standards and are safe.
- Comment on whether the station structure is safe, including in light of the results of the opening up process.

4. EXPERT'S DECLARATION

I understand that my primary duty in preparing this report and giving evidence is to the COI, rather than to the party who engaged me and I have complied with that duty.

I have endeavoured in this report and in my opinions to be accurate and to have covered all relevant issues concerning the matters stated which I have been asked to address.

I have endeavoured to include in my report those matters, which I have knowledge of or which I have been made aware, that might adversely affect the validity of my opinion.

I have indicated the sources of all information that I have used.

I have not, without forming an independent view, included or excluded anything which has been suggested to me by others (in particular my instructing solicitors).

I understand that:

- My report, subject to any corrections before swearing as to its correctness, will form the evidence to be given under oath or affirmation.
- I may be cross examined on my report by a cross examiner assisted by an expert.
- I am likely to be the subject of public adverse criticism if the COI concludes that I have not taken reasonable care in trying to meet the standards set out above.

I believe the facts I have stated in this report are true and that the opinions I have expressed are correct.

I enclose a copy of my CV in Appendix D.

5. INFORMATION REVIEWED

I have reviewed and relied upon the following information and documents in preparing this report:

Witness Statements and transcripts of oral testimony of the following Individuals:

- Lok Pui Fai, of BD.
- 2nd Statement of Ho Hon Kit, of BD.
- Leung Fok Veng, of MTR Corporation.
- Chan Kit Lam, of MTR Corporation.
- Ho Ho Pong James, of MTR Corporation.
- Ma Ming Ching Derek, of MTR Corporation.
- Kwan Pak Hei Louis, of MTR Corporation.
- Wong Chi Chiu, of MTR Corporation.
- 1st and 2nd Statements of Brett Buckland, of Leighton Contractors (Asia) Limited.
- 1st and 2nd Statements of Justin Taylor, of Leighton Contractors (Asia) Limited.
- 2nd Witness Statement of Stephen Lumb, of Leighton Contractors (Asia) Limited.
- 1st and 2nd Witness Statement of Jean-Christophe Jacques-Olivier Gillard of Intrafor.
- 3rd Witness Statement of Ho Hon Kit, of BD.
- 3rd Witness Statement of Stephen Lumb.
- 3rd Witness Statement of Brett Buckland.
- 3rd and 4th Witness Statements of Justin Taylor.
- Witness Statement of Mr Lee Wan Cheung of Atkins.
- Witness Statement of Mr LIM Paulino of BOSA provided to the BD.

Contract Information as follows:

- LCAL document “Chronology of Events Relating to EWL Design Change_r1”, attached in Appendix A.
- LCAL Drawings No 4.1, 4.2, 4.4, 4.5, 4.6 showing the general layout of the foundation construction.

- Atkins' drawings 1112/T/HUH/ATK/T25/013 to 022 showing the pre-contract award designed construction sequence of the d-walls and underpinning.

- Atkins' drawing 1112/W/HUH/ATK/C10/135 showing a typical cross section of the station box structure.

- Atkins' drawing 1112/W/HUH/ATK/C12/181 and 182 showing the working drawing details of the reinforcement in the EWL slab.

- Atkins' drawing 1112/W/HUH/ATK/C12/605, 606 and 607 showing the working drawing details of the reinforcement at the EWL / d-wall junction.

- Atkins' drawing 1112/W/HUH/ATK/C12/612 showing the working drawing details of the reinforcement in the d-walls.

- Atkins' drawing 1112/W/HUH/ATK/C12/538 showing the working drawing details of the reinforcement in the EWL and NSL slabs in section.

- Atkins' drawing 1112/W/HUH/ATK/C12/757 showing the working drawing details of the reinforcement at the EWL / d-wall junction.

- LCAL drawing 1112/C/HUH/LCA/C12/129 showing the revised design of the d-wall reinforcement prepared by their d-wall specialist Intrafor.

- LCAL drawings 1112/B/HUH/LCA/C12/001 to 834 showing the as constructed details of the EWL and NSL slabs and connections to the d-walls.

- Extract of LCAL Deliverable TWD-004B2 Design Report dated May 2015 which is a BD Consultation document justifying the design of the EWL slab in the temporary construction condition.

- Extract of LCAL Deliverable PWD-059A3 Design Report dated July 2015 prepared by Atkins justifying the re-design of the d-wall / EWL slab connection using the connection details proposed by LCAL.

- LCAL Technical Query no TQ-URS-0033 referring to the identification of positional out of tolerance couplers in the d-wall and proposing solution.

- LCAL Technical Query no TQ-URS-0034 referring to difficulties of installation of L-shaped bars onto the couplers of the d-wall in the OTE slab with Atkins solution of bending these bars upwards into the OTE upstand.

- Instrument of Exemption under Section 35(1) of the Kowloon Canton Railway Corporation Ordinance (Cap 372) in respect of Kowloon Canton Railway Corporation East Rail Extensions, dated 2nd January 2001.

- LCAL Deliverable TWD-004B3 Design Report dated June 2015 and transmitted to MTRCL on 20-7-15 which is a BD Consultation document that includes justification of the as-built reinforcement detail at the interface between the EWL slab and the d-wall between grid lines 22 to 40.

- MTRC Letter to BD dated 29th July 2015, reference 1112-COR-DM(SCL)-STO-000977, enclosing Design Report TWD-004B3 and CP / RGE Certificates 1112-IOE-AGM(SCLCEWCL-STO-000277.
- Letter from BD dated 8th December 2015 containing acceptance and no further comments of LCAL's temporary works design contained in the package "Excavation and Lateral Support Works (Shoring and Bulk Excavation) – Grid 22/40 and Grid J/N of Hung Hom Station (Contractors Design)", which includes comments in Appendix I on TWD-004B3 Design Report covered by CP / RGE Certificates 1112-IOE-AGM(SCLCEWCL-STO-000277 dated 29th July 2015.

Documents relating to the COI Inquiry's work

- Expert Adviser Team Interim Report No 1. dated 19 December 2018.
- Joint Statement made to the COI by Leighton and MTRCL regarding the as-built information.
- Joint Statement made to the COI by Leighton and MTRCL regarding shear key.
- BD's letters of consultation dated 25 February 2013, 25 February 2013, and 25 June 2014.
- Ove Arup Assessment Report on Holistic Study to Verify As-constructed Condition.
- Ove Arup's Design Spot Checks for Diaphragm Walls - Plaxis Analysis.
- Atkins calculations for both the "first change" and "second change".
- Report of Steve Rowsell dated 20 December 2018.
- Daily Reports for Opening Up Works up to 30 December 2018.
- BOSA How to measure thread length T1 & T2.
- Atkins' original design reports for the ELS.
- Opening Up Results to 29th December with associated photographs.

6. DESCRIPTION OF THE PROJECT, THE WORKS AND THE ISSUE

6.1 The Project

The Shatin Central Link ("SCL") development is a 17km railway link serving the New Territories, Kowloon and Hong Kong Island. It connects existing railway lines to create an East West Corridor ("EWL") between Tai Wai and Hung Hom and North South Corridor ("NSL") between Hung Hom and Admiralty, with a total of 6 interchange stations.

6.2 The Works

The Works under SCL Contract 1112 comprise a section of the Tai Wai to Hung Hom section, being the permanent and temporary works for the underground Hung Hom Station, Hung Hom Stabling Sidings, the South and North Approach Tunnels to the new platforms, and re-provisioning, remedial and improvement works. The existing Hung Hom Station requires integration with the new platforms and extensive underpinning and modification of the existing podium structure of the station.

The Works included construction of diaphragm walls on the sides and a central barette (all shown in blue in Figure 1 below) under the Western and Eastern sides of the new station box, between which the ground was excavated and the upper EWL (shown in red) and lower NSL (shown in magenta) platform slabs were constructed using the top down excavation method.

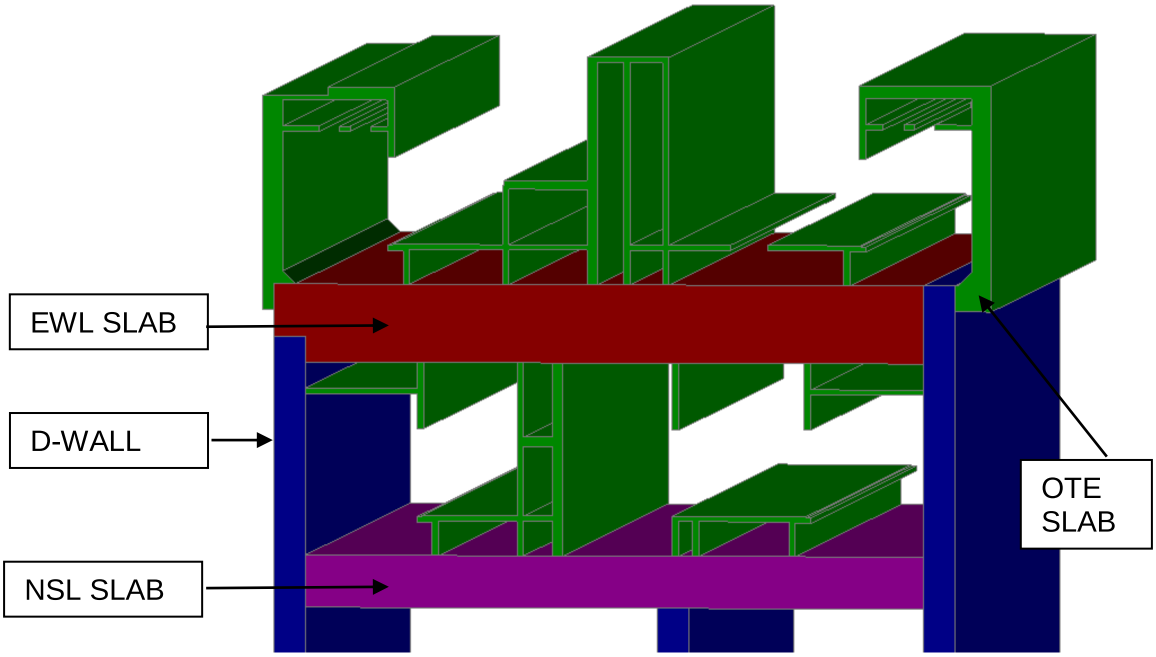


Figure 1 – 3D image of Hung Hom Station Box Structure

Based on Atkins drawing 1112/W/HUH/ATK/C10/135 rev E. It is indicative and does not show the detail changes being discussed.

Diaphragm walls (d-wall) are vertical walls of reinforced concrete that are constructed in the ground as a series of end to end panels, formed by excavating vertical trenches in the ground and then inserting the reinforcement cages and filling the trenches with concrete.

Their principal purpose is to form the side retaining walls of the station structure and to allow the excavation of the ground between the walls to enable construction of the two connecting platform slabs, and EWL and NSL slabs "in-situ" between the two inside faces of the d-walls.

The approved design consisted of making a connection between the d-walls and the slab using reinforcement bar couplers. This is shown diagrammatically below:

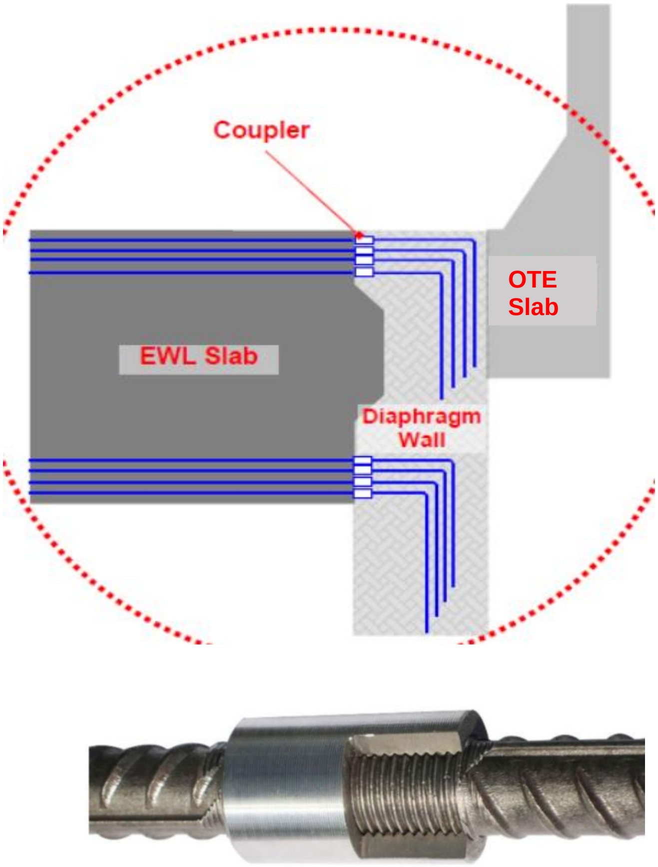


Figure 1 - Connection between Eastern D-wall and EWL Slab (image credit MTRCL) and Typical Reinforcement Bar Coupler

The OTE slab is the slab that forms the support to the Hung Hom podium and is also connected with the diaphragm walls using bar couplers.

The use of bar couplers in this instance is a 100% normal construction technique. When permanent diaphragm walls are used for a project bar couplers are almost always used to connect reinforcement between the wall and the slabs. This is particularly true for those slabs which are below ground level, where the use of couplers is the only practical method for providing reinforcement continuity.

6.3 The Issue

The Issue is that during the course of the construction in 2015 the use of bar couplers in the Eastern d-wall was replaced with continuous reinforcement, which was used across the top of the d-walls to connect the EWL slab and the OTE slabs to the d-walls.

7. HISTORY OF EVENTS

7.1 Chronology of Events

A detailed history of events has been prepared by LCAL is included in Appendix A for information. The pertinent events surrounding the Issue is discussed below.

7.2 Original Design

The original design of the horizontal reinforcement in the EWL slab was required to be made continuous with the horizontal reinforcement in the d-walls using bar couplers. The reinforcement design consisted of 2 rows of 40mm diameter ("T40") steel bars in the top surface of the EWL slab at 150 mm centres, with up to four layers of similar T40 bars in the bottom surface.

Likewise, the OTE slab that is connected to the outside of the d-walls was reinforced with a single layer of T40 bars in the top and bottom slab, also designed to be connected into the d-wall reinforcement using bar couplers.

The reinforcement arrangement of the top bars at the slab / d-wall interface is shown in Figure 4 below.

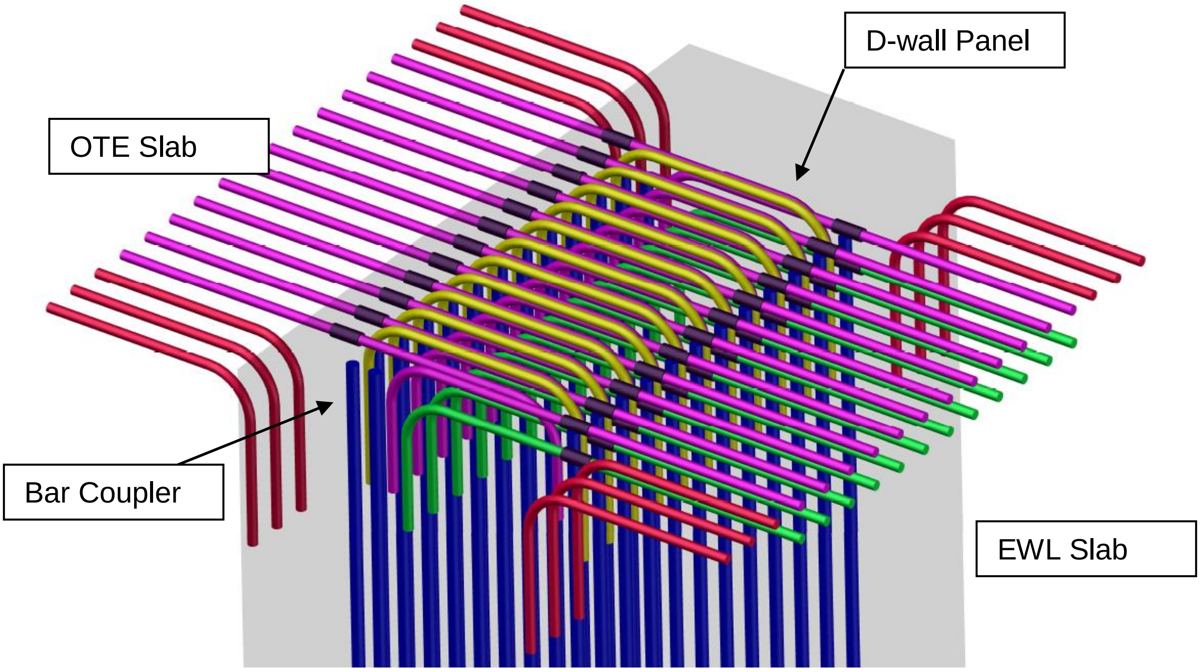


Figure 4 – Typical Reinforcement Arrangement at D-wall / Slab Interface

The reinforcement continuity of these T40 bars was to be provided using bar couplers, connecting to T40 L-shaped bars embedded into the top of the diaphragm walls at the level of the top and bottom of both slabs. Refer to the green and magenta coloured bars in Figure 4.

This is a common place detail proposed by many designers. This detail was accepted by BD through the consultation process and was part of the original design.

7.3 Revised Site Design

7.3.1 Reason for Change from Original Design

It is commonplace in Hong Kong that designers do not fully consider construction methods when detailing reinforcement. In this instance the detail of T40 bars at 150 centres across the top of the diaphragm wall panels makes no consideration of the only method that the contractor can pump fresh concrete into the panel, and also the requirement for presence of sonic and coring tubes for integrity testing of the panel after construction.

The contractor has to construct the d-wall panels using a 300mm diameter pipe (tremie pipe), which allows the concrete to be placed at the base of the panel to displace the supporting fluid (bentonite) in the open trench and therefore needs to be inserted into the top and centre of the panel. As can be seen in the Figure 4 above, there is no space at the top to allow a 300mm pipe to be inserted vertically into the reinforcement cage as the pipe clashes with the magenta, yellow and green reinforcement bars, which are spaced at 150mm centres.

7.3.2 Description of Change

Therefore, the horizontal bars at the top of the diaphragm wall panels were re-arranged into three layers so that a space in the middle of the panel was provided for the tremie pipe and the sonic test and coring tubes.

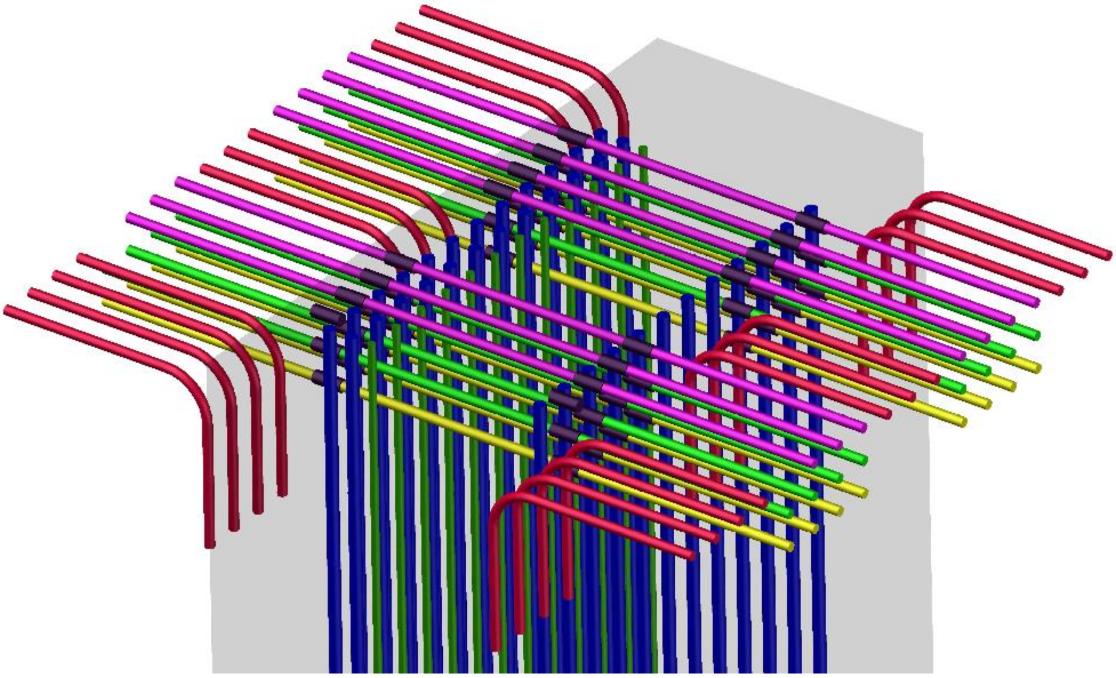


Figure 5 – Revised Reinforcement Arrangement at D-wall / Slab Interface

Of importance is that the magenta and green T40 bars are no longer turned down in the d-wall but are extended straight to the other face of the d-wall, with a bar coupler at each end and are arranged in two groups of 4 bars each, providing a clear space in the middle. There is also a third layer of reinforcement shown in yellow, so that the total number of horizontal bars remains unchanged at 24 bars per panel. The u-bars at the top of the d-wall, shown in yellow in Figure 4, were deleted as they were no longer necessary with the design approach now adopted by Atkins.

The means by which anchorage of the bars from the EWL slab was achieved was by extending all of these bars into the OTE slab. The magenta, green and yellow bars are shown extending out of both sides of the d-wall in Figure 5 above.

The rearrangement of these bars to allow for the practical aspects of construction is a normal occurrence and it is important to note that this change has had no overall effect on the global stability of the structure.

7.3.3 Consultation Over Revised Detail

It was a Contract requirement that details of the Contractor’s temporary works and construction sequence were to be consulted with BD through the consultation process, so this change of detail was wrapped up in that consultation and the contractor’s detail above was approved by the MTRCL for construction.

All the relevant d-walls were constructed on the project in accordance with these details.

7.4 Site Changes

After the d-walls were constructed the ground between the walls was excavated for construction of the EWL and OTE slabs.

7.4.1 Proposed Further Change of Connection Method

LCAL had been looking at choices for the methods and sequences for constructing the EWL slab and had been considering the option of removing the top section of the d-wall and providing continuous reinforcement between the EWL and OTE slabs over the top of the eastern d-wall.

LCAL documented this change proposal in their design report TWD-004B3, a BD consultation document, that was issued to MTRCL on 20 July 2015 and the pertinent wording in Section 6.2 of that document is extracted below.

> Excavation for construction of the station roof slab (the EWL slab) will then commence incorporating a top level temporary prop to the diaphragm wall.
>
> The top of diaphragm wall panel will be trimmed to the lowest level of top rebar for the EWL slab (min 420mm below the top level of EWL slab).
>
> The top rebar of EWL slab at the D-wall panel will then fix to the top rebar of OTE slab to achieve full tension laps.
>
> The EWL slab and OTE slab will be casted concurrently with temporary openings around the existing columns and pile caps.

7.4.2 Technical Query 33

At a similar timing in July 2015, LCAL issued two requests for clarification from the MTRCL’s designer Atkins. The first of these was Technical Query (“TQ”) 33, which sought clarification of the anchorage of the bars that were to be coupled into the d-wall and extend out into the OTE slab.

These bars were L-shaped and were used as part of the anchorage of the EWL top slab reinforcement. The problem was that with 3 layers of L-shaped bars, it was difficult to install the bars as they could not be easily rotated to be threaded into the bar couplers. There were also some sections of the OTE slab that were not big enough to accommodate the shape of these bars.

Atkins response was to adjust the arrangement of these bars and to remind the LCAL that the OTE slab and the EWL slab were to be cast at the same time (monolithically).

7.4.3 Technical Query 34

At the same time it transpired that the as-constructed position of the horizontal couplers in one of the first d-wall panels to be constructed, EH74, was not at the correct level.

This would have been caused by an out of tolerance installation of the reinforcement cage of this d-wall panel. As a result the levels of the reinforcement in the EWL slab would have dropped, reducing the strength of the concrete in this area of high stress, which would not be acceptable.

As a remedy it was proposed via TQ 34 to trim off the top portion of the d-wall so that bars from the EWL slab could be installed at the correct level. This involved removing the top layer of coupled bars and replacing with them continuous bars. Refer to figure 6 below.

This proposal by LCAL was approved by Atkins. An extract of the response of the TQ is shown below in Figure 6.

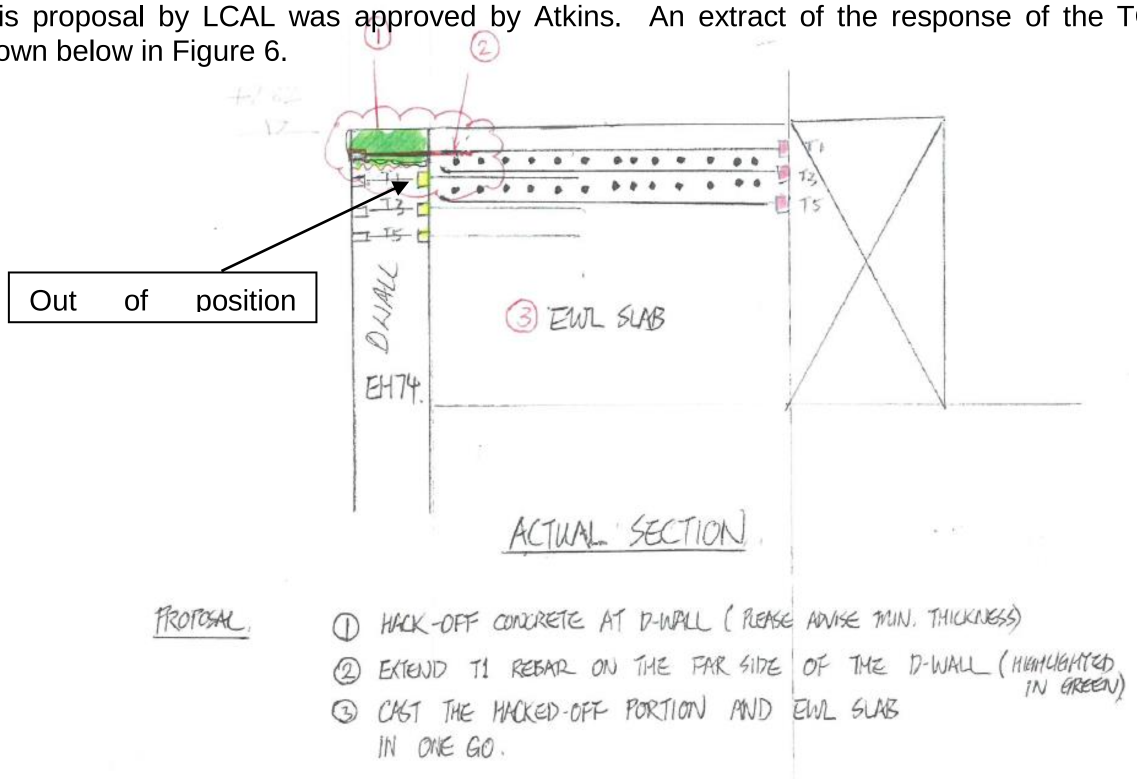


Figure 6 – Extract from TQ 34 showing the proposed remedial

7.4.4 Application to the EWL Slab

As a result of (i) the acceptance of the proposal in TQ 34, (ii) the response to TQ 33 and (iii) LCAL's proposal of the use of continuous reinforcement in the BD consultation document (TWD-004B3, as referred to 7.4.1 above), the method described in 7.4.5 below was developed and expanded to cover other sections of the eastern d-wall in Areas B and C1, C2 and C3.

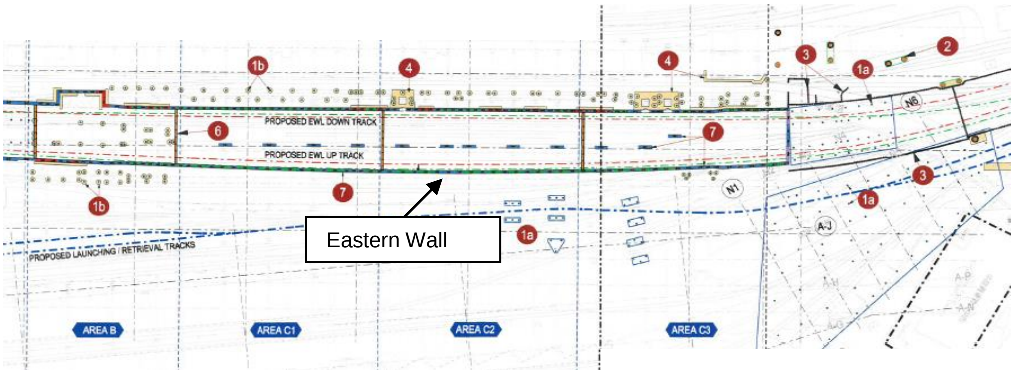


Figure 7 – Areas affected by out of tolerance d-wall

MTRCL and BD were made aware of this change via the design consultation document TWD-004B3, as referred to in 7.4.1. This submission was reviewed by BD as part of a larger submission covering Excavation and Lateral Support Works (Shoring and Bulk Excavation) – Grid 22/40 and Grid J/N of Hung Hom Station (Contractors Design), which was received by BD on 5th August 2015 and for which an acceptance with no further comments was issued by BD on 8th December 2015.

7.4.5 Actual Connection Method Used

The top 420mm of concrete of the d-walls was removed, so exposing all the horizontal T40 reinforcement with the couplers at each end shown in the working drawings detail.

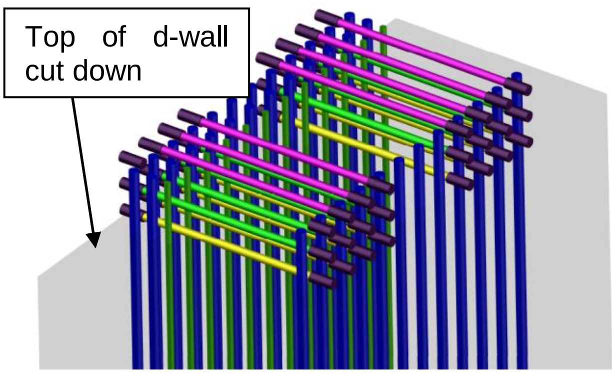


Figure 8 – Removal of concrete at top of d-wall

This approach allowed the contractor to remove the exposed bars and couplers and replace them with 2 layers of T40 bars at 150 spacing, the bars being continuous between the EWL slab, through the top of the d-wall and into the OTE slab without any couplers. Refer to Figure 9 below.

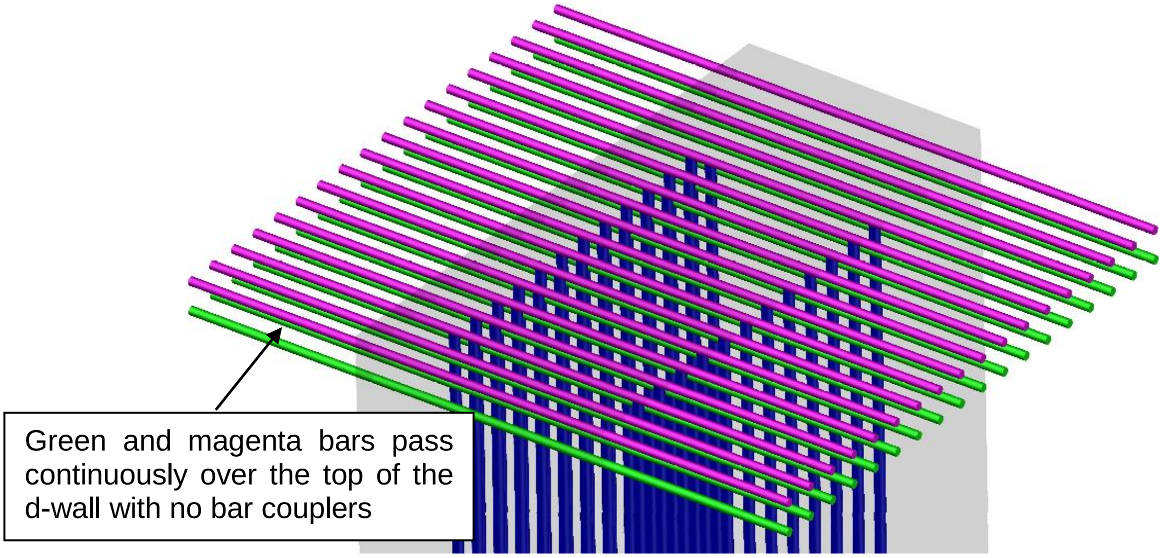


Figure 9 – Revised Reinforcement Arrangement

8. METHODS TO PROVIDE REINFORCEMENT CONTINUITY IN HONG KONG

8.1 Methods to Provide Reinforcement Bar Continuity

A discussion of the general methods is provided in Appendix C.

8.2 Code of Practice for Structural Use of Concrete 2013

Design of structural concrete in Hong Kong for MTRCL underground building structures is required by the MTRCL to be carried out using a design code prepared by BD. The current version of this document is the Code of Practice for Structural Use of Concrete 2013 (“HKCOP”) but it is understood that this project was designed to the 2004 version.

It is important to note that this is not a statutory document, but it does state that compliance with the provisions of the document is deemed to satisfy the relevant provisions of the Buildings Ordinance and the related regulations.

The HKCOP provides recommendations for the design, construction and quality control of reinforced and prestressed concrete buildings and structures where the concrete is made with normal weight aggregates. It covers the requirements for strength, serviceability, durability and fire.

8.3 Recommendations for Bar Continuity

The code of practice is split into 13 chapters, many of which provide recommendations for the design approach and the relevant calculations.

Chapter 8 however refers to the details recommended for the reinforcement, including that for reinforcement bar continuity in section 8.7.

The detailer of the reinforcement in the concrete is given the choice of using bar laps, welding or the use of mechanical couplers, as per the extract of the HKCOP below:

8.7 LAPS AND MECHANICAL COUPLERS

8.7.1 General

Forces are transmitted from one bar to another by:

(a) lapping of bars, with or without bends or hooks;
(b) welding; or
(c) mechanical devices assuring load transfer in tension and/or compression.

In joints where imposed loading is predominantly cyclical bars should not be joined by welding.

The HKCOP continues in Section 8.7.2 and 8.7.3 to specify recommendations for application of the lapping method.

8.4 Type 2 Mechanical Couplers

The requirements for the physical properties of the mechanical bar couplers are referred to in the Materials chapter 3, section 3.2.8. The bar couplers used for this project are Type 2 Mechanical Couplers and their performance requirements are extracted from the 2013 version of the HKCOP below:

3.2.8.4 Performance of type 2 mechanical couplers

Type 2 mechanical coupler should satisfy the following criteria:

(a) The splicing assemblies shall be tested to establish that they comply with the requirements given in clause 3.2.8.3.

(b) Static tension test: The splicing assemblies must develop in tension the greater of 100 percent of the specified tensile strength, R_m, of the bar, and 125 percent of the specified yield strength, f_y, of the bar

(c) Static compression test: The splicing assemblies must develop in compression 125 percent of the specified yield strength, f_y, of the bar.

(d) Cyclic tension-and-compression test: The splicing assemblies shall be tested in four stages as given in Table 3.4, and must sustain Stages 1 through 3 without failure. If the conditions of acceptance for the static tension test are complied with in Stage 4, the static tension test may be omitted.

The use of type 2 mechanical coupler should comply with the requirements given in clause 9.9.

Stage	Tension	Compression	Cycles
1	$0.95f_y$	$0.5f_y$	20
2	$2\varepsilon_y$	$0.5f_y$	4
3	$5\varepsilon_y$	$0.5f_y$	4
4	Load in tension to failure		

Notes:
1. ε_y is the strain of reinforcing bar at actual yield stress.
2. The actual ultimate tensile strength of the bar is obtained by testing samples from a referenced reinforcing bar. The test samples are obtained from the same referenced reinforcing bar.

Table 3.4 – Cyclic tension-and-compression test

8.5 Equivalency of Methods

The HKCOP allows the use of either laps or bar couplers. Either can be substituted for the other.

8.6 Choice of Methods

The choice between laps or couplers is a "detail" rather than a "design". The design is the amount and layout of reinforcement provided, the detail is the method of connection between separate bars. The choice is really dependent upon the construction sequence approach and method and that of cost.

The cost of reinforcement bar couplers varies according to the fluctuating price of steel. The lap length for T40 bars can be as long as 2.8m, so sometimes the additional cost of 2.8m of steel T40 reinforcement bar can be more than the cost of supply and installation of a T40 bar coupler.

For that reason sometimes contractors prefer to install laps, sometimes they prefer bar couplers. The HKCOP recognises this and allows the designer the choice to specify either option.

This choice is also present in all of the other international design codes, such as:

- Hong Kong Structures Design Manual for Highways and Railways
- Eurocode BS EN 1992-1-1:2004
- ASSHTO LRFD
- BS8110 / BS 5400

Eg, extract from Eurocode BS EN 1992-1-1:2004

8.7 Laps and mechanical couplers

8.7.1 General

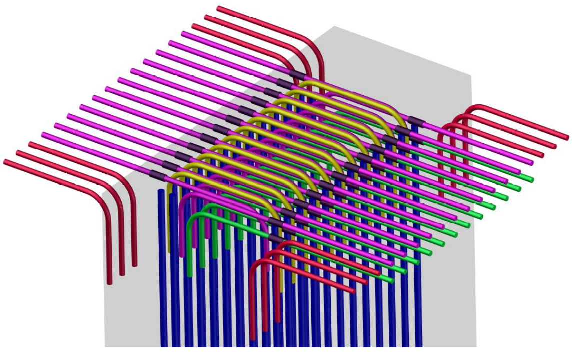
(1)P Forces are transmitted from one bar to another by:
- lapping of bars, with or without bends or hooks;
- welding;
- mechanical devices assuring load transfer in tension-compression or in compression only.

9. THE EFFECT OF THE CHANGE OF CONTINUITY DETAIL

9.1 Summary of Changes

The history of the change in reinforcement arrangement can be summarised simply as follows

1. Two layers of T40 bars at 150mm centres, total 24 bars per panel, top row coupled to EWL and OTE, second row coupled to EWL and turned down into the wall



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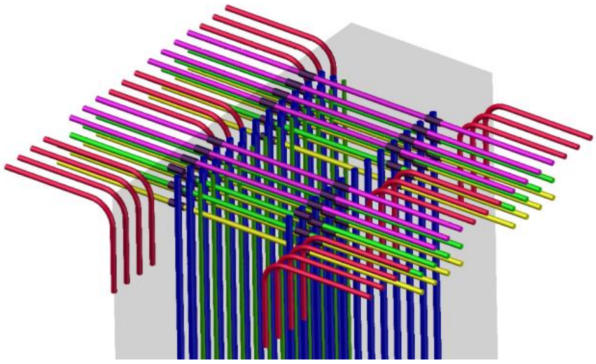
2. Three layers of T40 bars in two groups, total 24 bars per panel, all coupled to EWL and OTE



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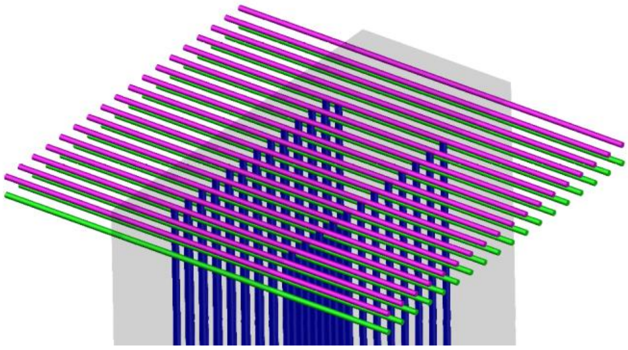
3. Two layers of T40 bars at 150mm centres, total 36 bars per panel, both rows continuous between EWL and OTE slabs



So in effect the as constructed situation is similar to the original design, except that the bar couplers were deleted and the amount of effective reinforcement was increased by using continuous bars across the top of the d-wall.

9.2 Effect of the Changes

The changes have no effect on the design, performance, behaviour or durability of the structure with respect to the requirements of the design codes and the HKCOP for the following reasons:

- The member sizes, sequence of construction of walls and slabs and all applied loadings are not altered by the change in reinforcement detail. Thus the bending moments and shear forces in the EWL and OTE slabs and the d-wall remain unchanged, so there is no change in load path and the manner in which the structure responds to the applied loadings.
- The top reinforcement in the EWL slab remains anchored into the OTE slab as per the accepted design.
- The deletion of the couplers in the bars as they pass over the top of the d-wall has no effect on the tension forces in the bars or the manner in which those tension forces are anchored into the OTE slab concrete.
- The bending strength of the EWL slab and OTE slab as they connect into the d-wall is not compromised, and in fact is increased – see section 9.5 below.

9.3 Is the Change Safe?

On the assumption that the original design (which BD approved) was safe and compliant with all design codes, there is no doubt in my mind that the as constructed situation is safe and is compliant with all design codes.

The as constructed detail could not be considered non-compliant because it was in effect the same as the originally approved detail but with an increased amount of reinforcement, providing additional strength.

To be clear however, I have not carried out a structural design check of the station box to independently determine the loading at the d-wall / slab junction.

9.4 Did the trimming of the D-wall affect its integrity?

When d-walls are constructed using a tremie pipe (see section 7.3.1) the concrete is cast to a level higher than the finished top of the wall (by up to approximately 500 to 1000mm), in order that all the bentonite and other contaminants float up with the tremie concrete to above the top level of the d-wall.

This over-poured concrete needs to be removed and this is normally done using large machine breakers for the majority of the excess concrete, but when the level of the wall nears that of the finished level, the machine plant is removed and smaller hand held breakers are used to trim the wall to its final level.

The smaller breakers are used so that the concrete that is to remain below the final level that the wall is trimmed to is not damaged. This is because if large machine plant had been used then there is a potential for the aggregate interlock of the concrete below to be fractured or damaged, so affecting the structural integrity of the concrete of the d-wall in this area.

As explained in Section 7.4.5, the top 420mm of the d-wall was trimmed below the top level of the d-wall, in order to remove the cast-in horizontal bars and couplers so they could be replaced with continuous horizontal bars. This trimming work was also done with the small hand held breakers.

The photographic evidence shows LCAL followed this process. Large machine breakers are shown to be trimming the over-poured concrete above the top level of the d-wall and workers with small hand held breakers are seen to be trimming the concrete in the areas of the vertical reinforcement.

The trimming of this top section of the d-wall concrete is no different from the trimming of the last section of over-poured concrete above. The latter is performed routinely for all elements constructed with concrete poured with the tremie method, so since this is permitted without question there should be no objection to concrete below being trimmed using the same method.

Therefore there is no concern of any potential damage to the existing concrete of the d-wall and its structural integrity would have remained intact.

It should be noted that the risk of trimming concrete and affecting its integrity as a result is solely a matter of workmanship and not a matter of design, as even the safest design can be badly executed.

9.5 Improvement to Design

I believe that the final as built detail is an improvement on either of the 2 previous arrangements for the following reasons:

9.5.1 Provision of additional reinforcement

The as-constructed detail increases the amount of reinforcement that connects the EWL slab to the d-wall, so the structure has an increased amount of strength and hence robustness and redundancy. This is because the amount of longitudinal reinforcement is increased. In Figure 10 below the red bars provide no structural strength to the EWL slab in this location as they are not connected into the d-wall and therefore do not contribute to the strength of the connection. Therefore the only bars that contribute are the magenta, green and yellow bars, 24 total per d-wall panel. In the as-constructed detail there are 36 bars of the same size (18 x 2) that contribute the strength of the connection. As a result, the bending strength of the EWL slab locally over the top of the d-wall has increased by 50%.

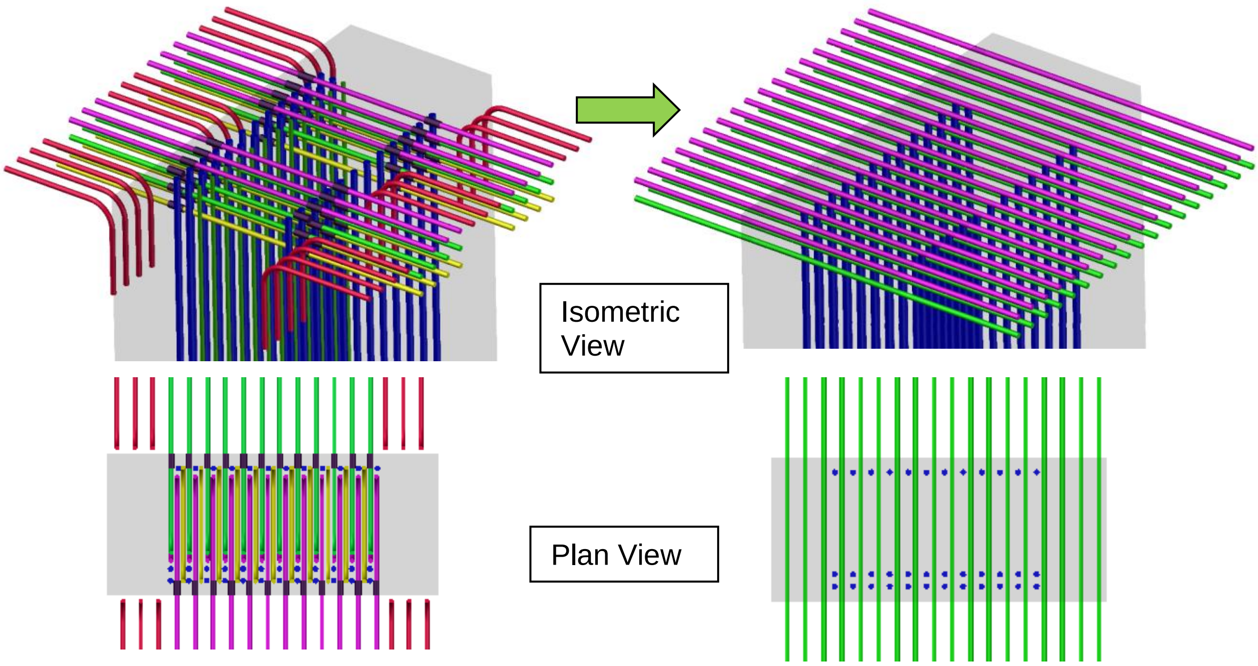


Figure 10 – Increase in EWL Slab reinforcement

9.5.2 Elimination of Construction Joints

In the original design and revised details, there was a vertical construction joint at the interface between d-wall and EWL slab and also between the d-wall and the OTE slab.

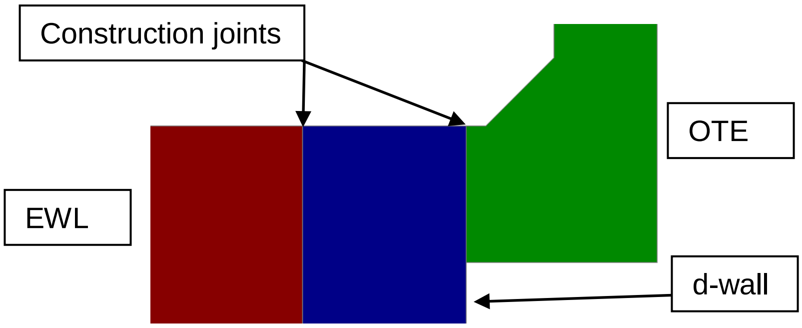


Figure 11 – Construction Joints in Original and Revised Design

The HK Code of Practice places no restriction on the location of construction joints and by the nature of the staged construction of the d-wall and EWL/OTE slabs, the construction joints are unavoidable.

However, these joints are at points of high stress and it is generally accepted as good practice to avoid construction joints at peak loading points.

Thus, in the as-constructed detail, the vertical construction joints between the diaphragm wall and the slabs were eliminated in the area of the main tension steel by the use of a continuous concrete pour between the EWL, over the wall and into the OTE slab.

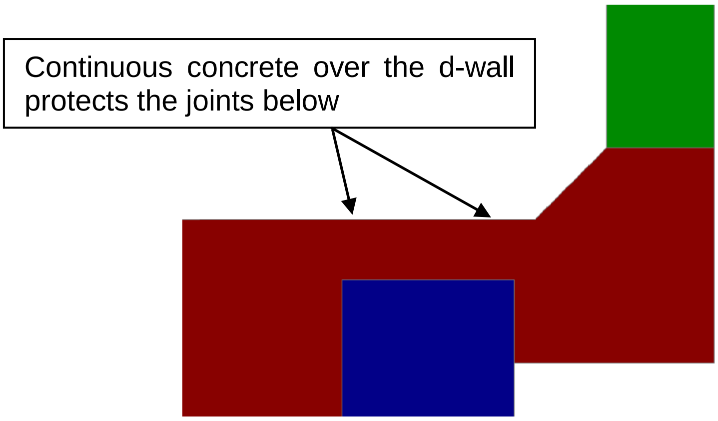


Figure 12 – Improved Arrangement of Construction Joints in As Constructed Detail

So by elimination of this joint in the top surface of the slab / d-wall concrete and in combination with the increase in the reinforcement, there will be an increase in the robustness and durability of the structure.

10. WAS THE CHANGE MINOR?

10.1 Material?

I understand that it is a question of legal interpretation as to the meaning of the word minor in the Building Ordinance and I do not express any opinion on this legal question.

From an engineering perspective however, there is a concept of whether a change is material, which the COI may regard as being of some assistance and this is explained below.

A material change from the perspective of structural engineering design and construction is one that creates a significant difference in the structural behaviour or one that affects the global stability of the structure.

Examples of material changes to the design in this instance would be as follows:

- Change to the configuration and layout of the station structure.
- Changes to the thicknesses of the d-walls or slabs.
- Changes to material strengths and concrete grades.
- Introduction or deletion of support columns or walls on the slabs – so changing the structural behaviour of the slab.

In this case the alteration of the main reinforcement of the slab has had no effect on its structural performance compared to the design accepted by BD for the following reasons:

- The member sizes, sequence of construction of walls and slabs and all applied loadings are not altered by the change in reinforcement detail. Thus the bending moments and shear forces in the EWL and OTE slabs and the d-wall remain unchanged, so there is no change in load path and the manner in which the structure responds to the applied loadings.
- The top reinforcement in the EWL slab remains anchored into the OTE slab as per the accepted design.
- The deletion of the couplers in the bars as they pass over the top of the d-wall has no effect on the tension forces in the bars or the manner in which those tension forces are anchored into the OTE slab concrete.
- The bending strength of the EWL slab and OTE slab as they connect into the d-wall is not compromised, and in fact is increased.

11. BD APPROVAL PROCESS

11.1 The Practice Note

BD describes its approval process for buildings in their document "Practice Note for Authorised Persons, Registered Structural Engineers and Registered Geotechnical Engineers, ADM-19". The Practice Note describes the positive approach that BD take in the approval process of buildings, including recognition of the disruptive effect that changes during construction can have on progress and steps that can be taken to mitigate this.

The Works at Hung Hom Station in Contract SCL 1112 have been exempted, via an Instrument of Exemption (IOE), from the BD prior approval and consent process, so the Practice Note referred to above and the approval process specified therein does not formally apply to these Works.

The IOE stipulates that the Works are to be constructed in consultation with BD, whereby in summary BD are invited to make comments on the design and the Competent Person responsible for the Works is delegated to ensure those comments are implemented.

Further discussion on the terms of the IOE are outside the remit of this report but I cannot see any relevant engineering considerations which could suggest that more onerous requirements are imposed under the IoE regime than if the formal statutory approval process had been applied in the first place.

Some provisions of the Practice Note which the Commission may find relevant to this case are as follows:

11.2 Non-Fundamental Issues

The version of the Practice Note current in 2015 states clearly in paragraph 13 that non-fundamental issues will not be checked by BD in the approval process:

> 13. Non-fundamental issues will not be checked and will not be raised as disapproval items. These relate generally to matters that do not affect the basic design of the proposed building. It is the responsibility of the AP/RSE/RGE to ensure that all such non-fundamental issues fully comply with the relevant regulations and codes of practice.

In the context of the SCL 1112, the change of detail is not a fundamental issue, for the reasons discussed in Section 10 above.

11.3 Changes to the Works

The Practice Note recognises that changes do occur in the construction phase of projects and allows revisions to occur without prior approval from BD. Refer to Sections 19 and 20, as extracted below.

Minor Amendments

19. The requirement for prior approval and consent for all amendments to building works for which consent has been given may affect the construction process.

20. Subject to a modification of Building (Administration) Regulation (B(A)R) 33(1) being granted by the Building Authority (BA) under section 42(1) of the BO, prior approval and consent to the minor amendments of building, superstructure (including curtain wall, cladding, space frame and similar superstructural elements) and drainage works, for which first consent has already been given, would not be required except for the following amendments :

This means that if approval and consent has already been given for construction of a building, then no resubmissions are required for changes in the works, if those changes are minor, unless they fall within that listed in Section 20(a), (b) or (c).

11.4 Exceptions

The Practice Note states what minor amendments are not allowed to be part of a deferred submission. The key ones are extracted below.

(a) For general building plan amendments and building (alteration and addition) amendments :

- an amendment resulting in a major revision or localized major revision as per criteria specified in Practice Notes for Authorized Persons and Registered Structural Engineers (PNAP) 143;
- an amendment having material effect on the fundamental issues;

(b) For superstructural plan amendments and superstructural (alteration and addition) amendments :

- an amendment affecting the overall structural stability of the building.

None of these exceptions are relevant in this case for the following reasons.

11.4.1 20(a) first bullet point

This refers to the definitions of a Major Revision and a Localised Major Revision that are listed in PNAP 143, which in November 2014 was renumbered as PNAP 55. The primary purpose of this PNAP is to describe charges associated with the BD approval process, but usefully, it defines major revisions in a building to be the following:

- changes in disposition and/or number of blocks within a development;
- change in the number of storeys, in particular, within the podium and number of basements;
- major changes in configuration of floor plans which would result in a fundamental reassessment of plot ratio, site coverage, lighting and ventilation and means of escape;
- change in the principal use of a building that would substantially affect the construction or lead to a reassessment of planning factors and/or means of escape, e.g. office to residential or hotel to office;
- substantial change in site area and configuration which would result in a fundamental reassessment of site coverage and plot ratio;
- changes that would seriously affect access to buildings;
- requests for substantial modifications, exemptions or bonuses that require a fundamental review of the original proposal;
- ground conditions assumed in the design found to be incorrect during initial excavation necessitating reassessment of the site formation works (for site formation works not resulting in a new building); and
- major changes which would require it to be examined under new or amended legislation or a new draft or approved Outline Zoning Plan.

A localised major revision is one where a major revision is “localised” to a particular area of the building.

"Localized" Major Revision

11. Where the major revision is "localized", the fee charges may be based on the "localized" GFA, i.e. per podium, or per affected floors of the podium, on the premise that part of a building is also a building. There would inevitably be other variations giving rise to complications in the implementation of the charging system and this could be considered on a case by case basis under section 42 of the BO.

Thus all of the definitions above refer to fundamental changes in the layout and use of the building and clearly not to a change in a reinforcement detail.

11.4.2 20(a) second bullet point

A change of reinforcement detail does not have a material effect on the fundamental issues affecting a building.

11.4.3 20(b) first bullet point

An amendment which would affect the overall stability of the superstructure of a building is not allowed to be considered as a minor amendment. An example of a change that would affect the overall stability of a building would be to adjust the locations of major load bearing elements (ie the principal structural elements such as columns and walls that support the building) or introducing or deleting foundation supports.

In this instance, the Issue is that the reinforcement details at the top of the diaphragm walls were rearranged. Such changes of reinforcement details do not affect the overall stability of the station structure.

Therefore, if these Works had been subject to the formal BD approval and consent process, then the change that occurred would not have been required to have been re-submitted prior to its construction and would be considered a Minor Amendment under the Practice Note.

11.5 Was the change made to a "foundation"?

There has been discussion on whether or not the change of detail was made to a foundation of the station or to a structural element of the station. I understand that BD believe the d-walls should be classified as foundations and that minor revisions to foundations are not exempt under the Practice Note from re-submission prior to their construction. For the reasons given in section 14.2 below it is my opinion that the top of the d-wall is an integral part of the station box structure and is not a foundation.

12. AS BUILT DRAWINGS

On the completion of a project, as built drawing are required to be prepared by the Contractor. This is the case for the SCL 1112 contract, but these have yet to be submitted.

Their purpose is to reflect all changes made in the specifications and working drawings during the construction process, and show the exact dimensions, geometry, and location of all elements of the work completed under the contract.

The deletion of minor details such as bar couplers and replacement with continuous bars would normally be recorded in the as built drawing submission.

13. POINTS RAISED IN WITNESS STATEMENT OF MR LOK PU FAI

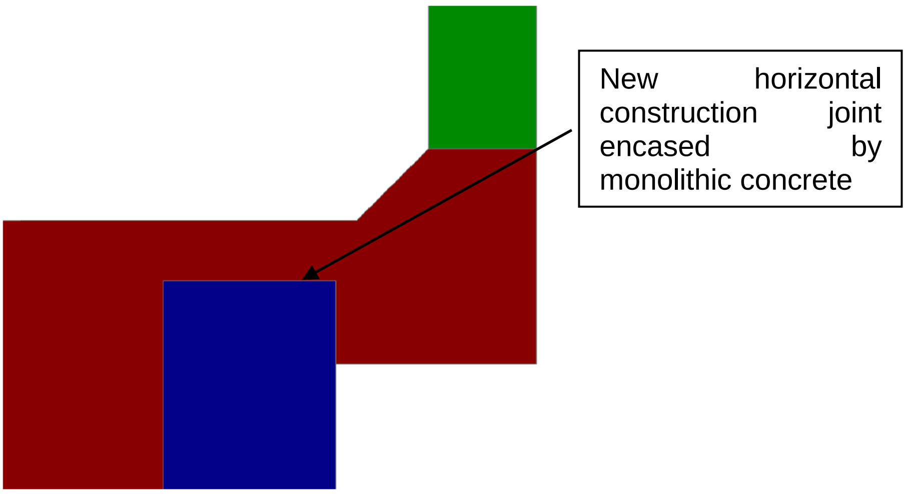
13.1 In paragraph 68(3)

Mr Lok Pui Fai states that:

> "Such changes to the accepted *plans cannot be regarded as minor alteration because the changes involve partial demolition of the completed diaphragm wall and alteration of the main reinforcement of the platform slab which would affect the structural performance of the platform structure."*

In my opinion, that statement is not correct for the following reasons:

- The partial demolition and replacement of the top 420mm of the d-wall has no effect on the structural performance of the d-wall, and for the reasons explained in 9.5 above, the resulting outcome is more durable than the original detail because of the elimination of the vertical construction joints between the d-wall and the EWL and OTE slabs. The detail does introduce a horizontal construction joint introduced into the d-wall 420mm from the top surface of the slab, but this joint is fully encased in surrounding concrete and is therefore fully protected.



- This horizontal construction joint will have had no effect on the structural performance of the d-wall.

- The alteration of the main reinforcement of the slab has had no effect on its structural performance compared to the design accepted by BD for the following reasons:

    - The member sizes, sequence of construction of walls and slabs and all applied loadings are not altered by the change in reinforcement detail. Thus the bending moments and shear forces in the EWL and OTE slabs and the d-wall remain unchanged, so there is no change in load path and the manner in which the structure responds to the applied loadings.

- The top reinforcement in the EWL slab remains anchored into the OTE slab as per the accepted design.
- The deletion of the couplers in the bars as they pass over the top of the d-wall has no effect on the tension forces in the bars or the manner in which those tension forces are anchored into the OTE slab concrete.
- The bending strength of the EWL slab and OTE slab as they connect into the d-wall is not compromised, and in fact is increased.

13.2 In paragraph 69

Mr Lok Pui Fai states:

> *"Any change in connection details without prior acceptance by BO could give rise to concerns about substandard works."*

As I have stated above, in my opinion a change in connection details is not a major change of design concept or method.

A comparison may be drawn to standard practice in the BD approval process for steel framed buildings. It is commonplace that the designer will prepare the framing plans and typical connection details for approval and consent by BD. These typical connection details are then developed by the contractor and the steelwork fabricator to be applied to all of the connections on the project and these would be shown on the workshop drawings. Sometimes the connection details are adjusted to suit material availability and fabrication preferences. For example, the thickness of steel plate stiffeners at the connections might be increased if the originally specified material thickness is not available or has long lead times. BD do not require submission of workshop drawings, so in such cases these changes would be considered minor changes and the adjusted details would only be submitted after construction of the project.

It is obvious that an increase in the material thickness in the example above does not result in substandard works. The end product is stronger. So a comparison may be drawn to the change in reinforcement at the top of the d-walls, where the deletion of the couplers and the increase in reinforcement passing over the top of the d-walls results in a stronger product, as explained in section 9.5 above.

A stronger product in this instance could not be considered to be substandard. The term "substandard works" is commonly referred to when materials used do not meet that required, ie concrete and steel reinforcement strengths, but this is not the case in this instance.

If his concern is that Works would be carried out, in practice, in a substandard manner, then in my view this has nothing to do with the safety or quality of the design itself. The safest design can be executed in a substandard manner but this cannot mean that the design itself is therefore rendered unsafe or questionable.

13.3 In Paragraph 71

Mr Lok Pui Fai states:

> *"The partial demolition of the as-built diaphragm wall and the alteration of the connection details is not a minor alteration. The alteration works could affect not only the distribution of load at the connection but also the structural integrity and safety of both the diaphragm walls and EWL slab. It is a major design change and the deviation from the accepted plans cannot be accommodated in the next stage of the construction works as both the diaphragm walls and EWL slab had been completed. As such, the deviation in 2018 has substantial implications on the structural safety and integrity of both the diaphragm walls and EWL slab and any proposed remedial works will lead to substantial demolition works instead of structural justification."*

I do not agree with that statement. There is nothing substandard in the as-constructed detail. It is actually a superior outcome which, for the reasons explained in 9.5 above, is stronger, more robust and more durable than the original detail.

There are no substantial implications on the structural safety and integrity of the Works and it is not correct to state that substantial demolition works will be required for any proposed remedial works for the following reasons:

- No remedial works are required as the structure is stronger and safer than the accepted design.
- If substantial demolition works were to be instructed, then it is not clear to me what benefit these works would achieve. The point of such demolition works would be to return the structure to the condition of the BD accepted design, but these works would be complicated and expensive and lead to an inferior product, as I discuss below.

The implication in the statement is that the concrete of the EWL and OTE slabs and top section of the diaphragm wall should be broken out and the reinforcement removed and replaced with the layout accepted by BD, as shown in Figure 5 above. This would involve the following steps:

- Providing temporary works to support the weight of the EWL and OTE slabs, the latter of which would require extensive works as there is no easy method to provide that support, unlike the EWL slab which could possibly be supported from the NSL slab.
- Breaking out of the concrete in the EWL and OTE slabs and the top section of the d-wall.
- Installation of the reinforcement shown in Figure 8 above and recasting of the top section of the d-wall.
- Installation of the reinforcement into the couplers embedded in the d-wall and lapping of this reinforcement with the remaining reinforcement in the EWL and OTE slabs that had not been demolished.
- Casting of the EWL and OTE slabs against the d-wall.

This work would be expensive and time consuming and would serve no benefit, and would result in a structure that is less robust, weaker and less durable than what has currently been constructed.

It would not result in a safer structure.

14. POINTS RAISED IN WITNESS STATEMENT OF MR HO HON KIT

14.1 In Paragraph 16

Mr Ho states that under the Instrument of Exemption (IOE), which these particular works were to be constructed under, that:

> *"No exemption is provided for so-called minor changes in construction details" as alleged by MTRCL and Leighton"*

Analysis of the wording of the IOE is a legal matter outside of my expertise and the remit of this report. However, it is clear that the purpose of the IOE document was to exempt the MTRCL from following the rigid procedure of the BD approval and consent process and instead follow a consultation process over a reduced approval period.

The implication of Mr Ho's belief is that every single change that occurred on a construction site that is exempted by the IOE would have to be consulted with BD prior to its implementation. This is an entirely impractical supposition that would result in BD being swamped with construction documentation and would likely require a full time team from BD being deployed on the construction site to deal with the volume of information.

Such a situation would almost result in a duplication of the site supervision team and the duties of the Competent Person and is in complete contradiction with the mission and published aims of BD to facilitate construction. In the Practice Note ADM-19, BD commit to a totally positive attitude towards building development – see extract below:

> **Mission**
>
> Buildings Department (BD) is committed to adopt a totally positive attitude towards building development.
>
> 2. Its mission is not to find faults in a building proposal but to facilitate building professionals in the approval process whilst ensuring public safety and health.

In section 19 of the Practice Note, BD recognise the fact that prior approval and consent of all amendments to building works may affect the construction progress and thus, to avoid this from happening, exempt minor amendments from being resubmitted.

> **Minor Amendments**
>
> 19. The requirement for prior approval and consent for all amendments to building works for which consent has been given may affect the construction process.

It therefore logically follows that it could not have been the intention of BD by issuing the IOE, that a more onerous process be adopted for the approval of minor changes than that already documented in the PNAP's for the standard BD approval and consent process. In this instance the Practice Note process was followed and thus could not be said to be in contradiction to the terms of the IOE.

14.2 In Paragraph 18 and 19

> *"As mentioned above, the diaphragm walls are foundations of the HUH Station Extension structure. As such, PNAP ADM-19 is not applicable to the deviation in question."*

Joseph E Bowles' book "Foundation Analysis and Design" is regarded by practising consulting engineers as one of the principal references for foundation design. In this book he defines a foundation as:

"The foundation is the part of an engineered system which transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self-weight."

He also states that a superstructure "*is commonly used to describe the engineered part of the system bringing the load to the foundation or substructure*".

The term foundation is also defined by BD in their publication "Code of Practice for Foundations 2017" as follows:

> *Foundation.* That part of a building, building works, structure or street in direct contact with and transmitting loads to the ground.

The term diaphragm wall is explained by BD in the same publication as follows:

> A diaphragm wall may be used as a temporary lateral support wall for deep excavation or the permanent wall of a basement, or it may be designed for both temporary and permanent uses. It may also be used to support vertical loads.

In the context of the SCL 1112 station box structure, the only parts of the diaphragm walls that can be considered to be the foundations of the station are that part of the d-walls below the bottom most NSL slab. These extend vertically downwards from the NSL slab to the underlying bedrock and therefore provide the vertical support to the station box structure above.

The section of diaphragm wall between the NSL and EWL slabs is not a foundation element. It is a structural element that forms the walls of the station box structure that spans vertically between the slabs and laterally retains the soil outside and provides structural support to the EWL slab. This element of the overall structure would be termed the superstructure.

The layout of the structure is shown in Figure 13 below with the demarcation between superstructure and foundation shown.

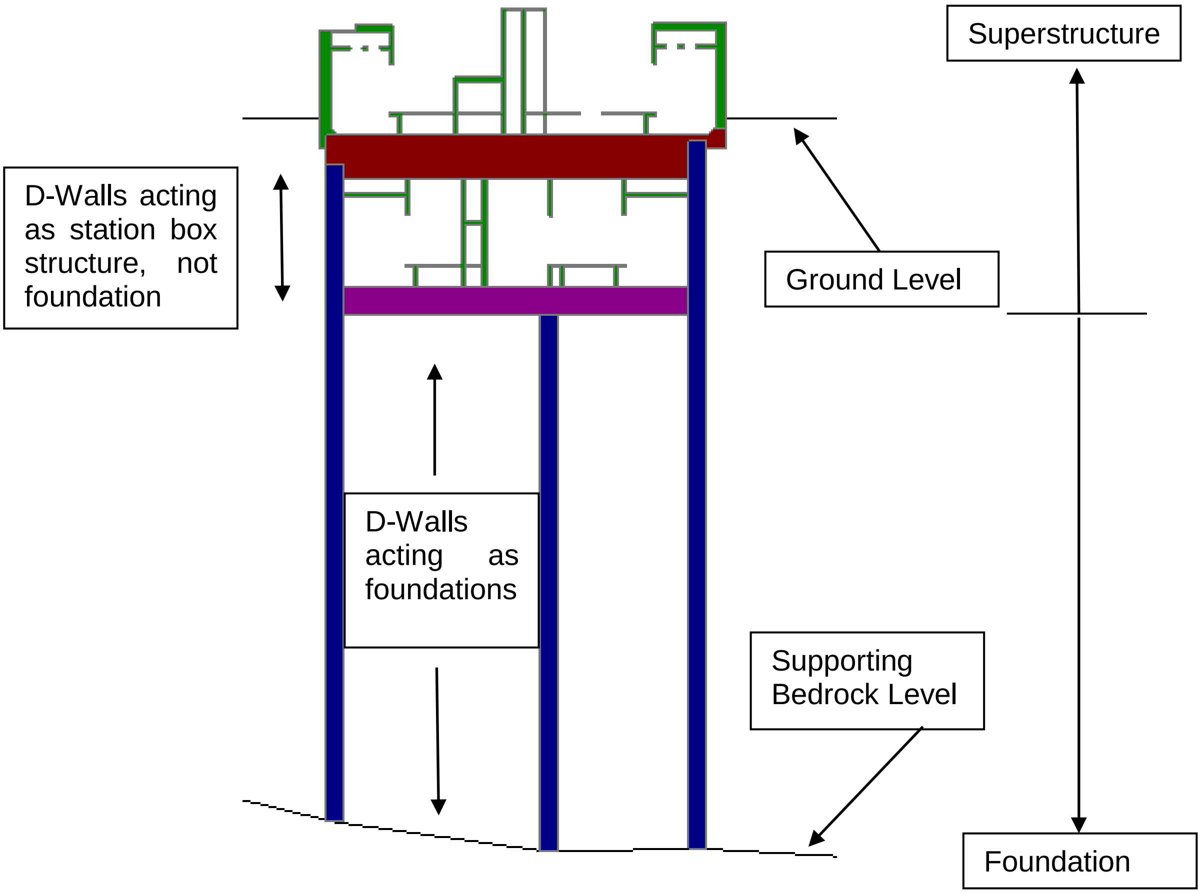


Figure 13 – Foundation Arrangement of HUH Station Extension Structure

This is further evidenced by Mr Ho's statement in Paragraph 32 that the NSL slab is not a ground bearing slab:

> *"I noticed that Mr. Aidan Rooney mentioned in paragraph 15(d) of his Witness Statement that "[t]he NSL track slab is a ground bearing slab with structural connections to the diaphragm walls at the east and west sides of the NSL track slab"* ***[B1/185].*** *I would like to point out that, according to the accepted plans and the supporting calculations* ***[H14/22991],*** *the NSL track slab is a suspended slab supported on piles and also on the diaphragm walls at east side and west side respectively. Therefore, the NSL track slab is not a 'ground bearing slab' as asserted by Mr. Rooney"*

If, as Mr Ho states the NSL slab is a suspended slab (and not a foundation or an on grade slab) and this is at the lower level of the station, then by his own definition it is not possible for a section of structural wall at the top of the station box (ie the EWL slab and diaphragm wall above the level of the NSL slab) to be classified as a foundation.

Mr Ho states that:

> *"In any event, the change to the design and construction of the connection between the east diaphragm wall and EWL slab in question cannot be regarded as a minor change or modification"*

As mentioned in Section 11 above, BD have a clear definition of what is a major change or revision. This does not include changes to localised connections and thus such changes can be regarded as minor.

Mr Ho also states that:

> *"Further, the junction between the completed east diaphragm wall and to-be-constructed EWL slab is a critical portion of the structural system which would have a bearing on the overall stability of the HUH Extension structure"*

The first half of this statement is true, the junction is a critical portion of the structural system and as such its design was consulted with BD and received BD's acceptance. But the change to the detail of the reinforcement that was effected on site by MTRCL and Leighton has no effect on the global stability of the HUH Extension structure because such changes did not alter the load paths and behaviour of the design that was previously accepted by BD. The change is not described as a major change in the definitive terms of BD and therefore is a minor change.

15. SITE INSPECTION AND TESTING OF AS-BUILT CONDITION

15.1 Site Investigation

The MTRCL have commenced an investigation into the as-built condition of the coupled reinforcement bars at the interface between the d-walls and the EWL and NSL slabs.

The investigation consists of breaking out of the concrete to reveal the bar couplers in the following number of locations:

- 24 specified locations at the top of the EWL slab at the interface with the east d-wall with the purpose of verifying the as-built condition.
- 84 randomly chosen locations of bars in the EWL slab, at both top and bottom of slab.
- 84 randomly chosen locations at the top of the NSL slab. It is not feasible to test locations at the bottom of the NSL slab due to its inaccessibility.

Once the bar couplers are exposed the embedded length of bar screwed into the couplers is to be determined using phased array ultra-sonic testing.

By determining the embedded length of the bars in the couplers, it is therefore possible to determine the total threaded length of the bar as the sum of the visible threaded length of the bar outside the coupler and the embedded length inside the coupler.

15.2 Method of Testing

The phased array ultrasonic testing is carried out by placing the sensor on the reinforcement bar immediately adjacent to the exposed bar couplers. The sensor needs to be placed on clean bare steel, so the surface of the bar has to ground down before the test can be carried out.

I do not know the specifics of how the system works, but I understand the ultrasonic wave pulses can be aimed along the length of the bar to its end and the timing of the reflection of the pulses can be calibrated to determine the length of the bar.

Reportedly the method has been calibrated in the laboratory and on site and it is able to measure the length of the bar to an accuracy of +/- 3mm.

15.3 Results of Testing

As at the 29th December 24 number ultrasonic tests had been carried out in 10 locations on the EWL slab.

Phased Array Preliminary Result (as of 29 Dec 2018)

Test	Date	Panel No.	Purpose	Test Item Indentity Mark	Engagement Length (mm)
1	14-Dec-18	E46	ii	EWL-E46-BB-B1-01-C1	34.91
2	14-Dec-18	E46	ii	EWL-E46-BB-B1-02-C1	29.65
3	17-Dec-18	E46	ii	EWL-E46-BB-B1-03-C1	34.32
4	19-Dec-18	E44	i	EWL-E44-TT-T1-01-C1	31.61
5	19-Dec-18	E44	i	EWL-E44-TT-T1-02-C1	6.22
6	21-Dec-18	E70	ii	EWL-E70-BB-B1-01-C1	40.51
7	21-Dec-18	E70	ii	EWL-E70-BB-B1-02-C1	36.78
8	21-Dec-18	E40	ii	EWL-E40-TT-T1-01-C1	39.21
9	21-Dec-18	E40	ii	EWL-E40-TT-T1-02-C1	40.81
10	21-Dec-18	E40	ii	EWL-E40-TT-T1-03-C1	38.57
11	28-Dec-18	E35	i	EWL-E35-TT-T1-01-C1	47.01
12	28-Dec-18	E35	i	EWL-E35-TT-T1-02-C1	45.70
13	28-Dec-18	E35	i	EWL-E35-TT-T1-03-C1	43.45
14	28-Dec-18	E32	i	EWL-E32-TT-T1-01-C1	36.65
15	28-Dec-18	E32	i	EWL-E32-TT-T1-02-C1	42.02
16	28-Dec-18	E32	i	EWL-E32-TT-T1-03-C1	41.51
17	28-Dec-18	E37	i	EWL-E37-TT-T1-01-C1	39.84
18	28-Dec-18	E37	i	EWL-E37-TT-T1-02-C1	42.51
19	28-Dec-18	E46	i	EWL-E46-TT-T1-01-C1	44.04
20	28-Dec-18	E46	i	EWL-E46-TT-T1-02-C1	33.00
21	28-Dec-18	E107	ii	EWL-E107-BB-B1-01-C1	35.34
22	28-Dec-18	E107	ii	EWL-E107-BB-B1-02-C1	9.40
23	28-Dec-18	E107	ii	EWL-E107-BB-B1-03-C1	40.91
24	28-Dec-18	E65	ii	EWL-E65-BB-B1-01-C1	42.43

Remark: Test Item Indentity Mark

Example: EWL (EWL/NSL) -E46 (E-East/W-West, Panel Number)-BB (Top/Bottom) -B1(Rebar Layer) -01 (Rebar Number)- C1 (C-Coupler + Coupler Layer)

The test results are summarised as follows:

The average engagement length or embedded length of bar is 35.6mm.

If test 5 and 22 are ignored, which show abnormally short embedded lengths, the average embedded length increases to 39.1mm.

15.4 What embedded length should we expect to see in the tests?

In the locations tested the reinforcement is T40 – ie 40mm diameter bars. The bar couplers are "Seisplice" Type 2 ductility couplers supplied by BOSA Technology (Hong Kong) Ltd.

The total length of the T40 bar coupler is 88mm, so the theoretical embedment length of each bar that is screwed into the coupler on each side is 44mm.

The pitch (spacing) of the threads for this coupler is 4mm, so this means there would be 11 full threads cut into each bar, ie 11 ridges visible at any one location aligned along the bar.

The result would be a symmetrical layout with a "butt to butt" joint between the two reinforcement bars as per Figure 14 below.

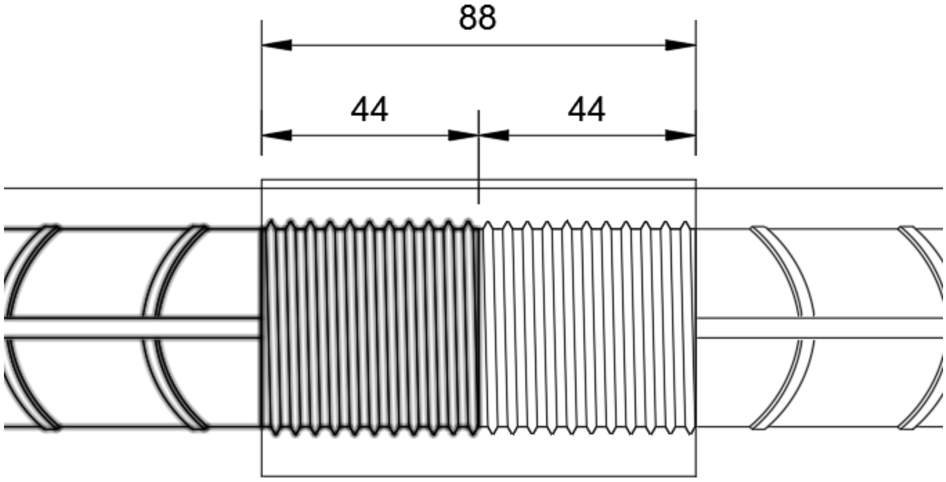


Figure 14 – Symmetrical Installation of Reinforcement Bars into Coupler, Butt to Butt

However, that level of precision installation in construction is rare, so tolerances are always built into any activity.

In both witness statement and under cross examination (day 36 pg 80-81) Mr Paulino Lim of BOSA confirmed that the tolerance added to the threaded length of T40 bars is up to a maximum of 4mm, ie the total threaded length can be increased to a maximum of 48mm, so there can be 12 full threads cut into the bar.

BOSA also advised that often the coupler is normally fully screwed on to the "parent" bar, ie the bar in the d-wall that the coupler is first attached to prior to the d-wall construction. There is no limiting device in the inside of the middle of the coupler, so it is probable that the coupler would have been screwed fully onto the d-wall bar, ie so no visible threads were showing outside the coupler on the side of the parent bar.

Jean-Christophe Jacques-Olivier Gillard of the d-wall subcontractor Intrafor has confirmed in his witness statement that the bar couplers were fully screwed on to the threaded ends of the horizontal starter bars in the d-wall.

The BOSA manual on acceptable thread tolerances shows the coupler is always fully screwed on to the parent bar, an extract of which is shown in Figure 15 below. This manual specifies the acceptable tolerance for the amount that a continuation bar has to be screwed into a coupler is a maximum of two exposed threads.

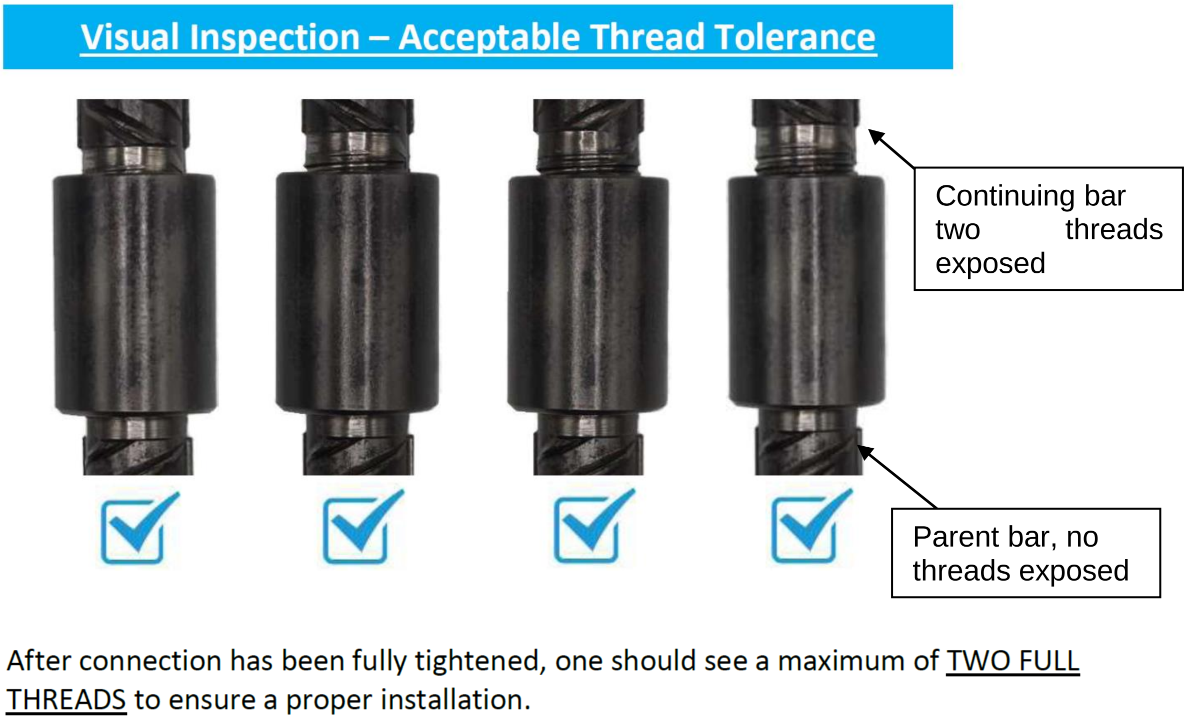


Figure 15 – Extract from BOSA Manual on Acceptable Thread Tolerance

As a consequence of these tolerances that BOSA have built into their coupler system, it would be possible to end up with an arrangement that has a 4mm gap between the ends of the bars inside the coupler and the continuation bar having an embedment length of **36mm** as shown in Figure 16 below

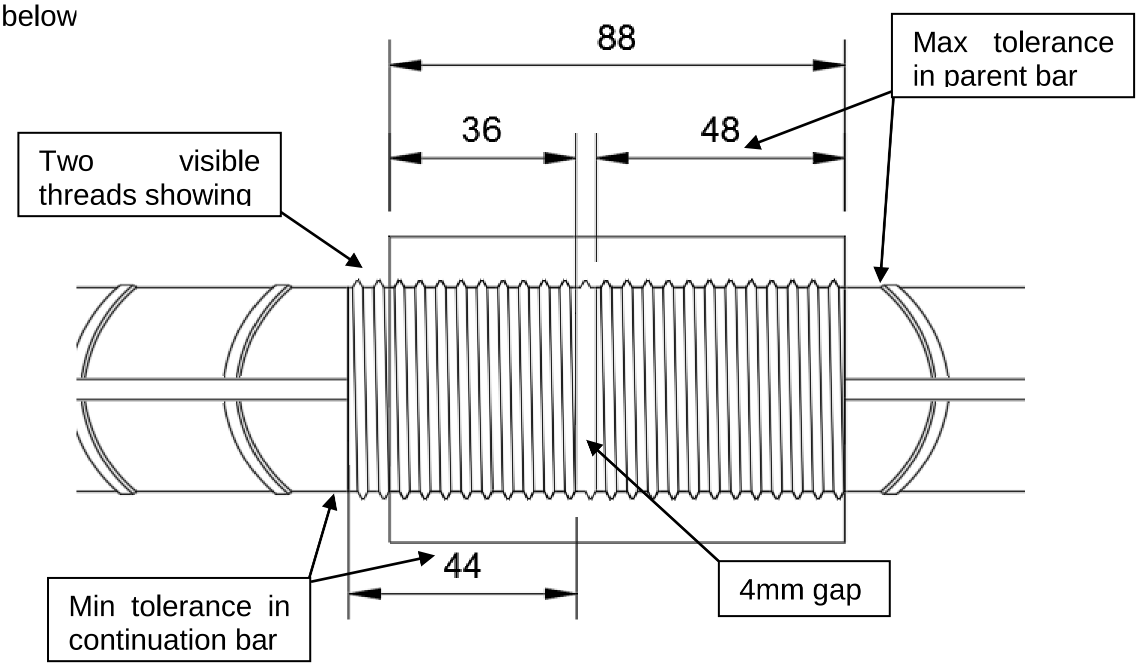


Figure 16 – Minimum Embedment Length as a result of BOSA Tolerances

Therefore, 36mm is, by default and by direct consequence of the in-built tolerances in BOSA's system, the permitted minimum embedment length of T40 bar into a coupler.

Because 36mm is the minimum embedment length it would be possible to see three threads exposed and for this to not be a cause for alarm or for a sign of non-conformance. This would happen if the continuation bar had been threaded with the additional 4mm tolerance to give the maximum threaded length of 48mm, as shown in figure 17 below:

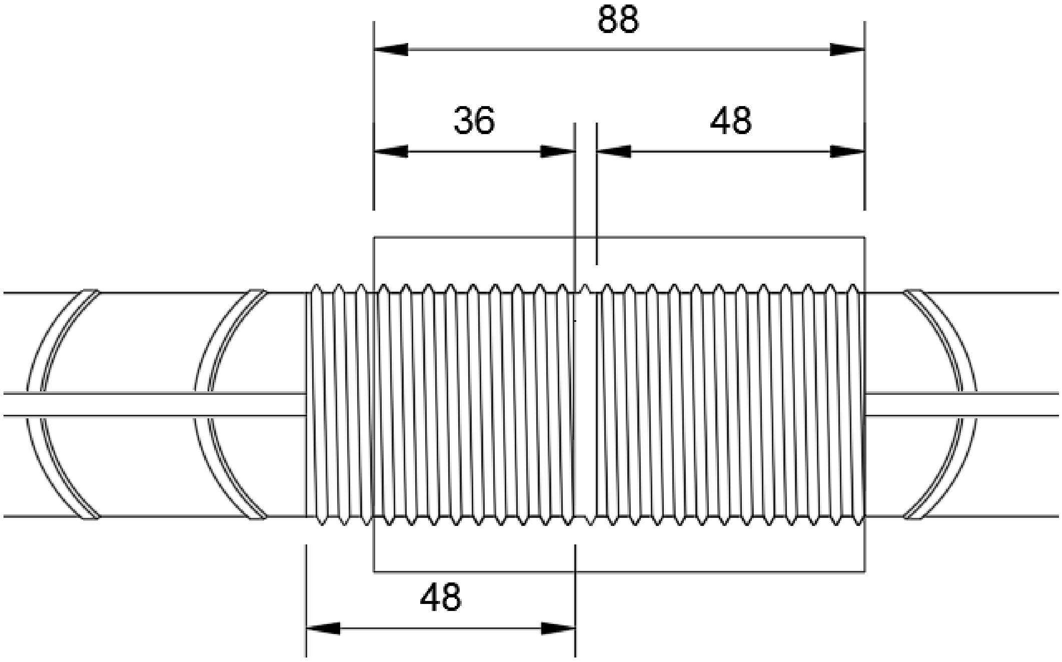


Figure 17 – Case of three threads exposed

Thus, during the opening up process, if couplers are seen with three threads exposed in the continuing bar it cannot be said by visual inspection alone that this coupled connection does not meet the BOSA specification.

15.5 What is the required minimum embedded length?

Bars that are found to be coupled with a shorter embedment length than 36mm do not meet the BOSA specification requirements.

However, this does not mean that the coupled connection is not strong enough to satisfy the performance requirements.

At the SCL1112 site inspection carried out by the COI's Experts on Wednesday 19th December 2018 I was handed the results of load tests carried out on the T40 bar coupler connections at the CASTCO Testing Centre on 21st November 2018. A series of destructive tests to failure were carried out on bar couplers that had differing percentages of threads engaged and the results are shown below:

BUILDINGS DEPARTMENT

RECORD PHOTO TAKEN ON 21-11-2018

File No.: SM/RAIL/30SCL/02-1112/C/3

Address: Bosa Site, No. 77 Ping Che Road, Lot nos. 883, 884, 908, 916-921, Fanling and CASTCO Testing Centre Ltd , No. 33 On Kui Street & No. 29A On Cheun Street, Fanling

	Specimen No.	Tensile Load (kN)	Tensile Strength (MPa)	Mode of Failure
30% Threads Engaged	ST0181121-201-1	526.11	419	S
50% Threads Engaged	ST0181121-202-1	791.54	630	C
60% Threads Engaged	ST0181121-203-1	886.22	705	B
70% Threads Engaged	ST0181121-204-1	870.96	693	B
100% Fully Engaged	ST0181121-205-1	833.46	663	B
Coupler Destructive Test	ST0181121-205-1	990.41	788	C

Legends:

B - Position of fracture at parent bar

S - Parent bar slipped out from the coupler

C - Position of fracture at connector

These results are explained as follows:

The T40 bars used in the structural design of the station were assumed to have an ultimate characteristic design tensile stress of 460 MPa, in accordance with the 2004 version of the HKCOP used for the structural design. This stress is equivalent to a tensile load of 577.76 kN in the bar.

Notwithstanding this, the 2004 HKCOP requires that the total bar coupler assembly has to have a greater design tensile strength of 483 MPa, in order that the bars each side will always fail before the coupler assembly, so the couplers do not become a point of weakness in the structure.

Thus the minimum characteristic design load for a bar coupler assembly is 606 kN.

However, the point at which the bar actually fails or fractures is known as the ultimate tensile strength. The tests that were done reported the fracture load, ie the load at which the bars failed, so the design characteristic strength of 606 kN must be increased to its nominal ultimate tensile strength in order to be comparable with the test results. The relationship between characteristic yield strength and ultimate tensile strength may be conservatively taken as 5%.

Thus the minimum fracture load allowed for a bar coupler assembly is 636 kN.

The test results show that when 50% of the threads are engaged in a bar coupler, the failure load was 791.54 kN. This is larger than minimum allowable fracture load, so 50% thread engagement could be said to be acceptable. But the recorded mode of failure was that of a fracture at the connector. This is not acceptable, as the concept of the design of the coupled connection is that the connector has to be stronger than the adjacent bars and does not fail first. Therefore this result cannot be used.

At 60% thread engagement the test showed that the failure load was 886 kN and the failure occurred in the parent bar. This therefore becomes the acceptable standard for a pass or fail of thread engagement. 60% thread engagement of the nominal threaded length of 44mm is 26.4mm.

The minimum acceptable embedded length from the perspective of structural safety is therefore 26.4mm, which is 6 ½ threads embedded in the coupler. 4 ½ or 5 ½ threads would be visible outside the coupler depending upon the tolerance of the threaded length.

15.6 Effect of Grade of Reinforcement

The SCL 1112 station structure was designed by Atkins to the 2004 version of the HKCOP. This specifies a maximum design tensile stress in the reinforcement of 460 MPa. So the amount of reinforcement and couplers were specified by Atkins based on this value of tensile stress.

The station structure was constructed in 2014 / 2015. At this time a newer 2013 version of the HKCOP had superceded the 2004 version. The 2013 version specifies a maximum design tensile stress in the reinforcement of 500 MPa, to reflect the advances made in the construction industry and the manufacture of steel reinforcement bars, where 500 MPa reinforcement had become the norm.

The SCL station structure was constructed using 500 MPa reinforcement. If this reinforcement had been used in the original design, then in many instances the amount of reinforcement could have been reduced by 1 - 460 / 500 = 8%.

As a result there is typically an 8% reserve in the ultimate strength bending capacity of the EWL slab and East d-wall.

I believe that the bar coupler testing was carried out using bars and couplers made from 500 MPa steel because Grade 460 steel is no longer commonly available in Hong Kong, so this helps to explain some of the large difference between the design strength of the coupled connection and the reported test values.

15.7 Reinforcement Material Safety Factor

As explained in Section 15.5 above the reinforcement design was based on maximum tensile stress of 460 MPa. However, in the design calculations a material safety factor of 0.87 is required to be applied in order to account for the potential variability of the strength of different batches of reinforcement bars. Thus the reinforcement demand in the design was based upon a maximum tensile stress of 400 MPa and a corresponding tensile load in the 40mm bars of 502.5 kN, thereby providing further margin in the design.

15.8 Conclusions of Test Results to date

As of the 29th December, all the test results apart from no 5 and no 22 demonstrate adequate embedment length, even allowing for the noted +/-3mm accuracy in the testing method. In short, on the basis of the test results to 29th December, the structure is safe.

16. STRUCTURAL REDUNDANCY IN THE DESIGN

16.1 Structural Utilisation

Structural utilisation is most commonly reported as a percentage of the ultimate applied loading, ie structural bending moment or shear, compared to the ultimate moment or shear capacity of the element. This is explained as follows:

The term ultimate applied loading is the total of all the actual loads applied to a slab multiplied by safety load factors, which account for any variability in loadings. These loadings create an ultimate applied bending moment in the slab.

The term ultimate bending strength used in this context is the point at which the slab starts to yield (fail) in bending, ie the reinforcement inside the slab starts to yield.

Thus for example if it is said that a slab has a 70% utilisation in ultimate bending, it means that the applied ultimate loading creating bending in the slab is only 70% of its ultimate bending strength.

Designers are required to keep the structural utilisation to 100% or less and in doing so the structure will be safe. In the example above, there is 100 – 70 = 30% spare capacity, so 30% of the strength of the structure could be reduced, for example by a reduction in reinforcement, and the structure would still be strong enough to resist the applied loads and would be safe.

In the following two independent assessment reports the structural utilisation of the EWL to Eastern d-wall connections have been investigated:

16.2 Arup Assessment Report

The consulting engineers Arup have conducted a holistic study to verify the structural safety of the as constructed condition on behalf of the MTR and this report has been submitted to the COI.

Their report discusses the levels of redundancy in the structure reported by the original designer Atkins. I have not seen Atkins report, but the Arup report states that the Atkins reported utilisation values are generally below 50% at the East d-wall to EWL slab connection with local points to above 60%. In the middle of the EWL slab the Atkins reported utilisation values are generally 60 to 70% with localised peaks of above 80%.

Arup advise in their report that they have carried out an independent check analysis of the EWL, NSL and D-walls. They report that their calculated utilisations are lower than the values advised by Atkins.

Arup advise that the EWL to Eastern d-wall connection only ever experiences a hogging bending moment, ie a bending moment that creates tension in the top surface of the EWL slab at that connection.

The Arup report does not include any calculations to demonstrate this check analysis, so I have not been able to review this analysis for accuracy.

16.3 COWI Assessment Report

LCAL have instructed the consulting engineers COWI to prepare an independent assessment of the loadings and strengths of the EWL / East d-wall connection.

I understand this report has been prepared in limited time and the current version of it will be submitted to the COI on Monday 7th January 2019. It is possible however that COWI may be able to refine their report in the coming week and I understand that if the refinements are deemed to be relevant their report will be re-submitted.

The COWI analysis has been carried out using the same basic assumptions as that used by Atkins for their original design, in order that meaningful comparative results could be obtained.

The analysis considered 3 separate areas of the structure for checking, from gridlines 16 to 19, 24 to 30 and 41 to 46. These areas where chosen as most representative of the different types of structural arrangements for this connection.

COWI report ultimate bending strength utilisations of less than 40% at the EWL to Eastern d-wall connection.

COWI report ultimate bending strength utilisations of typically less than 50% at the EWL to Eastern d-wall connection.

COWI also confirm with Arup that the EWL to Eastern d-wall connection only ever experiences a hogging bending moment.

The COWI report does include volumes of calculations to demonstrate this check analysis, but with the limited time available prior to the deadline of their submission to the COI I have not been able to review the calculations in depth.

16.4 Conclusion of Assessment Reports

Three separate consulting engineering companies have assessed the strength of the station box structure and all conclude that there is significant redundancy or over provision of reinforcement in the EWL slab.

I have not carried out those calculations myself, so cannot vouch for their accuracy.

However, if the COI accept these reports, given their independence from each other and the similar nature of their findings, then it necessarily stands that, at the very minimum, 40% of the bar couplers at the top of the EWL slab at the connection with the eastern d-wall could be considered to be totally ineffective and the connection would still be safe and strong enough to resist the design loadings.

At the underside of the EWL slab both assessment reports demonstrate that there is no tension demand on the couplers. I agree with Arup that the rules for the minimum percentage of reinforcement to be extended into the support region are for ductility requirements and are not applicable in this situation when there is no moment reversal.

17. CONCLUSION

In the course of construction of MTRCL's original design of the SCL contract 1112, some changes in the d-wall reinforcement details were implemented for ease of practical construction.

After construction of the d-walls, LCAL constructed the connection between the EWL and the Eastern d-wall using an improved detail that provided superior strength and robustness but remained practical for them to construct.

The change of detail was compliant with all the relevant design codes used for the design of the station structure, and the resulting structure is now stronger and more robust than the original compliant detail. The structure continues to be a safe design suitable for its designed use.

These changes were part of the normal construction process and did not represent any significant or material change in the design of the structure. In fact, the change had no impact on the overall stability of the station structure. It therefore follows that there was no requirement to inform BD of the change in detail, although BD were however made aware of this change in the overall construction sequence.

The results of the testing of the bar couplers which have been opened up at the EWL slab / eastern d-wall connection have shown that the significant majority have embedded lengths in excess of what is required by the manufacturer, which is a minimum of 36mm for a T40 bar. Testing to destruction of the bar coupler assemblies has shown that this embedded length may be reduced to 26.4mm, or 6½ threads without compromising the performance of the coupler.

The independent design reviews of the design of the structure all show that there is at least 40% spare capacity in the design of the coupled reinforcement connection between the EWL slab and the eastern d-wall. It follows therefore that at least 40% of the bar couplers at the top surface could be considered to be ineffective but yet the structural integrity of the platform slab will remain intact and the structure will remain safe and suitable for use. The bar couplers at the bottom surface are not used as structural design elements so it would be safe to allow 50% of these bars to be considered ineffective.

However, the opening up test results to date do not indicate that it would be necessary to disregard as large a percentage of bar couplers as mentioned above in order to ensure the structure remains safe for use. In fact only a small percentage are below specification requirement and are no cause for concern in terms of structural safety.