Shatin to Central Link

Final Verification Study Report

on

As-constructed Conditions of the

North Approach Tunnels,

South Approach Tunnels &

Hung Hom Stabling Sidings

Revision B | 18 July 2019
MTR Corporation Limited
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Executive Summary

1. In April 2018, MTR Corporation Limited ("MTRCL") issued Non-Conformance Reports ("NCR") to Leighton Contractors (Asia) Limited ("Leighton") because Leighton had not submitted the required "Request for Inspection and Survey Check Forms" ("RISCFs") for certain structural works of the North Approach Tunnels ("NAT") and the South Approach Tunnels ("SAT") of Hung Hom Station ("HUH") Extension in the Shatin to Central Link in accordance with the Inspection and Test Plan and General Specification of the Contract Documents.

2. On 20 December 2018, MTRCL informed the Highways Department ("HyD") that, in addition to the lack of RISCFs, there were insufficient construction records for couplers installation, changes of steel reinforcement lapped bars into coupler connections and insufficient materials testing for NAT structures. Subsequently, similar situations for SAT and Hung Hom Stabling Sidings ("HHS") were identified.

3. After deliberations with the Government, MTRCL submitted on 15 May 2019 to HyD a “Verification Proposal of As-constructed Conditions of the NAT, SAT and HHS” ("Proposal") to verify the as-constructed conditions, ascertain the structural integrity and ensure the quality assurance of the structures in NAT, SAT and HHS. The Proposal was accepted by the Government on the same day. The Proposal consists of 2 parts.

Part 1a Consolidation and verification of available construction records

4. This part consolidates and verifies all available construction records with a view to identifying any gaps in site inspection records, material testing records and design change records.

5. Availability of RISCFs for two Hold Points inspections at NAT, SAT and HHS structures was identified to be about 28%, 58% and 50% respectively.

6. Material testing records, including concrete cube test, rebar sampling tests and sand replacement tests ("SRT") are generally complete. A small number of concrete cube tests and some rebar test records were found missing and the issues are addressed in Part 1b and Part 2. Leighton contended in the Commission of Inquiry ("COI")’s Extended Inquiry that approximately 7% of the rebar delivered to site under Contract No. 1112 was not sampled for testing ("untested rebar") by a Hong Kong Laboratory Accreditation Scheme ("HOKLAS") accredited laboratory. MTRCL is continuing to seek clarification from Leighton in this regard.
Part 1b Review and ascertain the as-constructed conditions of the structures

7. This part reviews and ascertains the as-constructed conditions, including design changes, and the quality and workmanship of the structures to close the gaps identified in Part 1a. For the gaps that cannot be closed under Part 1b which may affect the structural integrity of the structure, they will be addressed in Part 2. In this context, “gaps” refer to the irregularities in the RISCFs and other known issues that have potential structural implications and need to be accounted for in the structural review in Part 2.

8. Available objective evidence, such as site photographs, site diaries and other construction records, were used to supplement the RISCFs and facilitate the assessment of the as-constructed conditions of NAT, SAT and HHS structures under Part 1b.

9. For checking concrete cover to rebar and rebar spacing, cover meter tests were conducted at selected locations at the NAT, SAT and HHS structures, where RISCFs are not available or where couplers were used to replace lapped bars. Test results of cover meter scans indicate appropriate rebar spacing and about 9% of scan locations without sufficient concrete cover.

10. Additional concrete coring and Schmidt Hammer tests were conducted to check the concrete strength at the locations without sufficient concrete cube test results. The results complied with the required design strength.

11. The findings under Part 1b have provided useful information for evaluating the key workmanship issues that may have implications on structural integrity. The recommended provisions to cater for the issues were identified and incorporated in the structural review under Part 2.

Part 2 Structural Review

12. This part conducts a structural review of the structures and devises schematic suitable measures to address gaps that cannot be closed out in Part 1. At the early design stage of NAT and SAT, a number of factors were unknown to the Detailed Design Consultants (“DDC”), in particular the detailed construction methodology. The original design was thus built up with extra provisions and flexibilities in order to cater for a wide range of uncertainties that might be realised during subsequent design and construction stages. However, with the completion of the detailed design and construction of the structures, these extra provisions/flexibilities can be
reviewed and rationalised as some of the uncertainties at the early design stage are either more certain or no longer need to be accommodated. Furthermore, it is acceptable to also adopt some other changes to the original design assumptions for this structure provided that suitable restrictions and precautionary arrangements are put in place.

13. In the light of this, a set of updated design assumptions are adopted in the structural review. MTRCL considers the adoption of these updates to be an appropriate approach for assessing the integrity of the structure and the extent to which further works are required to the structure. It reflects more accurately the actual situation. It also incorporates changes that have been selected to strike a suitable balance between the extent of further works to be carried out and the cost and time effectiveness of the works required, whilst ensuring that the functionality and performance of the structure are not compromised.

14. Based on the results of the structural review, some suitable measures have been identified and proposed at certain locations at the NSL tunnel of the SAT and trough walls of the HHS to ensure the structural integrity. These measures will be further developed for submission to the Government for acceptance. It is expected that the required works identified in this Final Report will be implemented concurrently with those for the HUH Extension.

15. The term “suitable measures” covers a wide range of actions and may include structural modifications, remedial works, long-term monitoring of the structure and surrounding areas, and the imposition of constraints on potential future modifications to the structure and its use. These measures serve to address the gaps and related workmanship/quality issues so as to achieve the safety level required in the then prevailing Code of Practice for Structural Use of Concrete (“Code”) for meeting the requirements of the Buildings Ordinance (“BO”) and the established good practice of engineering design. The MTRCL’s New Works Design Standard Manual (“NWDSM”) should also be complied with.

16. As part of the suitable measures, a long-term monitoring scheme including instrumentation monitoring and inspection will be developed to monitor the structural integrity of the NAT, SAT and HHS structures.

17. Based on the Part 2 structural review and inspections carried out, MTRCL considers that for the purpose of the ongoing construction activities, the NAT, SAT and HHS are structurally safe.
18. Formal design amendment submissions (as-constructed) will be made to the Government.

19. MTRCL will also explore options for providing the Government with additional quality assurance and/or an undertaking in respect of the structures where gaps are identified in Part 1a.
Section 1 Background

1.1 In April 2018, MTR Corporation Limited (“MTRCL”) issued Non-Conformance Reports (“NCR”) to Leighton Contractors (Asia) Limited (“Leighton”) because Leighton had not submitted the required “Request for Inspection and Survey Check Forms” (“RISCFs”) for certain structural works of the North Approach Tunnels (“NAT”) and the South Approach Tunnels (“SAT”) of Hung Hom Station (“HUH”) Extension in the Shatin to Central Link in accordance with the Inspection and Test Plan (“ITP”) and General Specification of the Contract Documents. An investigation into this incident revealed that RISCFs were also lacking for the construction of the Hung Hom Stabling Sidings (“HHS”).

1.2 On 20 December 2018, MTRCL informed the Highways Department (“HyD”) that, in addition to the lack of RISCFs, there were insufficient construction records for coupler installation, changes of steel reinforcement lapped bars into coupler connections and materials testing for the NAT structure. MTRCL advised that they were checking the latest contractor’s amendment drawings (as-constructed) against objective evidence and would submit a proposal to the Government for proving the as-constructed conditions and workmanship quality. At that time, MTRCL were expecting similar issues at the SAT.

1.3 On 30 January 2019, MTRCL briefed HyD and Buildings Department (“BD”) about the status of the available RISCFs for two Hold Points (i.e. rebar fixing and pre-concrete pour), as well as changes in steel fixing works from lapped bars to coupler connections and the material testing records for NAT, SAT and HHS structures.

1.4 On 15 May 2019, MTRCL submitted to HyD a “Verification Proposal of As-constructed Conditions of the NAT, SAT and HHS” (“Proposal”), which contains the following:

Part 1a Consolidation and verification of available construction records

This part consolidates and verifies all available construction records with a view to identifying any gaps in site inspection records, material testing records and design change records.
Part 1b Review and ascertain the as-constructed conditions of the structures

This part reviews and ascertains the as-constructed conditions, including design changes, and the quality and workmanship of the structures so as to close the gaps identified in Part 1a. In this report, “close the gaps” means determining whether the gaps identified in Part 1a need to be followed up with a structural review in Part 2. For the remaining gaps in relation to structural integrity of the structure that cannot be closed under Part 1b, they will be addressed in Part 2.

Part 2 Structural Review

This part conducts a structural review and devises schematic suitable measures to address any deficiencies identified. It also proposes a long-term monitoring scheme to monitor the structural performance of the as-constructed NAT, SAT and HHS structures, where and to the extent if necessary.

1.5 The Proposal was accepted by the Government on 15 May 2019. Upon completion of all parts of the Proposal in June 2019, MTRCL has prepared this Final Verification Study Report on As-constructed Conditions of the NAT, SAT & HHS (“Final Report”) to present all the findings and results.

1.6 MTRCL has engaged the Detailed Design Consultants (“DDC”) and two other External Engineering Consultants (“External Consultant”) to provide professional services in relation to the verification study for NAT, SAT and HHS structures:

a) Siu Yin Wai & Associates Limited (“SYW”)

SYW conducted a verification study on available project information in relation to NAT, SAT and HHS structures, viz. the latest contractor’s amendment drawings (as-constructed), the working drawings prevailing at the time of construction, site records, site diaries, photographs and inspection records.

SYW provided a structural review of the as-constructed structures at NAT, SAT and HHS based on desktop study and visual inspections.

SYW provided technical advice on preparation in respect of the application for the certificate of completion of works to the relevant Government departments.
b) Atkins China Limited ("Atkins")

Atkins is the DDC for the NAT and SAT structures and the hatched area in HHS as shown in Appendix A. In addition to their DDC role, their additional scope of service includes conducting a structural review of the NAT and SAT structures taking into account the as-constructed conditions including the quality and workmanship of the structures. This process involved a review of the statutory consultation submissions, working drawings and amendment drawings (as-constructed) prepared by Leighton for the structural works of NAT and SAT. Based on the results of the structural reviews, Atkins recommended suitable measures for the NAT and SAT structures, where and to the extent deemed necessary, following further detailed design.

c) AECOM Asia Company Limited ("AECOM")

AECOM is the DDC for the HHS structures except for the small portion shown in the hatched area in Appendix A. In addition to their DDC role, their additional scope of service includes conducting a structural review of the HHS structures taking into account the as-constructed conditions including the quality and workmanship of structure. This process involved a review of the statutory consultation submissions, working drawings and amendment drawings (as-constructed) prepared by Leighton. Based on the results of the structural reviews, AECOM recommended suitable measures for the HHS structures where and to the extent deemed necessary following further detailed design.

d) Ove ARUP & Partners Hong Kong Limited ("ARUP")

ARUP conducted an independent review of the structural integrity of the as-constructed works at the NAT, SAT and HHS structures with a view to providing further assurance on the structural safety of the as-constructed works.

1.7 In addition, at the construction stage, Leighton proposed amendments for parts of the substructure of the noise enclosure and the trough wall at the North Fan Area ("NFA"). SMEC Asia Limited ("SMEC"), the designer employed by Leighton, has also conducted a structural review of its alternative design for part of the substructure at NFA, taking into account the as-constructed conditions.
Section 2 Brief Description of the Structures in NAT, SAT and HHS

2.1 The layout of NAT, SAT and HHS is shown in Appendix A. The types of structures at NAT, SAT and HHS are as follows.

a) NAT – (i) an open-trough structure resting on soil for the East West Line ("EWL") and shunt neck; and, (ii) an underground box-section tunnel partly constructed on soil and partly supported by socketed H-piles for the North South Line ("NSL").

b) SAT – (i) an open-trough structure partly supported by socketed H-piles and partly on soil for the EWL; and, (ii) an underground box-section tunnel supported by diaphragm walls ("D-walls") for the NSL.

c) HHS – (i) open-trough structures resting on soil to house 15 railway tracks; (ii) two box-section underpasses resting on soil and beneath the railway tracks; (iii) open-trough structures at the NFA resting on soil and a noise barrier founded on piles; and (iv) eight single-storey accommodation blocks founded on piles.
Section 3 Methodology and Results of Part 1

Part 1 contains Part 1a and Part 1b in the Final Report. Detailed findings and results of Part 1 are given in the following paragraphs.

3.1 Part 1a - Consolidating and Verification of Available Construction Records

Site Inspection Records

3.1.1 The Hold Point inspections for “Fixing of reinforcement and Cathodic Protection” and “Pre-pour check for reinforcement fixing, alignment, level, formwork, cleanliness” for structural works as per Leighton’s ITP are considered essential check points for the purpose of this verification study. Hence, these associated RISCFs are collated where available.

3.1.2 Checking of the RISCFs primarily addressed the availability of the RISCFs. The availability of RISCFs is shown in Table 1 below.

Table 1: Summary of RISCFs Availability

<table>
<thead>
<tr>
<th>Structures</th>
<th>Number of RISCFs required</th>
<th>Number and percentages of RISCFs available</th>
<th>Number and percentage of unavailable RISCFs to be addressed under Part 1b</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT</td>
<td>Rebar</td>
<td>64</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>59</td>
<td>13</td>
</tr>
<tr>
<td>SAT</td>
<td>Rebar</td>
<td>42</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td>HHS</td>
<td>Rebar</td>
<td>659</td>
<td>287</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>611</td>
<td>344</td>
</tr>
</tbody>
</table>
3.1.3 This review also confirmed that inspection records by the Technically Competent Person (“TCP”) are generally available only in respect of the Competent Person stream. The RISCFs for the coupler installation works at the Variable Refrigerant Volume (“VRV”) Plant Room was rejected prior to concrete pouring, but concreting proceeded nevertheless. This works has not been accepted by MTRCL and will be rectified by Leighton.

3.1.4 In late 2017, water seepage was observed at three stitch joints at NAT. Investigation were carried out and defective coupler connections were identified. It was also found that at that time, RISCFs were not submitted by Leighton for the stitch joint construction. The three stitch joints were subsequently reconstructed in mid-2018. For these reconstruction works, RISCFs and couplers inspection records were complete and fully documented.

3.1.5 In light of the stitch joint incident, an investigation of the connection joint at the Shunt Neck was completed in March 2018 and defective coupler connections were also identified. A remedial proposal was developed by Leighton and was subsequently accepted by HyD on 28 May 2019.

**Material Testing Records**

3.1.6 As Leighton did not fully submit to MTRCL with the records of concrete cube test and rebar test, MTRCL has carried out a review on the availability of the records. In addition, the availability of sand replacement test (“SRT”) records has been reviewed.

**Concrete Cube Testing Records**

3.1.7 Concrete cube tests meet relevant test requirements and the records are substantially available for the NAT, SAT and HHS structures. However, there are five locations without concrete cube testing records at trough walls of HHS.

3.1.8 A summary of concrete cube testing records is shown in Table 2 below.
Table 2 - Summary of Concrete Cube Testing Records

<table>
<thead>
<tr>
<th>Structures</th>
<th>Location</th>
<th>Number of cube tests required</th>
<th>Number of cube test records available</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT</td>
<td>EWL / NSL / Shunt Neck</td>
<td>410</td>
<td>409</td>
</tr>
<tr>
<td>SAT</td>
<td>EWL / NSL</td>
<td>296</td>
<td>296</td>
</tr>
<tr>
<td>HHS</td>
<td>NFA</td>
<td>182</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>Underpasses, Track Slabs, Trough Walls</td>
<td>1,460</td>
<td>1,444</td>
</tr>
<tr>
<td></td>
<td>Accommodation Blocks</td>
<td>311</td>
<td>304</td>
</tr>
<tr>
<td></td>
<td>Underpinning</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Area A2</td>
<td>133</td>
<td>133</td>
</tr>
</tbody>
</table>

Rebar Testing Records

3.1.9 The available testing records show that the rebar which have been tested meet the relevant test requirements. The tonnage of rebar requiring testing was taken from the latest amendment drawings (as-constructed) provided by Leighton.

3.1.10 Leighton has contended in the Extended Inquiry of the COI that approximately 7% of the rebar delivered to site under Contract No. 1112 was not sampled for testing ("untested rebar") by a HOKLAS accredited laboratory. MTRCL is seeking clarification with Leighton in this regard because according to the Leighton’s submitted rebar testing record, the number of test samples required is consistent with the quantity of rebar taken off from the latest amendment drawing (as-constructed). In parallel, MTRCL has checked the rebar delivery summary records received from Leighton and compared these to the rebar sampling test records. It was found that based on the delivery summary, the rebar without sampling for test was about 3,500 tonnages which may have been used in NAT, SAT and HHS structures, but not for the accommodation blocks.
Sand Replacement Test Records

3.1.11 SRT is not a statutory requirement but it is specified in the MTRCL Material and Workmanship Specification. SRT is required to be carried out for a general fill area. Sufficient SRTs have been carried out, a summary of the available SRT records is shown in **Table 3** below.

<table>
<thead>
<tr>
<th>Location</th>
<th>Minimum number of SRTs required</th>
<th>Number of SRTs submitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT</td>
<td>450</td>
<td>536</td>
</tr>
<tr>
<td>SAT</td>
<td>307</td>
<td>384</td>
</tr>
<tr>
<td>HHS</td>
<td>1,554</td>
<td>1,845</td>
</tr>
</tbody>
</table>

3.1.12 Although the number of SRT record is generally more than the required minimum number as shown in **Table 3**, there are two missing SRT records at a localised area of HHS for stormwater pipe replacement works. As the missing test record amounts to a very small percentage, it is considered that the effect on the performance of the structure is insignificant.
Design change records

Change from Lapped Bars to Coupler Connections

3.1.13 MTRCL and SYW reviewed the latest amendment drawings (as-constructed) provided by Leighton and compared these against available objective evidence. It was found that couplers had been used in lieu of the lapped bars shown in the original accepted design at some of the construction joints at the following locations.

a) EWL and NSL structures at NAT;

b) EWL and NSL structures at SAT;

c) Underpasses, track slabs, trough walls and NFA structures at HHS; and

d) Base slab of VRV Plant Room for one of the accommodation blocks at HHS.

3.1.14 Since late 2018, the DDCs for NAT, SAT and HHS have reviewed the design change in construction joints. They consider that Type 2 couplers should be adopted for the construction joints in the NSL structure of the SAT and those in the tie beams for the pile caps at NFA. For other areas, Type 1 couplers could be adopted. However, Type 2 couplers were actually used for all areas, according to site records.

3.1.15 The RISCFs for the coupler installation works at the VRV Plant Room was rejected prior to concrete pouring. The works have not been accepted by MTRCL and will be rectified by Leighton.

Change from Coupler Connections to Drilled-in Bars

3.1.16 For the connection between the D-wall and NSL track slab of SAT, Type 2 couplers were detailed in the original accepted design. At some of these locations, drilled-in bars have been used, but the required pulled-out test records are not available.
3.2 Part 1b - Review and Ascertain the As-constructed Conditions of Structures

RISCFs status

3.2.1 To review the gaps in RISCFs identified in Part 1a, MTRCL collated the following objective evidence, with a view to assessing the as-constructed conditions of the structures:

a. Site photographs of rebar fixing and concreting as well as WhatsApp messages between the construction management teams of MTRCL and Leighton.

b. MTRCL’s site diaries which recorded rebar fixing and concreting activities; and

c. Pre-concrete pour quality control records provided by Leighton for Contract No. 1112 including the Concrete Quality Control Checklist (“CQCC”) and coupler installation checklist entitled “As-Built for On-site Assembly of (name of structures) couplers”.

3.2.2 Where RISCFs are not available or cannot be referenced for the two Hold Points for a particular structure, MTRCL and SYW have reviewed the relevant objective evidence with a view to assessing the as-constructed conditions of the structure, with the following considerations:

a) Site photographs

- Identify the location of the works shown in the photographs

- Correlate the dates of photographs being taken with the dates of rebar fixing and concreting of the structures; and

- Assess whether the rebar condition shown in the photographs is generally consistent with the accepted drawings.

b) Site diaries

- Correlate the dates and contents of the construction activities recorded in the site diaries with other objective evidence.
c) WhatsApp messages
   - Correlate the dates and contents of the messages with other objective evidence.

d) Leighton’s quality assurance records
   - Make use of CQCC and coupler installation checklist to correlate the contents of other objective evidence.

**Non-Destructive Test (“NDT”)**

3.2.3 Under *Clause 5.3.5* of the Verification Proposal, NDT would be applied to the structures with gaps identified in Part 1a. For checking concrete cover to rebar and rebar spacing, cover meter scanning was conducted at selective locations at the NAT, SAT and HHS structures, where RISCFs are not available or where couplers were used to replace lapped bars.

3.2.4 More than 400 cover meter scan locations, each of area generally about 1m by 1m, were identified at NAT, SAT and HHS structures, the latter also including the accommodation blocks. Test results indicate appropriate rebar spacing and about 9% of scan locations without sufficient concrete cover. Fire proof coating and concrete thickening will be applied at localised areas of insufficient concrete cover.

**Concrete Cube Test Records**

3.2.5 15 concrete core samples for testing the strength of concrete were taken at five locations where concrete cube tests were not available, i.e. sections of trough walls with a total length of about 70m spread over parts of HHS. There are five locations without the required number of concrete cube tests and, at these locations, Schmidt Hammer tests were carried out by a HOKLAS accredited laboratory to check the concrete strength. The test results complied with the design strength requirement. At other locations of the NAT, SAT and HHS, the results of the available concrete cube tests conducted during construction were satisfactory.
Workmanship of Shear Link Placement

3.2.6 Defects in the shear link placement were first discovered when the shear links at the EWL slab soffit were exposed during the honeycombing investigation in August 2018. In April 2019, MTRCL conducted additional investigation at other locations at the EWL slab on the as-constructed condition of shear link placement. As a result, defects regarding anchorage and/or spacing of shear links were discovered. This raised questions to the workmanship of the shear link placement in the NAT and SAT structures. In addition, the shear links at the HHS structures will also be included in the review.

3.2.7 MTRCL reviewed the RISCFs and objective evidence regarding the rebar fixing for NAT, SAT and HHS structures. Site photographs are available for a number of areas to demonstrate the as-constructed condition of shear links. Whilst not all photographs show the anchorage at the bottom of the shear links, based on the available photographs, MTRCL noted at NAT, SAT and HHS structures that,

a) The reinforcement was not congested, so fixing was relatively easy;

b) The slabs and walls were about 1m thick; and

c) The shear links were of a small diameter (from 10mm to 16mm) and in the form of a hook at top and L-Shape at bottom which is relatively not difficult to fix.

3.2.8 This presented generally a significantly easier steel fixing task at NAT SAT and HHS structures than that encountered in the EWL slab of HUH Extension, where the slab was typically 3m thick and the reinforcement in the top and bottom levels of the slab was relatively congested, with up to eight levels of T40 reinforcement bars at each level.

3.2.9 In view of the above, MTRCL considers it unlikely that there are any significant defects in the fixing of the shear links in the NAT, SAT and HHS structures. Nevertheless, the utilisation of shear links will be further reviewed in Part 2 to verify the structural integrity.
Results of Part 1b

3.2.10 Upon completion of the review under Part 1b, some objective evidence was identified for certain unavailable RISCFs. The summary of the results from the review is shown in Table 4 below:

Table 4: Summary of RISCFs Status after Part 1b review

<table>
<thead>
<tr>
<th>Structures</th>
<th>Nos. and % of RISCFs unavailable</th>
<th>Nos. of unavailable RISCFs with objective evidence identified</th>
<th>Nos. of unavailable RISCFs without objective evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT</td>
<td>Rebar</td>
<td>43 67%</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>46 78%</td>
<td>46</td>
</tr>
<tr>
<td>SAT</td>
<td>Rebar</td>
<td>19 45%</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>17 39%</td>
<td>17</td>
</tr>
<tr>
<td>HHS</td>
<td>Rebar</td>
<td>372 56%</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>Pre-pour</td>
<td>267 44%</td>
<td>219</td>
</tr>
</tbody>
</table>

3.2.11 The considerable proportion of missing RISCFs at NAT, SAT and HHS structures has raised questions as to whether or not the required site supervision and control were implemented at the relevant hold points and whether or not the works were carried out to the required standards. From the review under Part 1b, for the majority of the works for which the RISCFs are unavailable, relevant and consistent records viz. photographs, site diaries and WhatsApp messages, are available to match the scope and timing of the works carried out on site. These records showed that, in general, MTRCL’s site staff had knowledge of the works. They were present on site when the works were being carried out.
3.2.12 The possible gaps, which may be relevant to the structural review under Part 2, include the following key issues listed in Table 5 below. The findings under Part 1b have provided useful information for evaluating the key issues and the provisions required for dealing with the gaps in Part 2 structural review.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Findings</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Rebar workmanship and compliance with accepted drawings</td>
<td>No anomalies showing noticeable deviation of the size and spacing of the main rebar from the accepted drawings were found from the review of the available photographs (Section 3.2.2). Cover meter scans indicated appropriate rebar spacing (Section 3.2.4). Review of records suggested that significant defects in the placement of shear link are unlikely.</td>
<td>The rebar shown in the accepted drawings are assumed to be present in the as-constructed structures.</td>
</tr>
<tr>
<td>(b) Some rebar test records are missing</td>
<td>For NAT, SAT and HHS, Leighton’s delivery summary indicated that testing records were not available for about 3,500 tonnes (Section 3.1.10).</td>
<td>A reduction in the rebar strength of 4% and 13% is adopted in Part 2 (Section 4.3.2) for those structures constructed after the delivery of the untested rebar.</td>
</tr>
<tr>
<td>(c) Some concrete test records missing</td>
<td>No anomalies were found from the available concrete cube test records. The results of Schmidt Hammer tests and testing of concrete core samples carried out in Part 1b were satisfactory (Section 3.2.5).</td>
<td>The concrete of the as-constructed structures is assumed to have the required strength as specified in the accepted drawings.</td>
</tr>
<tr>
<td>Issues</td>
<td>Findings</td>
<td>Recommendations</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>(d) Concrete cover</td>
<td>Results of cover meter scans indicate about 9% of scan locations without sufficient concrete cover.</td>
<td>Fire proof coating and concrete thickening will be applied to localised areas of insufficient concrete cover (Section 3.2.4).</td>
</tr>
<tr>
<td>(e) Workmanship of coupler connections</td>
<td>Defective rate of 35% was adopted for coupler connections at NAT, SAT and HHS (Section 4.2.6).</td>
<td>Strength reduction factor of 35% is adopted for coupler connections in Part 2 (Section 4.2.6).</td>
</tr>
<tr>
<td>(f) Any other issues arising from changes to the works</td>
<td>The required pull-out test records of the drilled-in bars adopted between D-wall and NSL track slab at SAT were not available.</td>
<td>The strength of the drilled-in bars is ignored in Part 2.</td>
</tr>
</tbody>
</table>
Section 4 Structural Review under Part 2

4.1 Overview of Structural Review

4.1.1 The approach and findings of the structural review, including the nature and scope of the proposed suitable measures, are discussed below. It is considered that, given the findings of this verification exercise and with the implementation of the proposed suitable measures, the concern about the structural integrity of NAT, SAT and HHS arising from the missing RISCFs and other relevant reported issues is adequately addressed.

4.1.2 A comparison has been made between the deduced spare structural capacity and the assumed strength reduction factor for coupler installations. Similarly, the structural review also studies the possible impact to the structures based on the alleged untested rebar. If necessary, suitable measures will be determined and implemented at locations where the spare structural capacity is less than the reduction factor.

4.1.3 It is proposed that suitable measures will be implemented to address the gaps and related workmanship/quality issues so as to achieve the safety level required in the Code for meeting the requirements of the BO and the established good practice of engineering design. The NWDSM should also be complied with. The term “suitable measures” covers a wide range of actions and may include structural modifications, remedial works, long term monitoring of the structure and surrounding areas, and the imposition of constraints on potential future modifications to the structure and its use.

4.2 Review Approach of Coupler Connections

4.2.1 The structural review under Part 2 assesses the integrity of the as-constructed structures. Due consideration is taken of the as-constructed conditions of the structures by incorporating the findings and recommendations under Part 1b (Table 5).
4.2.2 At early design stage of NAT and SAT, a number of factors were unknown to DDC, in particular the detailed construction methodology. The original design was thus built up with extra provisions and flexibilities in order to cater for a wide range of uncertainties that might be realised during subsequent design and construction stages. However, with the completion of the detailed design and construction of NAT and SAT structures, it is considered these extra provisions/flexibilities can be reviewed and rationalised as some of the uncertainties at the early design stage are either more certain or no longer need to be accommodated. Furthermore, it is acceptable to also adopt some other changes to the original design assumptions for this structure provided that suitable restrictions and precautionary arrangements are put in place.

4.2.3 Arising from the considerations described in Section 4.2.2 above, the proposed updates to the original design assumptions are listed in Appendix B1 and B2 for the structural review of NAT and SAT respectively. The proposed updates include rationalisation of the original loading assumptions, use of refined structural modelling approaches and consideration of moment re-distribution, together with suitable precautionary provisions. MTRCL considers the adoption of these updates to be an appropriate approach for assessing the integrity of the structure and the extent to which further works are required to the structure. It reflects more accurately the actual situation. It also incorporates changes that have been selected to strike a suitable balance between the extent of further works to be carried out and the cost and time effectiveness of the works required, whilst ensuring that the functionality and performance of the structure are not compromised.

4.2.4 For the HHS, as the updated design assumptions at NAT and SAT are not applicable, the loading conditions of the original design criteria have generally been adopted in the structural review. However, at some locations, the utilisation percentages have been reviewed based on the actual trough wall height and actual position of piles/columns at the NFA. Moment redistribution has been adopted to assess the maximum utilisation of the tie beams at NFA. The proposed updates to the original design assumptions of HHS are listed in Appendix B3.
4.2.5 The percentage of strength utilisation in terms of bending and shear has been evaluated at different structural elements of selected critical locations. As such, the spare structural capacity of structural elements can be taken as the difference of the full structural capacity (i.e. 100%) and the strength utilisation rate.

4.2.6 Due to the lack of full records of the coupler connection works, it is considered prudent to apply a strength reduction factor in areas where coupler connections have replaced lapped bars on account of the uncertainty of workmanship. In the absence of any other alternative evidence or data, a strength reduction factor of 35% has been adopted. This is comparable to the strength reduction factor applied in respect of the NSL platform slab in the adjacent HUH Extension which is adjoining to NSL tunnel at SAT. For other structures in NAT, SAT and HHS, they are less complicated than the NSL tunnel at SAT in respect of construction difficulties.

4.2.7 The strength of any drilled-in bars between the D-wall and NSL track slab at SAT has been ignored in the structural review since their pull-out test records are not available.
4.3 Review Approach for Untested Rebar

4.3.1 Part 2 also assesses the possible implications at NAT, SAT and HHS structures arising from the untested rebar mentioned in Section 3.1.10.

4.3.2 For the gaps in rebar testing records, a strength reduction factor is considered, taking into account the records of the rebar tensile test results from MTRCL’s HOKLAS accredited laboratory. According to these records, there are no failures recorded in any of the testing carried out under Contract No. 1112. By comparison, there are only 55 failed samples out of about 110,000 samples tested by MTRCL’s laboratory since 2010. According to past nine years record of the failed sample, the maximum reduction in tensile strength is about 4% below the design tensile strength for rebar of diameter equal or greater than 16mm and the maximum reduction in tensile strength is about 13% below the design tensile strength for rebar of diameter less than 16mm. Hence, it is reasonable to adopt strength reduction factor of 4% for rebar of diameter 16mm or above and a strength reduction factor of 13% for rebar of diameter 12mm and below for the untested rebar used in NAT, SAT and HHS structures in carrying out the structural review.

4.4 Structural Connection at Shunt Neck

4.4.1 It should be noted that the gaps identified at the Shunt Neck of the NAT relating to coupler connections will be dealt with by remedial works with a revised connection detail. The remedial works proposal was accepted by HyD on 28 May 2019.
4.5 Results of Structural Review

Coupler Connections

4.5.1 For NAT and SAT structures, the spare structural capacity at critical coupler locations is greater than the assumed strength reduction factor of 35%. Suitable measures in respect of coupler connections are therefore not required.

4.5.2 However, for HHS structures, the spare structural capacity at critical coupler locations of trough wall kickers near movement joints of a total length of about 150m is less than the assumed strength reduction factor of 35%. Suitable measures are therefore required and illustrated in Appendix C. For other locations such as underpass corridor, culvert, track slab and NFA tie beam, the spare structural capacity is greater than the assumed strength reduction factor of 35%. Suitable measures are therefore not required.

Shear Capacity

4.5.3 For NAT and HHS structures, the spare structural capacity at critical shear locations is greater than the assumed strength reduction factor of 4% or 13% depending on rebar size. Suitable measures in respect of shear link are therefore not required.

4.5.4 For SAT structures, the spare structural capacity at critical shear locations of the EWL trough is greater than the assumed strength reduction factor of 4% or 13% depending on rebar size. However, in view of the concern about the unsatisfactory shear link placement in Area A of the NSL slab adjoining SAT, suitable measures to enhance the shear strength will be applied at the NSL tunnel box as illustrated in Appendix C.
Bending Capacity

4.5.5 As explained in Section 4.3.2, in carrying out the structural review a strength reduction factor of 4% has been applied to rebar of diameter 16mm or above and 13% for rebar of diameter 12mm or below for the untested rebar used in NAT, SAT and HHS structures.

4.5.6 For NAT, SAT and HHS structures, the spare structural capacity in bending at critical locations with rebar diameter of 16mm or above and without coupler connections is greater than the assumed strength reduction factor of 4%. Suitable measures are therefore not required.
Section 5 Way Forward

Coupler connections

5.1 Based on results of the structural review, works are required for trough walls near the movement joints at HHS as suitable measures. Proposed scheme of the suitable measures is illustrated in Appendix C subject to the detailed design.

Shear link placement

5.2 The structural review concludes that works are required for the NSL tunnel box at SAT as suitable measures. Proposed scheme of the suitable measures is illustrated in Appendix C subject to the detailed design.

Rebar testing

5.3 The structural review concluded that suitable measures are not required.

Long-term monitoring

5.4 In view of the gaps identified in Part 1a, as part of the suitable measures, a long-term monitoring scheme including instrumentation monitoring and inspection will be developed to monitor the structural integrity of the NAT, SAT and HHS structures. Suitable restrictions and precautionary arrangements, which are in connection with the use of updated design assumptions, will also be put in place as appropriate.

Additional quality assurance

5.5 MTRCL will also explore options for providing the Government with additional quality assurance and/or an undertaking in respect of the structures where gaps are identified in Part 1a.

Programme of Suitable Measures

5.6 It is expected that the required works identified in this Final Report will be implemented concurrently with those for the HUH Extension.
Section 6 Conclusion and Recommendations

6.1 Part 1b review identified gaps in site inspection records, material testing records and design change in rebar connection. Some alternative objective evidence was also identified for a number of unavailable RISCFs under Part 1b. Besides the findings under Part 1b have provided useful information for evaluating key issues and the provisions required for dealing with the gaps in Part 2 structural review.

6.2 Based on the results of Part 2 structural review, some suitable measures have been identified and proposed at certain locations at the NSL tunnel of the SAT and trough walls of the HHS to ensure structural integrity. These measures will be further developed for submission to the Government for acceptance. It is expected that the required works identified in this Final Report will be implemented concurrently with those for the HUH Extension. Upon satisfactory completion of the structural modifications and remedial works, the NSL tunnel of the SAT and trough walls of the HHS will achieve the safety level required in the Code for meeting the established good practice of engineering design. The NWDSM should also be complied with.

6.3 As part of the suitable measures, a long-term monitoring scheme including instrumentation monitoring and inspection will be developed, to monitor the structural integrity of the NAT, SAT and HHS structures. Suitable restrictions and precautionary arrangements, which are in connection with the use of updated design assumptions, will also be put in place as appropriate.

6.4 Based on the Part 2 structural review and inspections carried out, MTRCL considers that for the purpose of the ongoing construction activities, the NAT, SAT and HHS are structurally safe.

6.5 Formal amendment submissions will be made to the Government for consultation and acceptance.

6.6 MTRCL will also explore options for providing the Government with additional quality assurance and/or an undertaking in respect of the structures where gaps are identified in Part 1a.
Appendix A

General Layout Plan of the Hung Hom Station Extension
General Layout Plan of Hung Hom Station Extension at EWL Level
General Layout Plan of Hung Horn Station Extension at NSL Level
Typical Section of South Approach Tunnels (SAT)
Typical Section of Hung Hom Stabling Sidings (HHS)
Appendix B1

Summary of Design Assumptions for NAT
Table B1  Updated Design Assumptions Adopted for Structural Review of NAT

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Updated Design</th>
<th>Restrictions/Precautionary Arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Trackform Load</strong>&lt;br&gt;A superimposed dead load of 14.5kPa was allowed in the NAT design at the time when the trackform design was uncertain on account of it not having commenced at that time.</td>
<td>The trackform design has been finalised and the trackform has been installed. The trackform loading can therefore be updated according to the as-built drawing from trackwork contract.</td>
<td>Flexibility for future alteration works may be affected, in view of the revised loading provisions adopted in the Updated Design.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Seismic Loads</strong>&lt;br&gt;Pseudo-static acceleration of 0.15g together with a Load Factor 1.4 was applied in the Original Design.</td>
<td>Following the requirements stipulated in NWDSM.</td>
<td>NIL</td>
</tr>
<tr>
<td>3</td>
<td><strong>Modelling approach</strong>&lt;br&gt;Three separate 3-D shell or grillage models were adopted, which the structural behaviour could not be fully demonstrated especially the differential settlement at interface.</td>
<td>A single 3-D shell model is formed with consideration of staged construction at the stitch joint.</td>
<td>NIL</td>
</tr>
</tbody>
</table>

Remarks:

1) The above assumptions are consistent with those adopted in the Stage 3 of the Final Report on Holistic Assessment Strategy for Hung Hom Station Extension.
Appendix B2

Summary of Design Assumptions for SAT
### Table B2  Updated Design Assumptions Adopted for Structural Review of SAT

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Updated Design</th>
<th>Restrictions/Precautionary Arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Train Load</strong></td>
<td>Train load can be applied as per NWDSM Figure 4.4.6 F1 Rev D.</td>
<td>May affect the alteration of train type not already covered by current NWDSM, in view of the revised loading provisions adopted in the Updated Design.</td>
</tr>
<tr>
<td></td>
<td>A uniform live load of 108 kPa was allowed at all locations of the track area to</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>envelope the moving loading from trains.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>Seismic Load</strong></td>
<td>Following the requirements stipulated in NWDSM.</td>
<td>NIL</td>
</tr>
<tr>
<td></td>
<td>Pseudo-static acceleration of 0.07g together with a Load Factor 1.4 was applied</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in the Original Design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><strong>Trackform Load</strong></td>
<td>The trackform design has been finalised and the trackform has been installed.</td>
<td>Flexibility for future alteration works may be affected, in view of the revised loading provisions adopted in the Updated Design.</td>
</tr>
<tr>
<td></td>
<td>A superimposed Dead Load of 20kPa for NSL was allowed in the SAT design at the</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>time when the trackform design was uncertain on account of it not having</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>commenced at that time.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><strong>A 5m differential water pressure</strong> was applied and a load factor of 1.4</td>
<td>A 5m differential water pressure is considered to be an exceptional load case</td>
<td>Groundwater and loading conditions, say arising from future construction works in the vicinity of the site, will be controlled accordingly. This may pose a restriction on the future usage and development in the vicinity of the site. Long term monitoring scheme to be further developed.</td>
</tr>
<tr>
<td></td>
<td>subsequently applied.</td>
<td>in Clause 4.4.8.4 of the NWDSM. A load factor of 1.05 can be adopted according to Clause 2.3.2.2 of the Code.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Future Property Loading</td>
<td>After reviewing the site conditions around SAT, the potential for future</td>
<td>This poses a restriction on the future usage and development in the vicinity of the site.</td>
</tr>
<tr>
<td></td>
<td>A positive 20kPa lateral pressure acting on one side of the structure, and a</td>
<td>property development in the vicinity is under control of MTRCL. The</td>
<td></td>
</tr>
<tr>
<td></td>
<td>negative 20kPa lateral pressure acting on another side was allowed for.</td>
<td>application of 20kPa acted on both sides can therefore be excluded.</td>
<td></td>
</tr>
<tr>
<td>Original Design</td>
<td>Updated Design</td>
<td>Restrictions/Precautionary Arrangements</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>---------------</td>
<td>----------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>5</strong> Modelling approach</td>
<td>The NSL slab was actually supported on soil during the bottom up construction of the tunnel. Thus there was no locked-in stress on the D-walls during construction.</td>
<td>Flexibility of future alteration works may be affected, in view of the revised modelling conditions adopted in the Updated Design.</td>
<td></td>
</tr>
<tr>
<td><strong>6</strong> No redistribution of moment, which is the approach commonly adopted in designing railway and other structures in Hong Kong.</td>
<td>A maximum of 30% moment redistribution is adopted. i.e. for reinforcement concrete joint exceeding the structural capacity, the excess moment at the support between diaphragm walls and NSL slabs would be redistributed to the mid-span of NSL slabs.</td>
<td>This affects the reserve capacity of the structure.</td>
<td></td>
</tr>
<tr>
<td><strong>7</strong> Soil Stiffness Correlation Factor</td>
<td>The assessment of the stiffness can follow the Geotechnical Engineering Report (“GER”) which has been accepted by relevant Government departments during the early design stage.</td>
<td>NIL</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:
1) The above assumptions are consistent with those adopted in the Stage 3 of the Final Report on Holistic Assessment Strategy for Hung Hom Station Extension.
Appendix B3

Summary of Design Assumptions for HHS
Table B3    Updated Design Assumptions Adopted for Structural Review of HHS

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Updated Design</th>
<th>Restrictions/Precautionary Arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>No redistribution of moment</strong>, which is the approach commonly adopted in designing railway and other structures in Hong Kong.</td>
<td>A maximum of 20% moment redistribution is adopted in the review of the maximum utilisation of tie beams at NFA. Tie beams were monolithically supported on pile caps and hogging moment at the supports would be redistributed to the mid-span.</td>
<td>This affects the reserve capacity of the structure.</td>
</tr>
<tr>
<td>2</td>
<td>Additional moment was allowed in the design to cater for pile construction offset tolerance of 75mm.</td>
<td>Additional moment due to offset of pile is recalculated based on as-constructed condition.</td>
<td>NIL</td>
</tr>
</tbody>
</table>
Appendix C

Proposed Scheme of Suitable Measures
Section at SAT - Proposed Scheme of Suitable Measures
PROPOSED REINFORCED CONCRETE STRUCTURE

PROPOSED DRILLED-IN BARS

EXISTING CONCRETE PAVING

EXISTING TROUGH WALL

EXISTING FILL

Suitable Measures for Trough Walls of HHS - Type 1
Suitable Measures for Trough Walls of HHS - Type 2
PROPOSED REINFORCED CONCRETE STRUCTURE

EXISTING TROUGH WALL

EXISTING CONCRETE PAVING

PROPOSED DRILLED-IN BARS

EXISTING FILL

Suitable Measures for Trough Walls of HHS - Type 3