The Shatin to Central Link Project

Final Report

Volume 1 of 2

Expert Adviser Team

Transport and Housing Bureau

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Executive Summary

Shatin to Central Link ("SCL") Project

1. The SCL is one of the strategic railway lines recommended in the Railway Development Strategy 2000. It is about 17 km long, with ten stations. As the Project Manager, the MTR Corporation Limited ("MTRCL") is tasked to deliver the SCL Project under Entrustment Agreements with the Government.

2. Since late May 2018, reports began to appear in the local media about irregularities in the construction works of the SCL Project. In particular, there was major public concern about the alleged defective steel reinforcement bar ("rebar") connection works in the East West Line ("EWL") platform slab and diaphragm wall ("D-wall") at the Hung Hom Station ("HUH") Extension of the Hung Hom Site.[1] The settlement issues at the Exhibition Centre Station ("EXC") and To Kwa Wan Station ("TKW") sites have also attracted much attention.

Expert Adviser Team

3. On 15 August 2018, the Expert Adviser Team ("EA Team") comprising three senior retired Government officers was established under the Transport and Housing Bureau to provide expert advice in following up the case.

4. The EA Team issued an interim report in October 2018, in which a number of preliminary recommendations were presented. One of the recommendations was the formulation of a holistic assessment strategy for the HUH Extension. This included opening up of certain major structural members for investigation.

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[1] For the purpose of this report, the HUH Extension and the North Approach Tunnels, South Approach Tunnels and Hung Hom Stabling Sidings are collectively denoted as the Hung Hom Site. SCL Contract 1112 covers the Hung Hom Site, with Leighton Contractors (Asia) Limited ("Leighton") as the contractor.

Commission of Inquiry

Original Inquiry – HUH Extension

5. In July 2018, the Chief Executive in Council appointed the Commission of Inquiry ("Commission"), under the Commissions of Inquiry Ordinance (Cap. 86), to inquire into the rebar fixing works and other works which might raise concerns about public safety in the HUH Extension structure.

6. The first part of the hearings of the Commission ("Original Inquiry") was held between October 2018 and January 2019, with an interim report released for public viewing in March 2019.

Extended Inquiry – North Approach Tunnels ("NAT"), South Approach Tunnels ("SAT") and Hung Hom Stabling Sidings ("HHS")

7. Towards the end of the Original Inquiry hearings, new concerns arose in other areas of the Hung Hom Site, viz. NAT, SAT and HHS. These included defective works and lack of construction records. To deal with these concerns, the second part of the Commission's hearings ("Extended Inquiry") was held between May 2019 and January 2020.

8. The Final Report of the Commission was released to the public on 12 May 2020.

Holistic Assessment and Verification Study in Hung Hom Site

9. Following EA Team's recommendations, MTRCL formulated the proposal for the Holistic Assessment of the HUH Extension structure. The findings of the Holistic Assessment were given in the *Holistic Report*[2], which was issued by MTRCL and accepted by the Government in July 2019.

[2] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/01_Final_report_on_Holostic_Assessment_Strategy_e.pdf

10. For the NAT, SAT and HHS, a similar investigation denoted as Verification Study was conducted by MTRCL. The findings were presented in the *Verification Report*[3] in July 2019.

11. The nature and extent of the construction irregularities in the Hung Hom Site were assessed in the Holistic Assessment and Verification Study. Based on these, engineering analysis was carried out for evaluating the remedial works required for code compliance. The two reports were submitted to the Commission for scrutiny in the Extended Inquiry.

12. The Commission's findings, together with these two reports, provided the essential information on the facts and circumstances surrounding the irregularities in the Hung Hom Site. Apart from these, some other important issues of the SCL Project, such as the design of the HUH Extension structure, the situation in other SCL stations, and settlement monitoring and control, were also reviewed by the EA Team.

Irregularities in Construction

13. Various irregularities in the built structures in the Hung Hom Site were revealed from the investigation. These included defective rebar-coupler connections at the junction between the platform slabs and D-wall, mismatch of couplers with the threaded rebars in the stitch and shunt neck joints, missing and irregular shear links, illicit design changes at the connection between the EWL slab and D-wall, water seepage and corrosion, large voids in concrete backfill, and other workmanship defects resulting in honeycombing, inadequate concrete cover, etc. Most of these were examined in detail in the Commission's hearings.

14. The diverse types and significant extent of the construction irregularities are alarming, and unusual in major construction projects in Hong Kong. For example, for the rebar-coupler connections between the platform slabs and D-wall in the HUH Extension structure, statistical

[3] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/02_Final_Verification_Study_Report_e.pdf

analysis of the investigation results with a 95% confidence level gives a significant defective rate[4] of 36.6% and 33.2% at the EWL and North South Line ("NSL") slabs respectively.

15. The investigation results also indicate that the threaded ends of the rebars have been cut in an average of 3.3% of the connections between the EWL slab and D-wall. In 8.9% of the connections, the rebars were not connected to the couplers.[5] Based on an estimated number of 21,500 coupler connections between the EWL slab and D-wall alone, it implies that some 700 cut bars and 1,900 unconnected couplers may be present.

Irregularities in Site Supervision and Control

16. Apart from the construction irregularities, major anomalies in site supervision and control were noted, particularly in the hold point inspection process and keeping of contemporaneous site records.

17. According to MTRCL's Project Integrated Management System ("PIMS"), quality hold points are specified at key stages of construction where the designated representatives of MTRCL and Leighton have to inspect and certify the satisfactory condition of the works carried out before proceeding with the next phase of the works. This is a vital requirement in site supervision and control, and the relevant Request for Inspection, Survey and Check ("RISC") forms have to be completed as a traceable record of proper implementation of the hold point inspection process. However, a significant proportion of the required RISC forms are either missing or irregular in the HUH Extension. The situation for the NAT, SAT and HHS is particularly worrying in that as many as 78% of the RISC forms are unavailable for certain hold point inspections.

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[4] Samples not meeting the acceptance criteria of coupler installation are regarded as "defective". This included inadequate thread engagement length and unconnected couplers. Some of these also involved rebars which have obviously been cut.

[5] Unconnected couplers can be described as the extreme case of inadequate thread engagement in which the rebar has not been engaged into the coupler.

18. The multitude of irregularities in the works which had remained undetected during construction and the large number of missing or grossly irregular RISC forms are symptomatic of failures in the site supervision and control process in the Hung Hom Site.

19. The anomalies in keeping contemporaneous and traceable records are not confined to RISC forms, but are also found in other important site records, such as those required under the Quality Supervision Plan ("QSP") and as-built drawings. MTRCL had engaged in the compilation of a large amount of retrospective QSP records for the coupler installation works at the EWL slab. The Commission noted:

> *"The Commission also heard evidence of wide-scale retrospective compilation of construction records, these records all too often being inaccurate. In this latter respect, the Commission found that retrospective compilation of records had led to glaring inaccuracies in an important report submitted by MTRCL to the Government on 15 June 2018, this report concerning the integrity of the station box structure."* [6]

Safety and Compliance of Built Structures in Hung Hom Site

20. The construction irregularities and anomalies in site supervision and control give rise to a threefold concern about the quality and integrity of the built structures in the Hung Hom Site: (a) safety, (b) code compliance, and (c) contract compliance.

Safety

21. The issue of safety is associated with a pragmatic question about whether the built structures are safe to be used and would serve their intended functions, day in and day out. This was examined at length during the Inquiry, under the subject denoted as "*safe and fit for purpose*". The Commission concluded that:

[6] See paragraph 23 of the Executive Summary of the Final Report

> *"there was consensus among all the experts and the three involved parties (the Government, MTRCL and Leighton) that, whatever their conflicting views as to the need for remedial measures, with those measures in place, the station box structure will be safe and will also be fit for purpose."* [7]

22. The "*conflicting views*" as noted by the Commission stemmed from the two different approaches adopted by the structural experts in addressing the issue. Based on the *compliance approach*, the Government's expert advocated that *safe and fit for purpose* should be benchmarked with the applicable codes. A suite of *suitable measures* was recommended in the *Holistic Report* and *Verification Report*. The *suitable measures* included, among other provisions[8], essentially remedial works on the built structures for code compliance purposes. The Government's expert considered that without the implementation of the *suitable measures*, the built structures are not *safe and fit for purpose*.

23. The other experts who adopted the *forensic approach* considered code compliance not essential to the *safe and fit for purpose* evaluation. Instead, based on their expert experience and judgement, and with account taken of the condition and performance of the structures, they concluded that the structures were *safe and fit for purpose* as they stood.

24. The EA Team recognized that the difference in opinion represents two different, and perhaps complementary, schools of thought for dealing with the complex question about "how safe is safe". The EA Team was not a party in the Inquiry. However, with its close involvement and knowledge of the case, the EA Team is convinced that with the implementation of the required remedial works, it is safe in practical terms to use the built structures for their intended purposes.

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[7] See paragraph 412 of the Final Report

[8] These include long-term monitoring, and restrictions and precautionary arrangements on future modifications to the structures and future usage of the site and development in its vicinity. See paragraph 4.1.8 of the *Holistic Report* and paragraph 4.1.3 of the *Verification Report.*

Code compliance

25. Both the Government and MTRCL agreed that the completed works should comply with the applicable codes, which meets the established standard of good engineering practice and also forms part of the regulatory requirements. In the present case, the Code of Practice for Structural Use of Concrete ("Concrete Code")[9] issued by the Buildings Department ("BD") and the New Works Design Standards Manual ("NWDSM")[10] of MTRCL are the applicable codes in question.

26. Engineering analysis was carried out in the Holistic Assessment and Verification Study to determine the scope and type of the remedial works required to render the built structures code-compliant, given the presence of the construction irregularities. The required remedial works, were included as *suitable measures* to be implemented by MTRCL for code compliance purposes.[11]

27. In determining the required remedial works, MTRCL has adopted a set of *updated design criteria* in the engineering analysis. This is denoted as *Updated Design*, in contrast to the *Original Design* of the structures as originally accepted for construction. Adoption of the *Updated Design* contains the scope and extent of the remedial works, without contravening code compliance.[12] Nevertheless, there are notable implications.

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[9] The Concrete Code is the de facto design standard for concrete building structures in Hong Kong. It forms part of the regulatory requirements.

[10] According to the Entrustment Agreements, the SCL structures shall be designed to comply with the NWDSM. The NWDSM embraces the requirements for compliance with the Concrete Code. However, given the specific nature and requirements of railway structures, the NWDSM also contains additional requirements for such structures.

[11] Following the acceptance of the *Holistic Report* and *Verification Report* by the Government, MTRCL proceeded with the detailed engineering design and finalization of the exact extent and details of the required remedial works.

[12] See paragraphs 4.3.2 and 4.3.3 of the *Holistic Report* and paragraph 51 of the Final Report

28. Some of the *updated design criteria* involve reduction of the design loading provisions. This implies that the structures after implementation of the remedial works will comply with the code requirements, but up to the revised loading limits adopted in the *Updated Design*. Also, moment redistribution is used in the *Updated Design*, which reduces the reserve capacity of the structures in, say, accommodating future alteration works and withstanding unforeseen, accidental conditions. While MTRCL has confirmed that the adoption of the *updated design criteria* would not affect the functionality and performance of the structures, there are consequential restrictions and precautionary arrangements which are included as *suitable measures* to be observed in the long term.

29. On the premise that code compliance is not compromised, the EA Team has no objection to the adoption of the *updated design criteria*. This is a pragmatic solution, agreed between MTRCL and the Government, for addressing the engineering concerns about the structural integrity, so as to render the structures acceptable for being put into their intended use for the benefit of the community.

30. At the time of preparation of this report, the vast majority of the remedial works in the proposed *suitable measures* have been implemented. However, detailed proposals for dealing with water seepage, corrosion, long-term monitoring and additional undertaking of quality assurance from MTRCL are still being finalized. MTRCL and HyD should speed up the required follow-up actions.

Contract compliance

31. Whether the completed works were in accordance with the contractual requirements under the Entrustment Agreements was not explicitly addressed in the Holistic Assessment and Verification Study, nor in the Inquiry. None of these were intended to be a forum for deliberation of contractual liability.

32. While the gap between the completed works and the requirements under the Entrustment Agreements is apparent, examination of the extent of the possible discrepancies is outside the remit of the EA Team. This is a matter for the Government to follow up with MTRCL.

Long-term Monitoring

33. In view of the multitude of irregularities in the Hung Hom Site, introducing a suitable long-term monitoring programme would serve the beneficial purpose of continually checking the structural health condition, evaluating the structural performance, and identifying any necessary maintenance and repair works for upkeeping the condition of the structures.

34. "Monitoring" refers to a broad range of actions encompassing inspections, measurement, surveys and surveillance. This may or may not require the use of sensitive instruments for measurement of minute deformation. Indeed, the EA Team shares the view that such instruments should be used with caution, and they may not be appropriate for the structures in the Hung Hom Site.

35. Given the need to observe the restrictions and precautionary arrangements associated with the *Updated Design*, the relevant provisions should be included in the long-term monitoring programme. There is also scope for leveraging the monitoring programme to address possible concerns about the long-term performance and durability of the built structures. The EA Team has already conveyed its advice on the possible scope and considerations of the long-term monitoring to MTRCL and HyD. MTRCL and HyD should finalize the monitoring programme for implementation.

Spare Capacity in Design

Over-provision in design

36. As noted by the Commission, the original design of the Hung Hom Extension structure contained significant spare capacity.[13] This has helped compensate the structure for some, if not all, of the reduced structural capacity arising from the construction irregularities. Furthermore, with the changes in design criteria in the *Updated Design*, despite the host of irregularities, the structure could be retrofitted with less extensive remedial works to code compliance, without large-scale remediation or re-construction.

37. The EA Team did not directly take part in the engineering analysis conducted for the finalization of the required remedial works. However, the EA Team has spot-checked the original design of the EWL slab at selected locations which are representative. It was found that in the vast majority of the spot-checked locations, the spare capacity was indeed significant, ranging from 40% to over 100% on top of the design requirements. This arose from over-provision of the main rebars in excess of the amount required for code compliance. Also, it was apparent that the detailing of rebars in the design has not generally followed the good practice for curtailment of the main rebars.

38. It is uncommon for a detailed design which is finalized for construction to contain such a significant degree of over-provision. The design intent of providing the structure with the significant spare capacity in excess of the code requirement is unclear. Incidentally, the over-provision has helped mitigate the adverse consequences of the construction irregularities. However, as the presence of the irregularities would not have been foreseen in the design stage, it should not have been the design intent to introduce the significant over-provision to cater for the irregularities.

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[13] For example, paragraph 353 of the Final Report records that *"Atkins, Ove Arup and COWI all agreed that there is at least 40% spare capacity at the top mat of the EWL slab at the connection with the diaphragm wall"*.

39. The over-provision has cost and buildability implications. In the present case, congestion of rebars at the top and bottom mats of the EWL and NSL slabs had resulted in construction difficulty in rebar fixing, connection of couplers and concreting. The significant over-provision of rebars could have aggravated the buildability problem.

A requirement of the Concrete Code in question

40. In the Inquiry, different views were given by the experts about the detailing requirement of the Concrete Code that the amount of rebars at the bottom mat of the EWL slab should be at least 50% of that required at the top mat.

41. The experts who adopted the *forensic approach* considered this requirement not relevant to the *safe and fit for purpose* evaluation. The Government's expert, who favored the *compliance approach*, contended that this was required for enhancing the ductility and robustness of the structure, which is prudent for ensuring structural integrity and preventing uncontrolled collapse in accidental conditions.

42. The EA Team understood that the difference in opinion among the experts on this matter in the Inquiry hinged not on the structural engineering principle, but on whether this requirement is essential in evaluating *safe and fit for purpose*. Setting the *safe and fit for purpose* evaluation aside, this requirement was consistent with the consensus among the engineering profession about the good practice to adopt in structural design and detailing. The requirement is incorporated in the Concrete Code, as well as in similar codes elsewhere, as part of the recommended good practice.

Issues Relating to Design and Checking of Design

Avoiding conflict of interest

43. MTRCL's Detailed Design Consultant ("DDC"), Atkins, was also engaged by the contractor as the design consultant for the HUH Extension

under Contract 1112. In view of the potential conflict of interest that might arise from such an arrangement, the EA Team advised MTRCL to follow this up in October 2018.[14]

44. The Commission examined the matter in the Inquiry, and concluded that "*such an arrangement carries with it the immediate potential of both real and perceived conflict of interest*". [15]

45. Avoidance of potential conflict of interest is vital in upholding the necessary checks and balances. The arrangement as permitted by MTRCL is strictly prohibited in Government's public works projects.[16] Noting that the same arrangement has also been adopted by MTRCL in other SCL sites and is still in place at the time of preparation of this report, the EA Team opines that more concrete actions should be taken to debar the arrangement in future railway projects.

Plugging gaps in Government's design checking

46. The SCL Project should be designed to meet the requirements of the NWDSM, which embraces the Concrete Code. All along, the Government's design checking is undertaken by either the Building Authority ("BA") or HyD.[17] However, the checking is confined to regulatory compliance with the Concrete Code, which applies to buildings in general. The NWDSM contains additional requirements pertinent to railway structures. For instance, the performance of the structure under seismic condition (i.e. seismic design), which is specified in the NWDSM but not the Concrete Code, was not attended to. Moreover, a design life of 120 years is stipulated in the NWDSM which is more stringent than the 50-year design life in the Concrete Code.

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[14] This was included in one of EA Team's preliminary recommendations. See ***Appendix 2-1*** of this report.

[15] See paragraph 638 of the Final Report

[16] See Clauses 190 and 194 of the *Stores and Procurement Regulations* and the relevant requirements given in the *Handbook on Selection, Appointment and Administration of Engineering and Associated Consultants*

[17] Cases subject to Instrument of Exemption ("IoE") and Instrument of Compliance ("IoC") are checked by the BA and HyD, respectively.

47. Specifically for dealing with the structures in the Hung Hom Site, where structural integrity was in question due to the known irregularities, the Government's checking should encompass compliance with the NWDSM, rather than confining only to the Concrete Code. In response to EA Team's advice, HyD undertook to separately conduct the design checking for ensuring compliance with the NWDSM, in additional to the BA's checking against compliance with the Concrete Code. At the time of preparation of this report, HyD's checking has yet to be completed. This is unsatisfactory.

48. The gap in Government's design checking should be plugged in future railway projects. In the interest of streamlining procedures and providing one-stop service as far as practicable, HyD should also explore the possibility of having the compliance checking against the regulatory requirements and NWDSM carried out under one roof in future.

Gearing up for seismic design

49. A major anomaly in seismic design was noted during the Holistic Assessment, in that both the approach and procedures specified in the NWDSM for seismic design were not duly followed in the original design of the HUH Extension structure. This was neither identified in the internal checking by the DDC, nor by MTRCL's design management team which was tasked to certify the design. As seismic design is part of NWDSM's requirements which are not specified in the Concrete Code, the anomaly also slipped through Government's checking.

50. For the Hung Hom Site, HyD should ensure, via its design checking, that the seismic design is in compliance with the NWDSM. The EA Team has also advised HyD to take stock of whether the approach and procedures specified in the NWDSM for seismic design were followed in the design of the other SCL stations. HyD should speed up the stock-taking to ascertain whether any further follow-up actions are required.

Using couplers judiciously

51. Defective coupler connections are the most striking irregularity uncovered in the Hung Hom Site, with dire consequences for structural integrity. A large amount of coupler connections have been used in the Hung Hom Site. Many of these were apparently the contractor's decision, with neither prior acceptance by MTRCL nor contemporaneous and complete records on whether the installation works were properly carried out and supervised.

52. In terms of structural performance, a properly connected coupler would behave as satisfactory as connecting the rebars with an adequate lapped length. However, coupler connection involves much more delicate construction works, which need to be meticulously undertaken and closely supervised. Hence, it should be used judiciously, subject to due consideration of the relevant buildability issues and implementation of effective site supervision and control.

Ensuring cost-effectiveness in design

53. The significant over-provision in the original design of the HUH Extension structure points to a wider issue about cost-effective design.

54. In recent years, a series of new initiatives have been introduced for enhancing the cost-effectiveness of the design in delivery of public works projects. Attention is given to not only managing the cost of the project within the estimated budget, but also pursuing better value for money and cost-saving in all stages throughout the project.

55. While cost-effectiveness is a broad objective of MTRCL's project management, there is scope for MTRCL to review the relevant practices and provisions in its project delivery process for seeking improvement. HyD should also strengthen its management of future Government railway projects undertaken by MTRCL, so that these projects are at least on a par with Government's public works projects in the quest for improvement in cost management.

Assessment of Other SCL Stations

56. To ascertain if there are other irregularities in the construction of the key structures in the SCL Project, a "health-checking" assessment was carried out for the other SCL stations.

57. The assessment entailed a three-tier audit, with the first two comprising an internal audit by MTRCL's consultant and an independent audit by HyD's Monitoring and Verification ("M&V") Consultant. The last tier of vetting by the relevant authority, i.e. the BA or HyD as appropriate, follows the regulatory requirements for the Certificates of Completion prior to the built structures being put in use.

Audits by MTRCL and HyD

58. The findings of the two audits by MTRCL and HyD are collaborating with each other in many areas. Both audits have not identified any major construction irregularities with significant structural safety implications. However, deficiencies in construction control and record-keeping were identified in these SCL stations to various degrees.

59. The issues on site supervision and control revealed in the audits may need to be addressed through enhanced maintenance provisions and additional undertaking of quality assurance for the relevant stations.

Third tier of audit by relevant authority

60. In the last tier of the audit, the relevant authority has acknowledged the Certificates of Completion together with relevant documents including record drawings, test reports on construction materials and certificates submitted by MTRCL for the EWL stations audited.[18] This signifies the acceptance by the authority, in the public interest, for the completed works of these stations to be safely put in use.

[18] The only audited SCL station on NSL, i.e. Exhibition Centre Station, is still under construction at the time of preparation of this report. It will be vetted by the relevant authority in due course.

Settlement Audit

61. Construction projects with substantial underground works, such as the SCL Project, need to be cautiously carried out together with the implementation of an agreed monitoring and control system.[19] This is to ensure that the adverse impacts on the nearby facilities are kept within an acceptable level.

62. There has been major public concern about the settlement problems arising from the SCL works, particularly in the vicinity of TKW, EXC and the Fleet Arcade near EXC. Amid the concern, a new "monitoring and announcement mechanism for the impact of railway works to nearby structures and public facilities" ("*Enhanced Mechanism*") was implemented by HyD, BD and MTRCL on 28 September 2018.

63. While it was in the early stage of EA Team's involvement in the SCL Project, the views of EA Team were sought and incorporated in the *Enhanced Mechanism* before its finalization for implementation. The EA Team also stated in its Interim Report of October 2018 that it "*plans to conduct audits of selected cases in the SCL Project, including cases before and after the implementation of the mechanism, to assess the effectiveness of the monitoring and control system.*"[20]

Findings of audit

64. The settlement audit by the EA Team covered 17 selected monitoring points at or in the vicinity of TKW, EXC and the Fleet Arcade. It focused on reviewing the available records of the site activities associated with the exceedance of the *Alarm Level* and the response actions taken in the implementation of the Alert-Action-Alarm ("AAA") mechanism.

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[19] The system included a three-tier triggering mechanism, i.e. Alert-Action-Alarm (AAA) Levels, for response actions. When the highest pre-set trigger level, i.e. *Alarm Level*, is exceeded, suspension of the construction works is typically specified among other response actions.

[20] See paragraph 4.15 of the Interim Report of the EA Team

65. Before the implementation of the *Enhanced Mechanism*, at the 17 selected monitoring points, there were a total of 23 incidents of exceedance of the *Alarm Level*. The relevant construction works were continued without suspension after the exceedance.

66. Apart from three incidents which involved building settlement in TKW, suspension of the construction activities was specified in the accepted monitoring and control plans for the other 20 incidents. In three incidents in the Fleet Arcade site, which were related to tunneling works by tunnel boring machine ("TBM"), there is some ambiguity about the applicability of the requirement to suspension of the TBM works.[21] Apart from these six incidents, the lack of suspension of works in the other 17 incidents evidently did not conform to the requirements stipulated in the accepted plans.

67. In all the 23 incidents, the works had continued to proceed for a considerable period of time, many even to their completion, without the revision and acceptance of an updated set of AAA Levels. The AAA mechanism has broken down after the exceedance of the *Alarm Level*. Continuation with the works without a revised and accepted set of AAA Levels in place implies that the works are carried out without the control of an applicable AAA mechanism. This is unacceptable.

68. The non-conformance with the requirements for suspension of works upon the breach of the *Alarm Level* is a major irregularity in the implementation of the accepted monitoring and control plan. Other than this, the other precautionary and mitigation actions[22] were generally carried out by MTRCL according to the AAA mechanism. However, these precautionary and mitigation actions should not be taken as adequately replacing the need for suspension of works, as the two are required under the AAA mechanism for different purposes.

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[21] In these three cases, due to the delay in the ground response, the *Alarm Level* was exceeded when the TBM cutterhead was marginally beyond 50 m from the monitoring points.

[22] These included typically conducting reviews, enhancing the monitoring, carrying out ground treatment and other mitigation works, inspecting buildings for confirmation of structural safety, ensuring road safety via inspections and repairing pavements when found necessary, and liaising with the affected parties.

69. In connection with the implementation of the *Enhanced Mechanism*, the AAA Levels in EXC were revised and accepted in September 2018.[23] Since then, none of the monitoring points of EXC were reported by MTRCL to have further incidents of exceedance of the *Alarm Level*.

Areas for improvement

70. The settlement audit has provided insights into areas for improvement in the formulation and implementation of the monitoring and control system.

71. First, a realistic *Alarm Level* (i.e. the threshold limit for suspension of works) which tallies with the predicted ground response, subject to proper justification of the acceptability of this limit, should be set. Next, the requirements for suspension of the relevant construction activities upon exceedance of the *Alarm Level*, should be rigorously followed. In addition, the works should not be resumed without an applicable and accepted AAA mechanism being in place. The relevant Government departments should also adopt a proactive and firm approach to ensure that the response actions specified in the accepted monitoring and control plan are duly taken by MTRCL.

72. Furthermore, in the formulation and implementation of the monitoring and control system, due consideration should be given to avoiding damage in addition to ensuring safety. There is also a need to enhance the coordination in dealing with facilities affected by concurrent construction works of different parties. Besides, specifically for tunneling works, account should be taken of the possible delay in the response of ground and building settlements.

73. As for the *Enhanced Mechanism*, while the effectiveness of its implementation warrants further verification, the mechanism should be refined to incorporate the areas for improvement identified from the

[23] The works in TKW and the Fleet Arcade sites had been substantially completed when the *Enhanced Mechanism* was introduced in September 2018.

settlement audit and other experience gained to date, for adoption in future railway projects.

Project Management

74. The Commission, with advice from its independent project management expert, has made comprehensive recommendations on project management issues. In the light of its involvement in the review of the Hung Hom Site together with the observations made of the other facets of the works in the SCL Project in general[24], the EA Team shares similar views in many of the project management issues identified by the Commission. Several salient issues that warrant attention are highlighted to supplement the subject matter.[25]

Maintaining discipline in compliance with design and works requirements

75. The PIMS is a comprehensive document setting out the good practice for managing railway projects delivered by MTRCL. While there is scope for update and improvement of the PIMS[26], the EA Team does not consider that the PIMS has any fundamental deficiencies in its project management principles and processes. What matters in the present case, where manifold and extensive irregularities are present, is the apparent lack of discipline in complying with the established good practice, both for construction according to design and specifications and for site supervision and control.[27]

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[24] These included health-checking of the other SCL stations, settlement audit, and other aspects such as design- and audit-related matters.

[25] Some of the lessons learnt which have already been described, e.g. those relating to the observed irregularities, design and checking of design, are also related to project management.

[26] MTRCL has appointed an external consultant to carry out a full review and an update of the PIMS. The independent project management expert of the Commission has also given his views on the areas for improvement in the PIMS in his two expert reports to the Commission.

[27] Some of the major irregularities are not confined to the Hung Hom Site, e.g. deficient site records and non-conformance with the monitoring and control plans are found in other SCL stations.

76. MTRCL should review and implement measures for instilling a culture of good discipline in conformance with the design, works specifications, and site supervision and control requirements during construction. MTRCL should also look into any additional or enhanced provisions in its project delivery process, to ascertain that the discipline is maintained on site, both by the contractors and by MTRCL's site supervisory personnel.

Keeping contemporaneous and traceable site records

77. Many of the construction irregularities found in the Hung Hom Site are linked to the failure in keeping timely and traceable site records. Deficient record-keeping is not a minor flaw. It acutely undermines the effectiveness of the site supervision and control system in assuring the quality of the works and tracing the accountability of the supervisory personnel who is to give this assurance.

78. MTRCL should review the nature and causes of the irregularities observed in site record-keeping in the SCL Project, with a view to identifying improvement measures to avoid replication of similar problems in future. Account should be taken of the apparent widespread presence of similar problems in different station sites in the SCL Project, and not to overly rely on the newly introduced digital system[28] as a panacea for the deficiencies.

79. Given the importance of proper site record-keeping, enhanced provisions should be made by MTRCL and HyD in future railway projects for auditing the availability, timeliness and completeness of the site records, particularly those which are crucial to site supervision and control and in the assurance of the quality of the construction works.

[28] The new digital RISC form system, known as "*iSuper*", has been adopted in the EXC site since February 2019.

Conducting effective audits

80. Both MTRCL and HyD have their own provisions for auditing the SCL Project.[29] These audits should serve the important purpose of verifying whether the delivery and management of the SCL Project meet the established requirements. However, the widespread irregularities were not detected in the audits. Otherwise, the anomalies could have been identified in the early stage during construction, offering an opportunity for timely control and rectification of the problem. In this regard, even though the deficiencies in the audits may not be a direct cause of the irregularities, all parties should seriously review the lessons learnt and take improvement actions to ensure the effectiveness of the audits in future projects.

81. The culture of an organization and stance of the senior management have a profound influence on the effectiveness of the audits. An organization which takes audits as an opportunity for improvement instead of fault-finding would stand a much better chance of achieving the intended objectives of the audits. Where the senior management is receptive to identification of deficiencies and lessons learnt, this would encourage honest feedback from the audits. The senior management should take this into consideration in improving the effectiveness of the audits.

Probing into the underlying causes

82. The investigation completed to date has served to gauge the nature and extent of the irregularities in the Hung Hom Site, which enables an objective assessment of the structural integrity and the required remedial works for compliance with the applicable codes. It has also provided insights into the probable causes of the irregularities and areas for improvement.

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[29] MTRCL's personnel conducted regular Internal Quality Audits, Self Quality Audits and External Quality Audits. HyD's audits on the SCL Project were carried out by its M&V consultant based on the "check the checker" approach, focusing on cost, programme and public safety.

83. Notwithstanding this, the EA Team is both conscious of, and concerned about, the possibility that the underlying causes which are intrinsic and root to the irregularities might not have been fully unveiled. These underlying causes may be organization-specific, i.e. those on MTRCL's side may be different from those of the other parties.

84. Pinpointing such underlying causes will yield diagnostic insights into the inherent factors, which if duly addressed, would be pivotal in bringing about the required improvement and avoiding recurrence of similar problems in future. It would also shed light on where priority or focused attention should be given, among the large number of follow-up actions arising from the lessons learnt and recommendations which have already been identified.

85. The relevant key parties, viz. MTRCL and HyD in particular, should conduct a candid review for probing into the underlying causes of the irregularities. The senior management of the respective parties should give its firm commitment and attention to the review and implementation of the required follow-up actions. This is vital to the success of the exercise.

Relevance to Other Works Projects

86. Some of observations made and lessons learnt in this case may have relevance to other non-railway projects in Hong Kong.

87. Specifically, given the similarity of the SCL Project to other major public works projects in terms of their scale and complexity, it is advisable for the relevant Works departments to maintain awareness of the lessons learnt from the SCL Project and review any necessary improvement to be made in their project management and delivery.

Conclusion

88. With the completion of this final report, which summarizes EA Team's observations and recommendations on the SCL Project, the duties as mandated in the Terms of Reference for the EA Team are regarded as discharged. These observations and recommendations are intended primarily for bringing continual improvement to railway projects in specific and the construction industry in Hong Kong at large.

List of Abbreviations

A

AAA	Alert-Action-Alarm
ADM	Admiralty Station
ADMS	Automatic Deformation Monitoring System
AS	Authorized Signatory
Atkins	Atkins China Limited

B

BA	Building Authority
BD	Buildings Department
BO	Buildings Ordinance
BOSA	BOSA Technology (Hong Kong) Limited

C

CP	Competent Person

D

DDC	Detailed Design Consultant
DEVB	Development Bureau
DIH	Diamond Hill Station
DPA	Detailed Plan of Action
D-wall	Diaphragm wall

E

EA Team	Expert Adviser Team
EQA	External Quality Audit
EWL	East West Line
EXC	Exhibition Centre Station

G

GEO	Geotechnical Engineering Office
GKJV	Gammon-Kaden SCL 1111 Joint Venture

H

HHS	Hung Hom Stabling Sidings
HIK	Hin Keng Station
HOM	Ho Man Tin Station

HOKLAS	Hong Kong Laboratory Accreditation Scheme
HUH	Hung Hom Station
HyD	Highways Department

I

IAP	Independent Audit Panel
ICE	Independent Checking Engineer
IoC	Instrument of Compliance
IoE	Instrument of Exemption
IQA	Internal Quality Audit
ITP	Inspection and Testing Plan

K

KAT	Kai Tak Station

L

Leighton	Leighton Contractors (Asia) Limited

M

MTRCL	MTR Corporation Limited
M&V	Monitoring and Verification

N

NAT	North Approach Tunnels
NCR	Non-conformance Report
NSL	North South Line
NWDSM	New Works Design Standards Manual

O

OTE	Over track exhaust

P

PAUT	Phased Array Ultrasonic Test
PCMO	Project Cost Management Office
PSGO	Project Strategy and Governance Office
PIMS	Project Integrated Management System
PR	Preliminary Recommendation
PYPUN	PYPUN-KD & Associates Limited

Q

QAS	Quality Assurance Scheme
QCC	Quality Control Coordinator
QCS	Quality Control Supervisor
QSP	Quality Supervision Plan

R

RDO	Railway Development Office
RISC	Request for Inspection, Survey and Check
RGE	Registered Geotechnical Engineer
RSE	Registered Structural Engineer

S

SAT	South Approach Tunnels
SCL	Shatin to Central Link
SConE	Senior Construction Engineer
SDM	Structures Design Manual for Highways and Railways
SIOW	Senior Inspector of Works
SPR	Stores and Procurement Regulations
SQA	Self Quality Audit
SSP	Site Supervision Plan
SUW	Sung Wong Toi Station

T

T5	Grade T5 of Technically Competent Person
TAW	Tai Wai Station
TBM	Tunnel boring machine
TCP	Technically Competent Person
THB	Transport and Housing Bureau
TKW	To Kwa Wan Station

V

VR	Video Rigid

W

WSP	WSP (Asia) Limited

Glossary of Terms

Term	Definition
Alert-Action-Alarm Levels	As part of the monitoring and control plan for major excavation and underground construction works in Hong Kong, a three-tier activation mechanism is generally adopted. The trigger criteria for activation of response actions are commonly denoted as Alert-Action-Alarm ("AAA") Levels. The monitoring parameters (e.g. settlement and building tilting), pre-set trigger levels of the parameters (i.e. AAA Levels), and the response actions to be taken in the event of reaching each of the trigger levels are specified in the approved or accepted drawing which presents the monitoring and control plan. This three-tier activation mechanism is also known as "AAA mechanism".
BO Team	This is a team of professional staff seconded from BD to HyD to handle matters relating to the Instrument of Exemption and the Instrument of Compliance for the Express Rail Link Project and the SCL Project.
Concrete Code	Code of Practice for Structural Use of Concrete 2004 issued by the Buildings Department.
Enhanced Mechanism	Amid the concern about the settlement problems arising from the SCL Project, an enhanced mechanism for monitoring and making announcement for impact of the SCL works on nearby structures and public facilities was devised

Term	Definition
	and implemented by HyD, BD and MTRCL on 28 September 2018. *(Source : See **Appendix 9-1** of this report)*
Extended Inquiry	The second part of the hearing of the Commission of Inquiry to inquire into the facts and circumstances of problems surrounding the construction works in the NAT, SAT and HHS. The hearing commenced on 27 May 2019 and ended on 23 January 2020. *(Source : www.coi-hh.gov.hk)*
Extended Terms	The extended terms of reference of the Commission of Inquiry to inquire into the facts and circumstances of problems surrounding the construction of the NAT, SAT and HHS. *(Source : www.coi-hh.gov.hk)*
Final Report	"Final Report of Commission of Inquiry into the Construction Works at and near the Hung Hom Station Extension under the Shatin to Central Link Project" dated March 2020. *(Source : www.coi-hh.gov.hk)*
Holistic Assessment	It refers to the investigation and assessment of the as-constructed conditions and workmanship of the HUH Extension under the *Holistic Proposal*.
Holistic Proposal	"A Holistic Proposal for Verification & Assurance of As-constructed Conditions and Workmanship Quality of the Hung Hom Station Extension (East West Line Platform Slab, North South Line Platform Slab and the Connecting Diaphragm Walls)" issued by MTRCL on 4 December 2018.

Term	Definition
	(Source : www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/report_20181205_e.pdf)
Holistic Report	"Final Report on Holistic Assessment Strategy for the Hung Hom Station Extension" issued by MTRCL on 18 July 2019. *(Source : www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/01_Final_report_on_Holostic_Assessment_Strategy_e.pdf)*
Hung Hom Site	It is the collective description of the HUH Extension, NAT, SAT and HHS in Contract 1112.
Instrument of Compliance	Pursuant to the provision in Section 41 of the Buildings Ordinance (Cap.123), construction works of the SCL Project located in unleased land are exempted from the control of the Ordinance. In accordance with the Entrustment Agreements between the Government and MTRCL, the Director of Highways issued the *Instrument of Compliance* requiring MTRCL to follow the administrative procedures and requirements as stipulated in the Instrument for carrying out building works. The objective is to ensure that the quality of building works should not be inferior to the standards as required by the BO and its subsidiary legislations.
Instrument of Exemption	With the consideration of the specific nature of building works related to railway construction, the Building Authority, in accordance with Section 54(2) of the Mass Transit Railway

Term	Definition
	Ordinance (Cap. 556), issued the *Instrument of Exemption* ("IoE") to exempt MTRCL from certain requirements under the BO. The exemption is only limited to those procedures involving the appointment of Authorized Person and Registered Structural Engineers, approval of drawings, and issuing works permits and occupation permits. The IoE also stipulates that MTRCL has to appoint persons possessing the appropriate experience and qualifications to be responsible for works in different aspects, and to establish Project Management Plan for the relevant works. The Project Management Plan outlines the scope of the works for the SCL Project and provides details on how this project is to be managed by MTRCL in order to demonstrate that the proposed management process will meet the exemption requirements under the BO.
Original Design	It refers to the code-compliant design according to the design assumptions and models originally adopted in the accepted design of the structures in the Hung Hom Site. It was based on the *Original Design* that the proposed works were accepted as complying with the applicable codes for meeting the established good practice of engineering design. The proposed works are shown in the accepted drawings.
Original Inquiry	The first part of the hearing by the Commission of Inquiry to inquire into the facts and circumstances surrounding the steel reinforcement fixing works and other works that may raise concerns about

Term	Definition
	public safety in the station box structure of the Hung Hom Station Extension. The hearing commenced on 22 October 2018 and ended on 29 January 2019. *(Source : www.coi-hh.gov.hk)*
Original Terms	The original terms of reference of the Commission of Inquiry to inquire into the facts and circumstances surrounding the steel fixing works and other works that may raise concerns about public safety in the station box structure of the Hung Hom Station Extension. *(Source : www.coi-hh.gov.hk)*
Preliminary Recommendations	These are the recommendations made by the Expert Adviser Team to MTRCL and relevant Government departments in its Interim Report No. 1 dated 19 October 2018. A list of these recommendations is at ***Appendix 2-1*** of this report.
Suitable Measures	The term covers a wide range of actions and may include structural modifications, remedial works, long-term monitoring of the structure and the surrounding areas, and the restrictions and precautionary arrangements on future modifications to the structure and future usage of the site and development in its vicinity. It means actions which are deemed necessary to address the issues identified in the *Holistic Report* and achieve the safety level required in the Code of Practice for Structural Use of Concrete for meeting the requirements of the Buildings Ordinance and the established good practice of

Term	Definition
	engineering design. The NWDSM should also be complied with.
T5 Report	"T5" is the short form for Grade 5 Technically Competent Person as specified in the Code of Practice for Site Supervision 2009 and the Technical Memorandum for Supervision Plans 2009. T5 is a registered professional engineer with minimum 5 years of relevant experience. The T5 under the Registered Geotechnical Engineer's ("RGE") stream is responsible for "*checking that site works comply with the approved plan, design requirements including those of the method statements, precautionary and protective measures*" and "*dealing with nonconformities by making referral to the RGE's Representative*", among other duties. One of the duties of the T5 is submitting regular reports of the findings and recommendations to the RGE. RGE shall formally submit these reports (denoted as "*T5 Reports"*) to the relevant Government departments.
Updated Design	It refers to the code-compliant design carried out with the use of some revised design assumptions and models for the structures in the Hung Hom Site in the Holistic Assessment and Verification Study. These revised design assumptions and models are denoted as *updated design criteria* in the *Holistic Report* and *Verification Report*. Most notably, the *updated design criteria* involve reduced loading limits and use of moment redistribution in the design analysis. Adoption of the *updated design criteria* results in less

Term	Definition
	extensive remedial works required on the structures, while still complies with the codes. However, there are implications, such as reduced structural capacity in comparison with the *Original Design* and the need for putting in place restrictions and precautionary arrangements for the future use of the structures. The required remedial works form part of the *suitable measures*.
Verification Proposal	"Verification Proposal of As-constructed Conditions of the NAT, SAT and HHS" issued by MTRCL on 15 May 2019.
Verification Report	"Final Verification Study Report on As-constructed Conditions of the North Approach Tunnels, South Approach Tunnels and Hung Hom Stabling Sidings" issued by MTRCL on 18 July 2019. *(Source : www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/02_Final_Verification_Study_Report_e.pdf)*
Verification Study	It refers to the investigation and assessment of the as-constructed conditions and workmanship of the NAT, SAT and NAT under the *Verification Proposal*.

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Section 1 Introduction

Background

1. Since late May 2018, there have been reports in the local media about irregularities in the construction works of the Shatin to Central Link ("SCL") Project carried out by the MTR Corporation Limited ("MTRCL"). Background of the SCL Project is at ***Appendix 1-1***.

2. Various construction irregularities were reported. These included part of the concrete walls of To Kwa Wan Station ("TKW") not properly constructed, steel reinforcement cages of the diaphragm wall ("D-wall") installed in the wrong direction at Exhibition Centre Station ("EXC") and excessive settlements at the TKW and EXC sites, etc. The most notable irregularity was probably the alleged defective connection of reinforcement steel bars ("rebars") in the Hung Hom Station ("HUH") Extension, which raised concern on the safety of the station box structure.

3. According to certain information provided by MTRCL to Highways Department ("HyD") on the reported irregularities in the HUH Extension on 15 June 2018, HyD considered that the matter might involve criminal elements and thus referred the case to the Police for follow-up action.

4. On 10 July 2018, the Chief Executive in Council appointed the Commission of Inquiry ("Commission") under the Commissions of Inquiry Ordinance (Cap. 86) to inquire into the steel reinforcement fixing works and other works which might raise concerns about public safety in respect of the D-walls and platform slab construction works in the HUH Extension structure under the SCL Project. This included, but not limited to, those works at locations that had given rise to extensive public concern since May 2018.

5. From a review of the information submitted by MTRCL on 13 July 2018, HyD and Buildings Department ("BD") identified that the information provided by MTRCL about the connection details between the

platform slab of the East West Line ("EWL") and the D-wall of the HUH Extension was inconsistent with the design drawings previously accepted by the Building Authority ("BA"). The number of couplers used in connecting the rebars was also inconsistent with the site records previously provided by MTRCL and its contractor.

Establishment of Expert Adviser Team

6. On 8 August 2018, the Chief Executive announced the appointment of three senior retired Government officers, namely Dr LAU Ching-kwong, Mr HUI Siu-wai and Mr WONG Hok-ning, to form the Expert Adviser Team ("EA Team") for the SCL Project. The EA Team was formally established by the Transport and Housing Bureau ("THB") on 15 August 2018. By late August 2018, three senior professional officers were deployed from HyD, BD and Civil Engineering and Development Department respectively to provide technical support to the EA Team.

7. The EA Team is tasked to conduct an overall review of the project management system of MTRCL, and recommend additional management and monitoring measures to be undertaken by MTRCL and the relevant Government departments as appropriate, in taking forward the SCL Project. In particular, the EA Team will provide expert advice on ascertaining the as-built condition of the platform slabs and D-walls of the HUH Extension, possible measures to ascertain if there are other irregularities in the construction of the key structures in the SCL Project, and any other matters relevant to the works of the SCL Project. The Terms of Reference of the EA Team is at ***Appendix 1-2***.

8. The EA Team was appointed for a period of one year initially. Due to the discovery of further matters of public concerns as explained in *paragraph 10* below, its appointment was extended to 30 April 2020 with a further extension to 31 December 2020 to tie in with the publication of the Commission's Final Report and completion of a few other outstanding issues including the assessment and settlement audit of other SCL stations.

Hearings of Commission of Inquiry

9. The first part of the hearings by the Commission was held between October 2018 and January 2019 to inquire into the facts and circumstances surrounding the steel reinforcement fixing works of the construction of the platform slab and D-wall construction in the HUH Extension ("Original Inquiry").

10. Towards the end of the Original Inquiry hearings, other matters of public concern arose in other areas of the HUH Extension, viz. lack of construction records and uncertain quality of work done in respect of the North Approach Tunnels ("NAT"), South Approach Tunnels ("SAT") and Hung Hom Stabling Sidings ("HHS"). The Terms of Reference of the Commission were extended in February 2019.

11. An interim report of the Commission, addressing the safety of the D-walls and platform slabs of the HUH Extension as uncovered in the Original Inquiry was released for public viewing in March 2019.

12. The second part of the hearings by the Commission was held between May 2019 and January 2020 to deal with the further matters of public concern ("Extended Inquiry").

13. The Final Report of the Commission ("Final Report") was released to the public on 12 May 2020.

Scope of this Report

14. This report of the EA Team comprises 12 sections with ***Section 1*** giving an overview of the report.

15. ***Section 2*** describes the essence of the work done by the EA Team, in order to provide greater transparency of its involvement in the appointment.

16. ***Section 3*** deals with irregularities in construction as well as irregularities in site supervision and control in the HUH Extension, NAT, SAT and HHS (collectively described as "Hung Hom Site" in this report).

17. ***Section 4*** is about the safety and compliance of the built structures in the Hung Hom Site. It deals with the safety, code compliance and contractual compliance aspects of the built structures in the Hung Hom Site. It also addresses the related matters including the difference between the *Original Design* and *Updated Design* and the implications of the *suitable measures*.

18. Areas for attention in the long-term monitoring of the built structures in the Hung Hom Site are described in ***Section 5***.

19. ***Section 6*** explores why the built structures in the Hung Hom Site with a host of construction irregularities could be reasoned as safe and code-compliant through partial structural strengthening, without the need for large-scale remediation or re-construction. The spare capacity in the *Original Design* and the revised design criteria adopted in the *Updated Design* are examined.

20. ***Section 7*** seeks to discuss areas for improvement in the design and the checking of the design in the light of lessons learnt in the Hung Hom Site.

21. ***Section 8*** reports on the assessment of other SCL stations based on "health-checking" audits undertaken by independent consultants of HyD and MTRCL. The scope, methodology and findings of the audits are explained with EA Team's observations on the assessment.

22. ***Section 9*** summarizes the background, scope and findings of the audit carried out by the EA Team on selected settlement cases at TKW and EXC sites and the Fleet Arcade near EXC. The areas for improvement to the settlement monitoring and control system identified from the audit are presented.

23. ***Section 10*** covers some salient project management issues relating to the construction works of the SCL Project (not limited to the HUH Site).

24. While the observations and recommendations made in this report relate primarily to the works in the Hung Hom Site and the SCL Project, ***Section 11*** addresses the possible relevance to other works projects in Hong Kong.

25. ***Section 12*** is a summary of recommendations made in this report.

Section 2 Work Undertaken by Expert Adviser Team

General Duties of EA Team

26. Since its establishment in August 2018, the EA Team has been providing the relevant Government departments and MTRCL with advice in following up the irregularities in the SCL Project. This has been made through meetings, joint site inspections and written correspondence.

Timeline of Key Events

27. The investigation into the irregularities in the Hung Hom Site by various parties has spanned over a period of more than two years. The timeline below shows the sequence of the key events during the period for easy reference.

Date		Key Event
2018	May	Complaints about rebar cutting first surfaced.
	15 June	MTRCL issued "Report on SCL Contract 1112 – Review of the EWL Slab Construction".[30]
	10 July	Commission appointed by the Chief Executive in Council.
	15 August	EA Team established by THB.
	22 October	Substantive hearing of the Original Inquiry commenced.
	24 October	EA Team's Interim Report was released through THB website.[31]
	4 December	MTRCL issued "A Holistic Proposal for Verification & Assurance of As-constructed Conditions and Workmanship Quality of the

[30] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/report_20180614_e.pdf

[31] https://www.thb.gov.hk/eng/psp/publications/transport/studies/index.htm

Date		Key Event
		Hung Hom Station Extension" ("*Holistic Proposal*").[32]
2019	29 January	Hearing of Original Inquiry completed.
	25 February	Commission submitted its Interim Report to the Chief Executive.
	26 March	Commission's Interim Report was released to the public in redacted form.[33]
	15 May	MTRCL issued "Verification Proposal of As-Constructed Conditions of the North Approach Tunnels, South Approach Tunnels & Hung Hom Stabling Sidings"[34] ("*Verification Proposal*").
	27 May	Substantive hearing of the Extended Inquiry commenced.
	18 July	MTRCL issued both *Holistic Report*[35] and *Verification Report*[36] with respect to the *Holistic Proposal* and *Verification Proposal* respectively.
2020	23 January	Hearing of Extended Inquiry completed.
	27 March	Commission submitted its Final Report to the Chief Executive.
	12 May	The Final Report of the Commission was released to the public in redacted form.[37]
	December	EA Team submitted its final report to THB.

[32] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/report_20181205_e.pdf

[33] https://www.coi-hh.gov.hk/pdf/COI_Interim_Report_Eng.pdf

[34] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/report_20200921.pdf

[35] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/01_Final_report_on_Holostic_Assessment_Strategy_e.pdf

[36] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/02_Final_Verification_Study_Report_e.pdf

[37] https://www.coi-hh.gov.hk/pdf/COI_Final_Report_Eng.pdf

EA Team's Interim Report

28. Two months after its appointment, the EA Team issued its Interim Report on 19 October 2018 to present the progress of its work and its views on the required further investigation. The report also summarized a total of 16 Preliminary Recommendations ("PR") that had already been made by the EA Team in assisting the relevant parties in pursuing their investigation work. These PRs are listed in ***Appendix 2-1***.

29. Having attended over 200 meetings and site inspections, the EA Team has been providing expert advice on the formulation and execution of the investigation in the Hung Hom Site, settlement audit and assessment of other SCL stations, as well as review of project management issues.

30. In order to provide greater transparency of the work undertaken by the EA Team throughout its appointment, the major tasks done are summarized in the ensuing paragraphs.

Holistic Assessment Strategy for HUH Extension

31. In reviewing the irregularities of the HUH Extension, the EA Team identified the need for and recommended a holistic strategy for assessment of the irregularities and structural integrity (i.e. "Holistic Assessment") in its Interim Report, in lieu of the load tests originally proposed by MTRCL. This formed the framework of MTRCL's Holistic Assessment of the HUH Extension, which promulgated, among others, the necessity to open up certain major structural members for investigation.

32. The relevant PR reads "*The EA Team recommends that MTRCL formulate a holistic strategy for agreement with the relevant government departments for assessing the acceptability of the works in the Hung Hom Station Extension, covering the EWL and NSL platform slabs and the diaphragm walls. The strategy may include a combination of diagnoses based on the available objective records, physical inspections through opening up the structures, non-destructive tests and load tests, for assessing the acceptability of the structures and for establishing the key*

parameters that may be required for the design and implementation of any necessary remedial/improvement works."[38]

33. During its inspections of the HUH Extension site in August and September 2018, the EA Team noticed a number of defects, such as large areas of surface honeycombs, exposed reinforcement layers and gaps between columns and the upper platform slab, which should be addressed as part of the Holistic Assessment. The EA Team relayed these observations and advised the relevant Government departments and MTRCL to step up inspections. The EA Team also regularly participated in meetings on investigation of the irregularities and formulation of the required remedial measures.

34. The *Holistic Proposal* was formulated by MTRCL, in consultation with the EA Team, HyD and BD. Support was also provided by Government's structural engineering and statistical experts.

35. Following the *Holistic Proposal*, MTRCL conducted the Holistic Assessment from October 2018 to July 2019 under the close scrutiny of HyD, BD, Police and the EA Team. Government's structural engineering and statistical experts also provided input where needed.

36. During the course of investigation, a review of the Phased Array Ultrasonic Test ("PAUT") methodology with the testing laboratory was required when some discrepancies between the PAUT readings and actual measurements were identified in four samples in late January 2019. Other experts were also enlisted to study the aspect of corrosion on the coupler connections as recommended by the EA Team.

Holistic Report

37. Intensive task force meetings comprising representatives from HyD, BD, MTRCL, the EA Team and other experts were held from April to July 2019 in reviewing the findings of the Holistic Assessment. These

[38] See PR 2.2 in ***Appendix 2-1***

are presented by MTRCL in the *Holistic Report*. Upon acceptance by the Government, MTRCL issued the *Holistic Report* on 18 July 2019.

Verification Report

38. Similar to the Holistic Assessment for dealing with the issues under the Original Terms, the issues under the Extended Terms were addressed by the Verification Study. The proposal for the Verification Study ("*Verification Proposal*") was formulated by MTRCL in consultation with HyD, BD and the EA Team to: (a) verify the as-constructed conditions including quality, workmanship and design changes of the structures for the NAT, SAT and HHS, and (b) ascertain the structural integrity and ensure the quality assurance of the structures in the NAT, SAT and HHS.

39. No physical opening up was carried out in the NAT, SAT and HHS structures under the Verification Study. The verification work has mainly been the checking of available objective evidence, such as site photographs, site diaries and other site records. Non-destructive tests including cover meter scanning were performed at selective locations where the Request for Inspection, Survey and Check ("RISC") forms were not available or where couplers were used to replace lapped bars. A decision was taken by MTRCL to adopt the defective rate of 35% for the HUH Extension structure. This served to save the time and effort in repeating the laborious opening up and carrying out of PAUT for coupler connections at the NAT, SAT and HHS. Similarly, where the required pull-out test records of the drilled-in bars adopted between the D-wall and North South Line ("NSL") track slab at the SAT were not available, the strength of the drilled-in bars was ignored in the structural assessment. This explains the short period of time between the completion of *Verification Proposal* (May 2019) and the *Verification Report* (July 2019).

40. Upon the completion of the Verification Study, the EA Team in conjunction with the relevant parties continued to provide input to MTRCL's compilation of the *Verification Report.* The report was issued on 18 July 2019.

Assessment of Other SCL Stations

41. To address the concern about whether other SCL stations may suffer from irregularities similar to those of the HUH Extension, the EA Team initiated an exercise of "health-checking" audit on the other stations constructed or modified under the SCL Project. The EA Team reviewed the findings in the two parallel audits conducted by the consultants of MTRCL and HyD. The audits did not reveal any major issues in the overall structural integrity at the stations, but found deficiencies in construction control and record-keeping.

Settlement Audit

42. In recognition of the public's concern about ground and building settlements arising from the works of the SCL Project, HyD, BD and MTRCL jointly formulated a monitoring and announcement mechanism of the impact of the SCL works on nearby structures and public facilities ("*Enhanced Mechanism*").[39] The EA Team offered advice, which were incorporated in the *Enhanced Mechanism* before its implementation on 28 September 2018.

43. As stated in its Interim Report, the EA Team conducted an audit of the settlement and related issues on selected cases of the SCL Project before and after the implementation of the mechanism.

Project Management

44. The EA Team is tasked under its Terms of Reference to review the Project Integrated Management System ("PIMS") of MTRCL to identify areas for improvement, as well as enhancement in communication and check-and-balances including, but not limited to, how hold point inspections are to be conducted. The EA Team also advises on additional management and monitoring measures to be taken by MTRCL and Government departments to avoid recurrences of similar incidents in the construction of the remaining parts of the SCL Project.

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[39] See ***Appendix 9-1***

45. In reviewing the organization of the design team, the EA Team noted that there might be potential or perceived conflict of interest in that MTRCL's Detailed Design Consultant ("DDC") was also employed by the contractor for preparing designs for the contract. The EA Team reported this finding and its recommendation on avoidance of conflict of interest in its Interim Report in October 2018.[40]

46. Having heard evidence given by the parties involved, the Commission is of the view that "*it is not good practice for the same design firm to provide services both to the employer, in this case MTRCL, and the contractor, in this case Leighton. As illustrated, such an arrangement carries with it the immediate potential of both real and perceived conflict of interest.*"[41]

47. The investigation in the Hung Hom Site and review of issues in the other SCL sites has provided the EA Team with the opportunity to identify other areas for improvement in the project management aspects. The findings and recommended improvement measures are presented in this report.

Final Report of EA Team

48. With the completion of this final report, which summarizes EA Team's observations and recommendations on the SCL Project, the duties as mandated in the Terms of Reference for the EA Team are regarded as discharged.

[40] See PR 2.10 in ***Appendix 2-1***

[41] See paragraph 638 of the Final Report

Section 3 Irregularities in Hung Hom Site

Introduction

49. The HUH Extension is one of the ten new or extension of existing stations of the SCL Project. It is an underground station constructed underneath the existing concourse of HUH, under Contract 1112 – Hung Hom Station and Stabling Sidings. The contractor is Leighton Contractors (Asia) Limited ("Leighton"). A more detailed description of the construction works involved in the Hung Hom Site is at ***Appendix 3-1***.

Irregularities in Construction

50. Various irregularities concerning the built structures in the Hung Hom Site were reported through the media, reports and information provided by MTRCL, assessments by HyD and the relevant Panel meetings of the Legislative Council. The nature and extent of the irregularities were investigated in the Holistic Assessment and Verification Study. Most of these irregularities were examined at length during the hearings of the Commission. These construction irregularities are listed as follows:

(a) coupler connections;

(b) defective stitch joints and shunt neck joint in NAT;

(c) honeycombing;

(d) shear link placement;

(e) gaps between platform slab and walls/columns/hanger walls;

(f) horizontal construction joints and related illicit design changes;

(g) water seepage and ponding;

(h) corrosion;

(i) unauthorized change from lapped bar connections into coupler connections;

(j) over track exhaust ("OTE") ducts and walls; and

(k) voids in concrete backfilled areas.

51. The above construction irregularities are located in different areas of the Hung Hom Site and of varying extents. This Section explores the facts and circumstances of these irregularities to see how they may impact on the integrity of the station structures. Some of these irregularities have shaken the confidence of the public about the reputation of the construction industry in Hong Kong.

Coupler connections

52. Coming up high on the list of irregularities is the improper connection of the rebars between the D-wall and the EWL and NSL slabs of the HUH Extension structure, including an unknown number of the threaded sections of rebars being cut short, rebars not fully connected to couplers and threaded sections of rebars cut but appeared to be a proper connection.[42]

53. When two rebars need to be connected to ensure adequate load transfer, this may either be achieved by lapping the rebars for an adequate length, or by threading the ends of two rebars and connecting them with a steel coupler. According to the design drawings accepted by the BA, couplers were adopted for connection between the rebars that went through the D-walls and platform slabs. Couplers were also used to connect the vertical rebars within the D-walls and horizontal rebars between different bays of concrete in the platform slabs. A large number of coupler connections were also used in the NAT, SAT and HHS.

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[42] THB and HyD have reported the case in LC Paper No. CB(4)1514/17-18(01) entitled "Incident Relating to Construction of the Platform Slab of Hung Hom Station Extension Works under the Shatin to Central Link Project" for discussion in the LegCo Panel on Transport on 31 August 2018. It was also reported in Apple Daily on 31.5.2018. (https://hk.news.appledaily.com/local/daily/article/20180531/20406666)

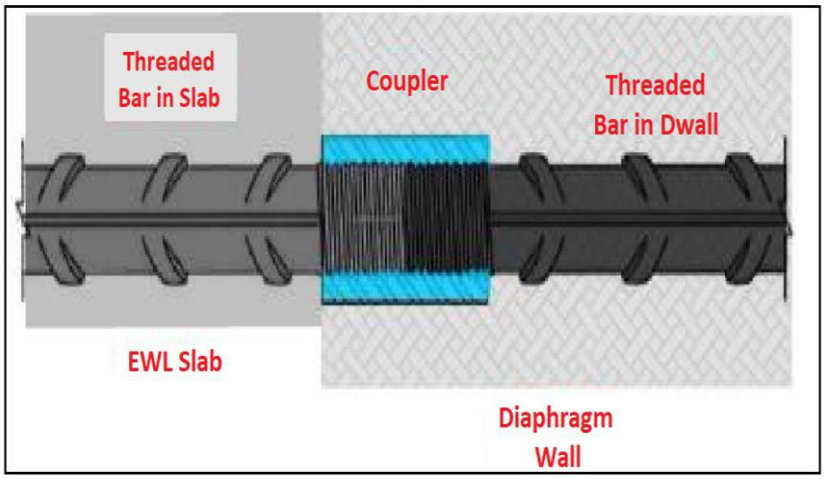

Figure 3-1 Typical BOSA Coupler Connection

(Source : Page 17 of "MTRCL Report on SCL Contract 1112 – Review of the EWL Slab Construction" dated 15 June 2018. BOSA stands for BOSA Technology (Hong Kong) Limited.)

54. Following the statistical sampling requirements set out in the *Holistic Proposal*, rebar-coupler connections at different locations in the EWL and NSL slabs were randomly selected for opening up and PAUT measurement. Since the NSL slab had been cast against underlying soil, access to the NSL slab soffit was not feasible. The as-constructed conditions of rebar-coupler connections at the bottom mat of NSL slab cannot be verified by opening up. A total of 183 coupler samples with valid PAUT results were examined.

55. Amongst the 183 samples with valid PAUT results, there are 48 defective connections, including eight cases where the rebars are not connected to the couplers and five cases where the rebars have been cut. In three of the five cut bar cases, the rebars are also not connected to the couplers.

56. A total of 48 out of the 183 samples, including 25 samples at EWL and 23 samples at NSL, are regarded "defective" because they do not meet the acceptance criteria of coupler installation agreed by MTRCL and the Government departments for use in this exercise. Based on the binomial analysis, with a 95% confidence level, this corresponds to a defective rate of 36.6% and 33.2% in the coupler connections at the EWL and NSL slabs respectively[43].

[43] See Tables 1 and 2 of the *Holistic Report*

57. The statistical results of the overall deficiencies of the coupler connections are summarized in ***Table 3-1***.

Table 3-1 Deficiencies in Coupler Connections

	EWL		**NSL**	
No. of samples with valid PAUT results	90		93	
No. of defective coupler connections	25		23	
	Binomial	**Mean**	**Binomial**	**Mean**
	36.6%	27.8%	33.2%	24.7%
● No. of cut bars	3[44]		2[45]	
	8.4%	3.3%	6.6%	2.2%
● No. of unconnected couplers	8[46]		0	
	15.5%	8.9%	-	-
● No. of inadequate thread engagement[47]	17		21	
	27%	18.9%	30.9%	22.6%

58. Non-conformance Report ("NCR") 157 issued by Leighton in December 2015 to its steel fixing subcontractor during the construction of the EWL slab is a vivid example showing the cut and unconnected rebars (see ***Figure 3-2***).

[44] See Item Nos. 17, 19 and 20 of Table B3.1 of the *Holistic Report*. All three cut rebars are also unconnected.

[45] See Item Nos. 7 and 8 of Table B3.2 of the *Holistic Report*

[46] See Item Nos. 13 to 20 of Table B3.1 of the *Holistic Report*

[47] Excluding unconnected couplers

Figure 3-2 Site photograph at Panel EM100 in NCR 157 before rectification works

(Source : Figure 7 of the Holistic Report)

59. From any practical viewpoint, the situation of the coupler connections between the D-wall and the slabs of EWL and NSL is far from satisfaction. It was argued extensively at the Commission's Inquiry that partially engaged threads in couplers were capable of meeting certain strength requirements. However, they failed to meet the requirements for restricting elongation. A partially engaged coupler does not meet the installation specifications of the coupler supplier (i.e. BOSA), although the compatibility between the BOSA's inspection protocols and their intent to achieve a butt-to-butt connection was queried by some structural engineering experts in the Inquiry.

60. It may be useful to take a look at the different types of coupler connection problems.

(a) *Inadequate thread engagement* is the most common problem identified in the PAUT results. It means that the rebars have not been sufficiently engaged into the couplers according to the supplier's specifications. It reflects primarily on the improper installation workmanship and unsatisfactory quality of supervision.

(b) <u>*Unconnected couplers*</u> can be described as the extreme case of inadequate thread engagement with zero engagement. The situation is not only a workmanship issue but a blatant disrespect of the installation protocol. The quality of supervision is highly questionable.

(c) <u>*Cut bars*</u> is another category of problem in coupler connections. The worst kind of *cut bars* is trimming off a substantial portion of the rebar, whether it is from a Type A or Type B rebar, and pretending that the engagement length meets the requirements [48] . Evidence was also adduced in the Inquiry that on a number of occasions, the cutting was done when workers converted Type B rebars (of about 20 to 21 threads) into Type A rebars (of about 10 or 11 threads) when they ran out of Type A rebars.

61. Converting Type B to Type A rebars by cutting should not have been allowed on site. This cutting runs the risk of damaging the threaded end, which may make the engagement difficult. Besides, the ordinary cutters used would not produce a chamfered rebar end which will help engage the rebar with the coupler during installation. Trimming off the exact length of threads would also be a challenging task in the site condition. A more plausible action to be taken may be to simply engage the Type B rebar as it is by exposing about 10 or 11 threads on the rebar end. The relevant Quality Control Supervisor ("QCS") and Quality Control Coordinator ("QCC")[49] must of course be informed before they conduct the checking on the splicing assemblies.

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[48] See Item Nos. 19 and 20 of Table B3.1 and Item No. 8 of Table B3.2 of the *Holistic Report*. The lengths of the threaded ends are way shorter than a Type A rebar with the first two items each of 3-4 threads and the third item of 5.3mm only.

[49] Quality Control Supervisor and Quality Control Coordinator are the supervisory personnel appointed under the Quality Supervision Plan who are responsible for the supervision and inspection for the installation of coupler works.

62. Hence, the issue of cut bars is of particular concern. The investigation has revealed a relatively small proportion of cut bars (i.e. mean value of 3.3%, based on 3 out of 90 samples in the connections between the EWL slab and D-wall). The *Holistic Report* has assessed that "*These findings indicate that the cutting of the threaded ends of rebar is real although not extensive, but other deficiencies in coupler connections are more widespread.*"[50] As the total number of coupler connection between the EWL slab and D-wall alone may amount to about 21,500[51], having 3.3% of cut bars implies that as many as 700 bars would have been cut. This is more than an ad hoc activity on site.

63. Separately, unconnected couplers amount to about 8.9% (i.e. 8 out of 90 samples) of the samples in the connections between the EWL slab and D-wall. This means that among the 21,500 coupler connections alone, there are some 1,900 unconnected couplers. It should be visually obvious on site that these unconnected "coupler connections" are unacceptable. In a properly managed and supervised site, it is very unusual that such a significant number of unconnected couplers could go unnoticed and unrectified.

64. No opening up for PAUT on coupler connections was carried out for the NAT, SAT and HHS structures in the Verification Study. As explained in *paragraph 39* above, a defective rate of 35% was adopted for coupler connections for structural assessment purpose.

Defective stitch joints and shunt neck joint in NAT

65. The irregularity in the three defective stitch joints and the shunt neck joint in the NAT was examined in the Extended Inquiry. Once again, defective coupler connections have come in the spotlight.

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[50] See paragraph 12 of the Executive Summary of the *Holistic Report*

[51] According to the review report of MTRCL dated 15 June 2018, there are 23,500 threaded bars being connected to the D-wall for the construction of the EWL slab. However this number was found to be materially less as a result of the second design change (see para 571d of the Final Report). At the press conference held on 13 July 2018, the then Director of Highways advised that the change in design had caused a decrease of 2,000 couplers from the original 23,500 couplers.

66. Of the four joints involved, one stitch joint at the NSL slab is situated wholly within Contract 1112 area. The other two stitch joints and the shunt neck joint are *interface joints* situated at the interface between Contract 1112 and the adjacent SCL contract, i.e. Contract 1111, with Gammon-Kaden SCL 1111 Joint Venture ("GKJV") as the contractor.

67. The construction of these joints required the use of couplers to connect the rebars on both sides of the joint, at the base slabs, roof slabs and walls as the case may be, before concrete was poured to construct the structures in question. Different brands of couplers were used in Contracts 1111 and 1112 – the tapered threaded Lenton couplers in Contract 1111 and the parallel threaded BOSA couplers in Contract 1112.

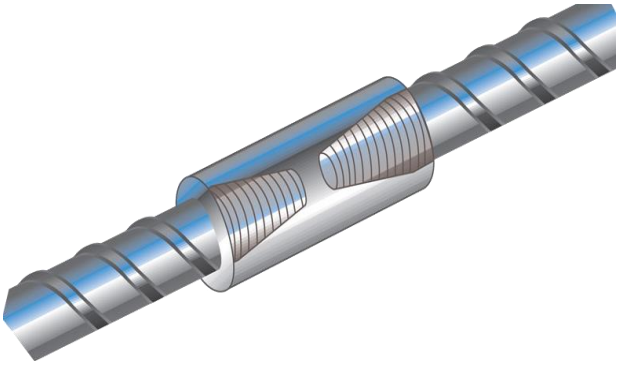

Figure 3-3 Lenton coupler connection

(Source : https://midlandsteelreinforcement.co.uk/products/ lenton-rebar-coupler-systems/)

68. Shortly after completion of the NSL interface stitch joint in August 2017, MTRCL observed water seepage at the joint. Leighton was required to carry out grouting to seal up the water seepage but to no avail. The concrete at certain locations of all three stitch joints was chipped off for investigation. It was found that many of the rebars had not been properly connected to the couplers in all three stitch joints. In the two stitch joints which are at the interface between Contacts 1111 and 1112, the rebars used by Leighton were parallel threaded and hence were not compatible with the tapered threaded Lenton couplers installed by GKJV.

69. One of the three stitch joints is situated wholly within Contract 1112 i.e. not an *interface joint* and hence not affected by the problem of mismatch between the rebars and couplers. However, the rebars were still not properly connected with the couplers.

70. At around the end of 2017, MTRCL observed minor cracks in the shunt neck structure. Investigation by chiselling off the concrete revealed similar problem at the shunt neck joint as the two stitch joints at the interface between Contracts 1111 and 1112. The rebars were not screwed into the Lenton couplers installed by GKJV on the Contract 1111 side. Some rebars were only slotted into the couplers.

71. Remedial works were eventually carried out by Leighton to all three stitch joints and the shunt neck joint under the supervision of MTRCL.

72. The issue of defective construction of the three stitch joints and the shunt neck joint has been described in some detail in Chapter 10 of the Final Report.[52] Witnesses from the steel fixing subcontractor, Leighton and MTRCL failed to provide a satisfactory account at the Extended Inquiry as to what had happened when the joints were constructed or who had carried out the supervision. Evidence heard before the Commission seemed to suggest that the problem might have been attributed to a breakdown in communication within MTRCL and Leighton in respect of procurement of materials for the stitch joints and shunt neck joint.

73. A more fundamental issue is whether or how the hold point inspections had been carried out. The impossibility of engaging the BOSA parallel-threaded rebars by the steel fixing subcontractor of Contract 1112 into the tapered threaded Lenton couplers imbedded in the Contract 1111 interface side was *"visually very obvious"*, according to the evidence of the steel fixing subcontractor at the Extended Inquiry.[53] There is no record of any RISC forms being generated for the required hold point inspections of rebar fixing and concrete pouring by Leighton and MTRCL. The necessary records on the coupler installation were also unavailable. The issue of hold point inspections and RISC forms which seems to be recurring for various irregularities will be discussed later.

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[52] See paragraphs 471 to 514 of the Final Report

[53] See paragraph 494 of the Final Report

Honeycombing

74. Honeycombed concrete at the EWL soffit was observed in July 2018. Automatic hammer and tapping hammer were used to identify the suspected areas at the soffit. The suspected areas were then opened up for verifying the actual condition.

75. The investigation has identified approximately 12% of the inspected area with shallow honeycombing (i.e. less than 50 mm deep) and approximately another 7% of the inspected area with deeper honeycombing (i.e. 50 mm to 350 mm deep) as shown in ***Figure 3-4***. A location plan showing the areas with honeycombing is in ***Appendix 3-2***.

Figure 3-4 One of the deeper honeycombing areas after removal of honeycombed concrete at soffit of EWL slab

76. Apart from concrete quality issues, other defects were discovered at the honeycombing inspected areas, such as insufficient rebar lap length, water dripping and irregularities in shear link placement.

77. MTRCL carried out remedial works to rectify the identified defects and reinstate concrete cover to the reinforcement. The *Holistic Report* concluded that the honeycombing was likely related to unsatisfactory workmanship of the concreting works. Evidence heard at the Inquiry suggested that the difficulties in concreting the 3 m deep EWL slab with congested reinforcement might have led to the poor concreting works.

Shear link placement

78. The EWL and NSL platform slabs are 3 m and 2 m thick respectively. Shear links are vertically placed rebars, linking rebars at the top mat with those at the bottom mat. The top and bottom mats were congested with closely spaced rebars, with up to eight levels of 40 mm diameter rebars in each mat. The purpose of the shear links is to resist shear forces in the structure.

79. During the investigation of the honeycombing, major irregularities in the shear links were identified in 22 locations in the EWL slab. In order to examine the severity and structural implications of the improper placement of shear links in platform slabs, an investigation, especially at critical areas subject to high shear stresses, was carried out. Taking into account site accessibility and shear stress concentration, 18 additional locations at the EWL slab soffit were opened up by MTRCL for the investigation.

80. The opening up works also revealed major shear link irregularities at all 18 locations. These included missing shear links, smaller bar sizes and insufficient anchorage lengths. The findings of the shear link defects discovered at the 40 locations above are shown in ***Appendix 3-3***.

ID	Area	Is Shear Links found	No. of shear links	Size	Anchorage Length	Spacing at East-West Direction (y-direction)	Spacing at North-South Direction (x-direction)	Latest Design Working Drawing Requirement
HZ1	Area C1	No	NA	NA	NA	NA	NA	T16-206-150-300 (1112/W/HUH/ATK/C12/063C)

Figure 3-5 A photo showing missing shear link

(Source: Appendix JL1-E of the COI-1 Structural Engineering Expert Report of Dr James Lau)

81. Since the NSL slab had been cast against the underlying soil, access to the NSL slab soffit was not feasible and the as-constructed conditions of shear link placement could only be examined through a desktop review. The available records, such as site photographs and construction drawings, were studied. Whilst there was evidence showing the presence of certain shear links at the top of NSL slab, there were insufficient photographs showing the condition of shear links installation at the bottom of the platform slab.

82. The irregularities of shear link placement in the EWL slab did not conform to the design in that the shear link rebars as specified in the accepted design were either missing or not properly provided. The irregularities which should be obvious to be detected on site were not identified in the relevant hold point inspection process. This reflected construction and supervision issues.

83. There was no opening up to expose the shear links in the NAT, SAT and HHS. Instead, MTRCL had reviewed the RISC forms (where available) and available records regarding the rebar fixing for the NAT, SAT and HHS structures. Site photographs are available for a number of

areas to demonstrate the as-constructed condition of shear links. MTRCL noted the relatively simpler NAT, SAT and HHS structures (i.e. thinner slabs and walls of about 1 m thick; shear links of smaller diameter and less congested reinforcement) presented generally an easier steel fixing task at these structures than that encountered in the EWL and NSL slabs of HUH Extension. Whilst not all photographs showed the anchorage at the bottom of the shear links, based on the available information, MTRCL considered it unlikely that there were any significant defects in the fixing of the shear links in the NAT, SAT and HHS structures.

Gaps between platform slab and walls/columns/hanger walls

84. In late 2018, gaps were identified between the soffit of the EWL slab and parts of some columns, walls and hanger walls in the HUH Extension. After thorough inspections, a total of 31 gaps which were either unfilled or filled with improper materials were revealed. Reinforcement and coupler connection issues were identified in some of these gaps. A summary of the types of defects identified in the gaps is at ***Appendix 3-4.***

Figure 3-6 Gap between EWL slab and column

85. These gaps reflected unsatisfactory concreting workmanship, which was not identified during supervision of construction works.

Horizontal construction joints and related illicit design changes

86. Records showed that 66 out of the 76 east D-wall panels in Areas B and C were trimmed down by Leighton, without seeking the required prior agreement from MTRCL and BD, in order to replace the cast-in coupler connections with the EWL slab by either through bars or semi-through bars. A horizontal construction joint was formed between the existing concrete of the trimmed D-wall and the newly placed concrete of the EWL slab. There was concern about the workmanship quality and the structural integrity of these horizontal construction joints.

87. The condition of the concrete interface at the horizontal construction joints was examined using the Video Rigid ("VR") Scope.

88. Irregularities were found from the VR Scope at two of the four locations examined. A gap was observed at the concrete interface at one location. Remnants of a hessian sheet were found in the concrete sample taken at another location.

89. External consultants were engaged by MTRCL to review the concrete core samples and the results of the VR Scope inspection. It was concluded that the irregularities were related to workmanship issues during construction of the joints.

90. All four independent structural engineering experts agreed at the Extended Inquiry that the irregularities at the horizontal construction joints "*is solely a workmanship issue*".[54] Concern was raised by the Government's experts, in both the Original Inquiry and Extended Inquiry, about the structural integrity of the connection between the EWL slab and the east D-wall. The concern came partly from the details of the steel rebars at the connection arising from the illicit design changes, which deviated from established good detailing practice. It also arose partly from the irregularities in the workmanship at the construction joints.

[54] See paragraph 405 of the Final Report

Water seepage and ponding

91. For an underground structure as deep and extensive as the HUH Extension, it is not uncommon that a certain degree of water seepage may occur at the D-wall joints. Leighton had previously carried out remedial grouting works at the locations with water seepage.

92. In the course of the Holistic Assessment, water seepage was observed in five opening up locations at the EWL slab soffit. At the top surface of the NSL slab, water seepage and ponding were also found at 20 opening up locations. The concrete at these locations had been opened up to expose the coupler connections between the platform slab and the D-wall. To reduce water seepage, remedial grouting works[55] were arranged by MTRCL at the locations where seepage was observed.

Figure 3-7 Water ponding at opening up location at NSL platform

[55] Remedial grouting works were carried out on a number of occasions after the completion of the Holistic Assessment. In response to media reports about water seepage in the HUH Extension on 21 July 2020, MTRCL investigated and reported that there were 41 locations with water seepage requiring rectification.

93. In this connection, and notwithstanding the remedial grouting works carried out, the EA Team had two key concerns.

94. Firstly, whether the allowable design limit of water seepage rate is exceeded, and if so, the effectiveness of the remedial works in controlling the seepage rate to within the allowable limit. This refers to the rate of water seeping from the outside ground into the station structure. Commonly, areas with defective waterproofing at the vertical construction joints between adjoining D-wall panels are vulnerable to excessive water seepage into the structure. However, the possibility of any other major sources or pathways of water seepage should also be examined.

95. Secondly, it was observed at some opening up locations that water was seeping out of the concrete structure. This raised the concern about the possible presence of water pathways within the concrete structure, which might lead to corrosion of the coupler connections and adversely affect the durability of the structure. The construction joints between the NSL slab and the D-wall might be a possible seepage pathway within the structure, should there be defects in the waterproofing provisions therein.

96. These two concerns were highlighted in the *Holistic Report*, with the following descriptions:

> "*It was observed that the seepage rate at a few locations at the NSL slab has exceeded the allowable design limit.*"[56]

> "*Water seepage/ponding was observed at some opening-up locations at the platform slabs. This was possibly due to the water seepage through the construction joints between the D-wall panels and those between the platform slabs and D-walls. The infiltrated water was saline, implying sea water.*"[57]

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[56] See paragraph 3.6.14 of the *Holistic Report*

[57] See paragraph 3.6.17 of the *Holistic Report*

97. As stipulated in paragraph 3.6.18 of the *Holistic Report*, MTRCL has to submit a detailed proposal on water seepage prevention measures with continuous monitoring for the water seepage condition to the Government. No proposals in response to the two concerns above, have been accepted by the Government at the time of writing this report.

Corrosion

98. During the Holistic Assessment, some of the exposed coupler connections were cut and unscrewed for verification by physical measurement. Apparent signs of rusting were observed on most of the unscrewed threaded bars. MTRCL appointed a material specialist to assess the extent and causes of the corrosion. Additional samples were also retrieved from the NSL slab for examination.

99. From detailed examination, the material specialist concluded that most of the rusts on the samples were rather stable and the rusting process had ceased in most samples. The rusting had likely resulted from moisture trapped in the couplers when the rebars were installed. Formation of fresh rust on some samples from the NSL slab was likely caused by water ponding occurring after the opening up with the couplers submerging in the water for some time. Other apparent signs of rusting were mainly due to trapping of yellowish or brownish sand and not due to corrosion attack.

Figure 3-8 A corroded threaded rebar under examination

100. One of the samples from the EWL slab exhibited signs of rusting over the whole end face that exhibited signs of improper shearing/cutting, with some very fresh spots of rust stain found over the threaded portion and end face. This was the most seriously affected sample amongst all samples examined. The threads near the end had also been damaged to some extent, whereas the other portions of the threads were found covered mainly with sands or the like.

101. The corrosion of other samples was less severe. The rusting in general has not caused any obvious dimensional change to the threaded portion of the rebar and hence not resulted in any significant effect on the overall strength of the coupler connections.

102. To ensure that no further rusting would take place in the long term, the material specialist advised that the couplers should not be left immersed in a wet and moist environment. Grouting or other water seepage prevention measures should be implemented.

103. In this respect, the proposal to be submitted by MTRCL to the Government on water seepage prevention measures with continuous monitoring for the water seepage condition should also serve to address the corrosion problem.

104. The material expert's findings about the presence of soil debris in the coupler connections also reflected possible deficiency in workmanship and supervision. The couplers and threaded rebars should be protected from and cleaned of any debris before connection, and this falls within the inspection requirements on the rebar-coupler installation.[58]

Unauthorized change from lapped bar connections to coupler connections

105. In December 2018, MTRCL informed HyD that, in addition to the lack of construction records, there were changes of steel reinforcement lapped bars into coupler connections for the NAT structure.

[58] Reference can be made to *paragraph 388* below on the coupler installation requirements.

106. It transpired that the changes of steel reinforcement lapped bars to coupler connections had occurred in the SAT and HHS structures as well. A reason behind the changes was to form openings for the provision of temporary site vehicular access which would otherwise have been prevented or obstructed by the presence of vertical starter bars.

107. As MTRCL and Leighton had neither notified nor obtained permission from the Government prior to the changes, the Government considered these "unauthorized" changes.

108. Evidence heard in the Inquiry revealed that no proper as-built records were prepared for the coupler connections which are the subject of this matter.

109. Quality Supervision Plan ("QSP") is an enhanced supervisory regime for the installation of couplers submitted by MTRCL to BD prior to the commencement of construction works. Details of the supervision and inspection have to be recorded in coupler inspection record sheets and inspection log books by the designated supervisory personnel of both MTRCL and Leighton.

110. Both MTRCL and Leighton have failed to adhere to the supervision requirements of coupler installation where the lapped rebars were changed into coupler connections in the NAT, SAT and HHS. In this regard, the Commission has determined that "*with respect to this change, both MTRCL and Leighton failed to comply with the requirements of Contract 1112.*"[59]

111. In paragraph 523 of the Final Report, it is stated that -

> "*the change from **correctly lapped** bars to **properly installed** mechanical couplers should have no structural implications. However, a difficulty arises should there be doubt regarding the proper installation of the couplers.*" **[Emphasis added]**

[59] See paragraph 522 of the Final Report

112. Mr Steve Rowsell, the independent project management expert appointed by the Commission, commented on the need for Leighton to have full time and continuous supervision of the mechanical coupler works as follows:

> *"It is likely that this requirement was included because it was recognised that it would be a* ***technically difficult process with a high risk of problems being encountered****. I consider that the interpretation of this requirement is very simple and requires the need for the coupler works to have continuous supervision.*"[60] **[Emphasis added]**

113. Details of QSP will be elaborated later in this Section when the irregularities in site supervision and control are discussed.

OTE ducts and walls

114. An allegation arose in May 2019 about the construction of OTE ducts which were hanging from the soffit of EWL slab and running along the whole length of the tracks on both sides of the NSL platform. The details of the affected OTE ducts are shown in ***Figure 3-9***.

[60] See paragraph 78 of the Expert Report prepared by Mr Rowsell dated 20 December 2018

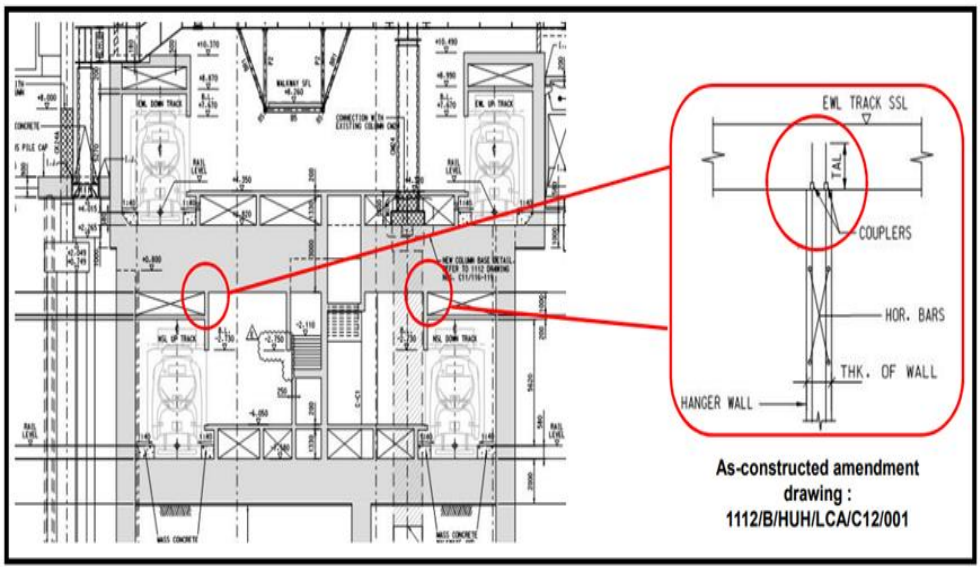

Figure 3-9 Connection details of OTE between the soffit of EWL slab and the OTE duct

(Source: Page 5 of Appendix 1 of the Report on Couplers Connection at OTE Duct submitted by MTRCL to BD dated 7 April 2020)

115. OTE duct is a common feature in underground train stations for the purpose of extracting waste heat and hot air during normal operation. It also serves to extract hot smoke out of the station in case of train fire or station fire, which facilitates people to evacuate safely from the station.

116. According to the original accepted drawings, the vertical rebars of the OTE ducts are connected by lapped rebars. However, Leighton's as-built drawings showed that these had been changed to coupler connections. From a review of the available photographic records, it was found that about 15% of the couplers were connected to drilled-in bars at the EWL slab. Unfortunately, records of the required pull out tests on the drilled-in bars were not available. A photograph showing the coupler and drilled-in bars in one bay was presented in ***Figure 3-10***.

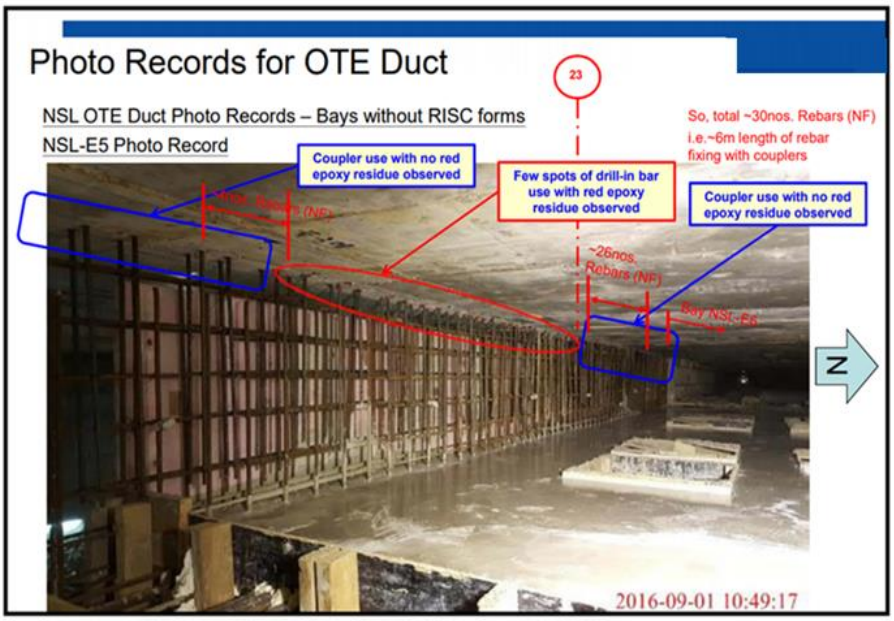

Figure 3-10 Photographic records for OTE duct with rebars installed by couplers and some drilled-in bars

(Source : Page 22 of Appendix 2 of the Report on Coupler Connection at OTE Duct submitted by MTRCL to BD dated 7 April 2020)

117. The RISC forms for 22 of the 38 bays of OTE ducts were missing and not a single RISC form could be found for those areas with drilled-in bars. No proper construction records were available to show what had been constructed.

118. MTRCL proposed the installation of 139 sets of steel angle brackets with anchor bolts as strengthening works at the 22 bays of OTE duct where RISC forms were missing. The proposal was accepted by the BA.

Figure 3-11 Steel angle brackets installed inside OTE duct

(Source : Photo taken by site staff of MTRCL on 29.7.2020)

119. During the scrutiny of design amendment drawings for OTE ducts by BD in September 2019, it was discovered that the original lapped rebar details for the vertical reinforcement in the OTE walls above the EWL slab, were also changed to coupler connections ***(see Figure 3-12)***. A strength reduction factor, which was based on those used in the coupler connections in the Holistic Assessment was adopted in the structural assessment of the OTE walls and the required extent of remedial works.

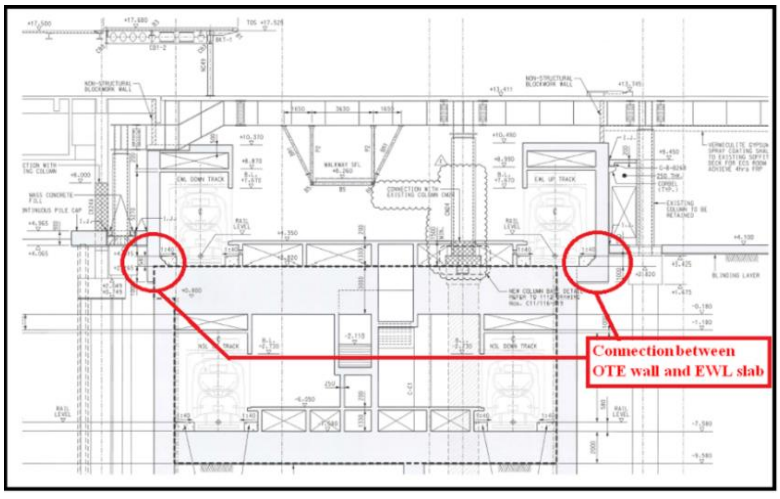

Figure 3-12 Connection between OTE wall and EWL slab

(Source : Adapted from Drawing No. 1112/B/HUH/ATK/C10/128 rev F submitted by MTRCL to BD on 11 March 2016)

Voids in concrete backfilled areas

120. In the meeting of the Subcommittee on Matters Relating to Railways of the LegCo Panel on Transport held on 13 July 2018, it was revealed that the concrete subcontractor for Contract 1112 had refused to pour light-weight concrete to some backfilled areas in Area A of the HUH Extension in around end 2016. It was alleged that the site had not been properly cleared of broken concrete and debris and that the concrete pouring was later done by Leighton instead.

121. Subsequent investigation by laser scanning and coring carried out by MTRCL and Leighton discovered that a significant part of the required backfilled areas at the NSL track level and the NSL mezzanine level had not been filled with concrete. According to the design, the purpose of the concrete fill is for buoyance resistance and the backfilled areas should be completely filled up, i.e. without any voids.

122. Remedial proposal to backfill the voids was submitted by MTRCL to the BA for acceptance. The remedial works commenced in June 2020 and was about 75% complete as at mid-November 2020. The total volume of voids to be filled in the remedial proposal is about 1,750 m^3, which is about a quarter of the total volume of backfilled areas supposedly to be completed in Area A.

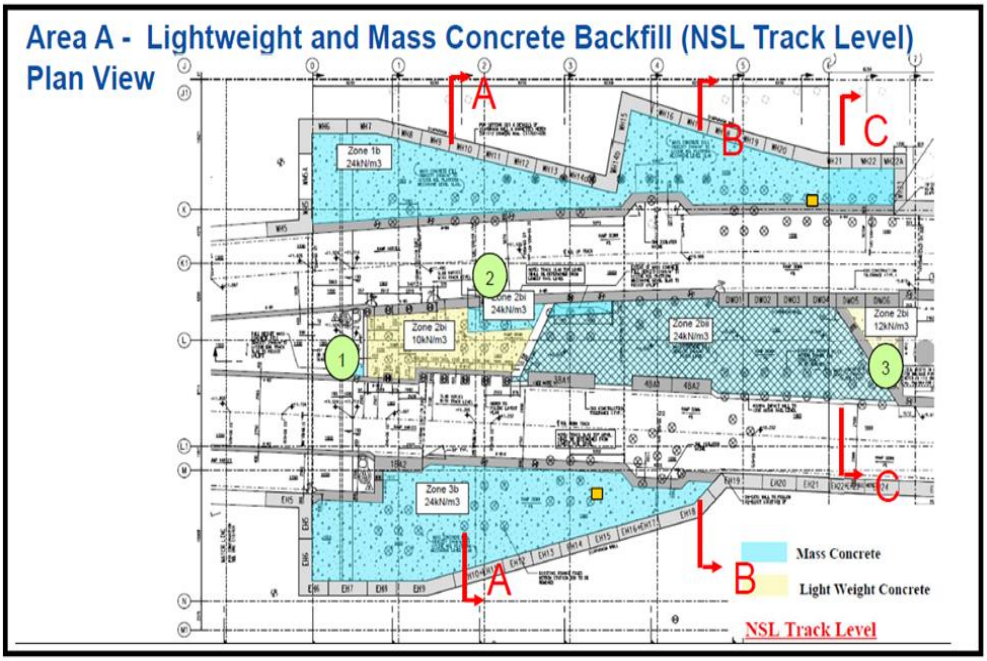

Figure 3-13 Plan view of backfilled areas at NSL Track Level

(Source : A presentation by MTRCL on Area A – Backfill dated 31 March 2020)

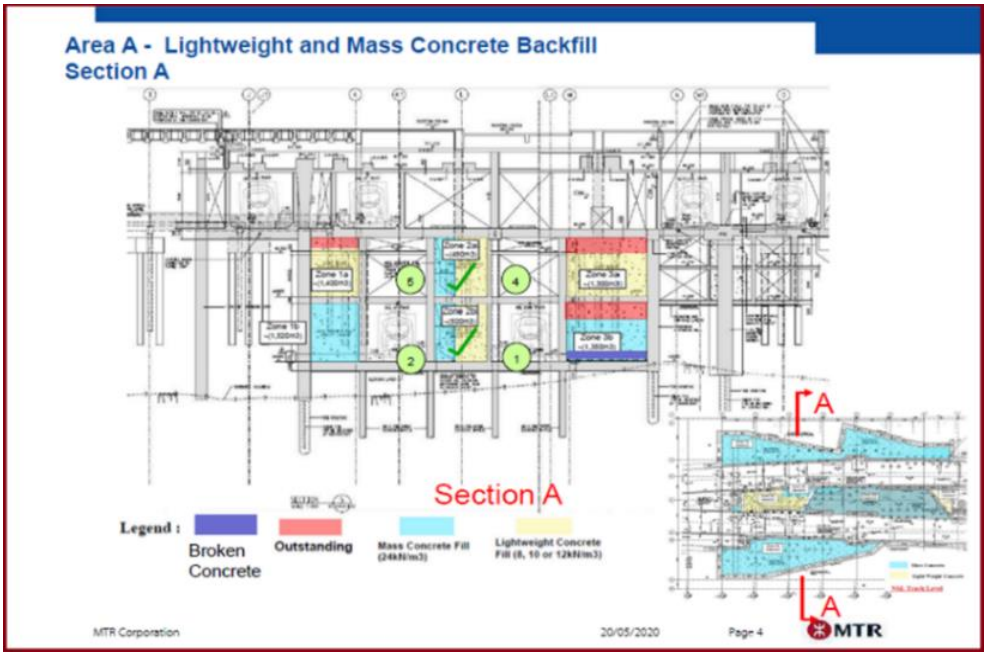

Figure 3-14 A section showing the backfilled areas and voids

(Source : A presentation by MTRCL on Area A – Backfill dated 31 March 2020)

Irregularities in Site Supervision and Control

123. The irregularities in construction described in the preceding paragraphs have covered a variety of defects. Many of them have been attributed to causes such as poor workmanship, site difficulties and miscommunication. However, one might wonder why so many construction irregularities could have occurred, and apparently remained unnoticed or unrectified during the construction. Furthermore, the works have also been subject to the scrutiny of the building control system of BD and regular audits by both MTRCL and the Monitoring and Verification ("M&V") Consultant of HyD.

124. The irregularities in site supervision and control as observed in the Hung Hom Site are discussed in the ensuing paragraphs. Particular attention is given to the following aspects:

(a) failure to properly conduct hold point inspections and complete RISC forms;

(b) failure to comply with QSP;

(c) failure to carry out quality testing of rebars; and

(d) failure to maintain contemporaneous construction records.

Hold point inspections and RISC forms

125. MTRCL's PIMS sets out the procedures for formal inspections and acceptance of site works. Prior to the commencement of works, Leighton has to develop the Inspection and Test Plans ("ITP"), which lays down how the different elements of works are to be inspected and tested. The ITPs also specify the *quality hold points*[61] ("hold point") and *quality*

[61] According to Section 3.1 of MTRCL's PIMS/PN/11-4/A5, "a *Quality Hold Point* is a point in time when a notice of permission, consent or no objection by the Engineer is required or an approval or consent by a relevant authority or utility undertaker is required before the Contractor can commence, proceed with or terminate an activity."

control points[62] ("control point") to be adopted at the key stages of construction. The ITP should be agreed between MTRCL and Leighton.

126. A good design of ITP is essential to ensuring that the hold point inspections would serve the intended purpose. In the case of the HUH Extension, a single hold point was designated for checking the rebars in both the top mat and bottom mat. This is unsatisfactory. The Commission noted that:

> *"There was also the difficulty that these hold point inspections were not fully documented. Only the inspection of the top mat*[63] *was recorded in the RISC form. There were no specific records indicating when or by whom the inspection of the bottom mat had been carried out."*[64]

127. The request for inspection at each hold point and the granting of permission to the next stage of the works are recorded using MTRCL's RISC forms. These RISC forms have to be submitted by Leighton in respect of each hold point, and MTRCL's personnel is required to inspect and certify the satisfactory condition of the works carried out. The completed RISC forms are then endorsed typically by the Senior Inspector of Works (SIOW) of MTRCL before returning to Leighton for uploading in their project management system.

128. Properly completed RISC forms are important documents in that they record the inspection results of the construction works on site. Despite their significance, it is noted that a large number of RISC forms were missing in Contract 1112, which also cast doubt on the proper implementation of ITP and hold point inspections on site.

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62 According to Section 3.2 of MTRCL's PIMS/PN/11-4/A5, "a *Quality Control Point* is a point in time when a notice or other document is to be submitted to the Engineer before the Contractor can commence, proceed with or terminate an activity."

63 Both the EWL slab (3 m thick) and the NSL slab (2 m thick) contain horizontal rows of rebars towards the top of the slab ("top mat") and further horizontal rows of rebars towards the bottom of the slab ("bottom mat").

64 See paragraph 605d of the Final Report

129. Two examples of major hold points are (1) rebar check on rebar and shear link sizes, spacing and fixing etc., and (2) pre-pour check to ensure the rebars, formwork and cleanliness are in order before concrete can be poured.

130. Back in June 2018 when the significant difference in the number of couplers used in the D-wall and EWL slab at the HUH Extension came to light, PYPUN-KD & Associates Limited ("PYPUN"), the M&V consultant of HyD, was instructed to check the site records in conjunction with MTRCL and BD. The results were contained in the "*Report on On-site Check on Inspection & Supervision Record in Relation to Construction of the EWL Slab of SCL Hung Hom Station Extension (WC1112)*"[65]. The tables below show the results of two major hold points, i.e. Hold Point Item No. 9 on rebar check and Hold Point Item No. 10 on pre-pour check on the construction of EWL slab.

Table 3-2 Hold point for rebar check

Construction of -	**Total No. of RISC forms**	**No. of available RISC forms**		**No. of irregular RISC forms[66]**	
(a) EWL slab	32	32	100%	19	59%
(b) closing up temporary slab opening	13	13	100%	11	85%
(c) capping beam	23	14	61%	11	48%

[65] "Report on On-site Check on Inspection & Supervision Record in Relation to Construction of the EWL Slab of SCL Hung Hom Station Extension (WC1112)" (Final Issue dated 11 December 2018) was prepared by PYPUN-KD & Associates Ltd.

[66] Irregularities in RISC forms for this hold point inspection include some forms with no inspection dates, unsigned forms, some parts of RISC forms are left blank, late endorsement dates by MTRCL on some forms and names of MTRCL's supervisors not recorded on some forms.

Table 3-3 Hold point for pre-pour check

Construction of -	Total No. of RISC forms	No. of available RISC forms		No. of irregular RISC forms[67]	
(a) EWL slab	32	32	100%	7	22%
(b) closing up temporary slab opening	13	13	100%	13	100%
(c) capping beam	23	21	91%	12	57%

131. The above tables show that while the availability of RISC forms may be as high as 100% for certain elements in the construction of EWL slab, the accuracy and credibility of the contents of the RISC forms is a different story.

132. Comparing with ***Tables 3-2*** and ***3-3*** above, as revealed in the *Verification Report*, an appalling low percentage of the RISC forms in the NAT, SAT and HHS are available ***(see Table 3-4)***[68]. In view of the construction irregularities in the HUH Extension despite the available RISC forms, there is a concern about how many of these available RISC forms in the NAT, SAT and HHS are consisted of accurate and credible information on the supervision and inspection of the hold points.

[67] Irregularities in RISC forms for this hold point inspection include no follow-up inspection for some cases were made, some parts of the RISC forms are left blank, unsigned forms, late endorsement dates by MTRCL on some forms and names of MTRCL's supervisors not recorded on some forms.

[68] See section 3.1.2 and Table 1 of the *Verification Report*

Table 3-4 Number and percentages of available and unavailable RISC forms in NAT, SAT and HHS

Structures	**Number of RISC forms required**		**Number and percentage of available RISC forms**		**Number and percentage of unavailable RISC forms[69]**	
NAT	Rebar	64	21	33%	43	67%
	Pre-pour	59	13	22%	46	78%
SAT	Rebar	42	23	55%	19	45%
	Pre-pour	44	27	61%	17	39%
HHS	Rebar	659	287	44%	372	56%
	Pre-pour	611	344	56%	267	44%

133. The Commission has arrived at the following conclusion on ***Table 3-4***:

> "*In the opinion of the Commission, the table is evidence that, in respect of the approach tunnels and stabling sidings at least, the RISC scheme, as a primary quality assurance scheme,* ***came close to redundancy****."*[70] **[Emphasis added]**

134. The situation of the three stitch joints and shunt neck joint discussed in *paragraphs 65 to 73* above requires something more than mere coincidence that the relevant RISC forms are nowhere to be found. The Commission states in paragraph 480 of its Final Report the following:

> *"In the judgement of the Commission, it is important to note that not a single RISC form appears to have been generated in respect of the original construction of the stitch joints and the shunt neck joint."*

[69] The follow-up action of the unavailable RISC forms was addressed in the *Verification Report*.

[70] See paragraph 437 of the Final Report

135. The following matrix presents the different scenarios of availability of RISC forms and carrying out of supervision at the hold point inspections. If the supervision and control are properly carried out in accordance with the ITP as required by the PIMS, all cases would fall under the *Normal Scenario*. However, in the Hung Hom Site, some other scenarios are also encountered.

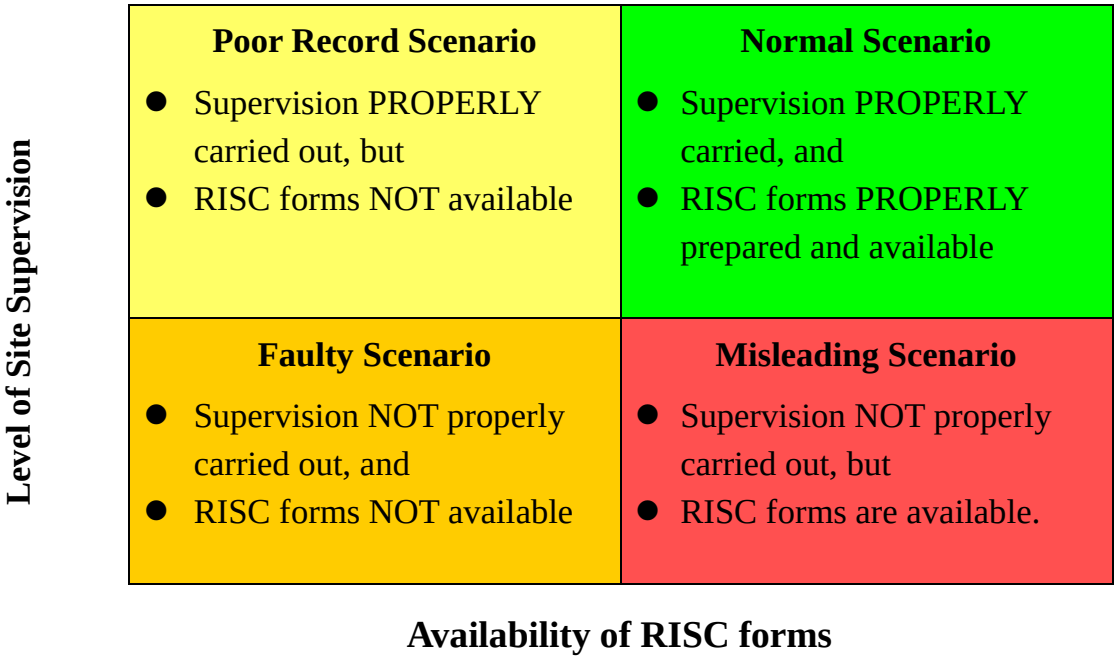

Figure 3-15 Scenarios of availability of RISC forms and site supervision

136. The four scenarios and their implications are explained as follows:

(a) *Normal Scenario*

This refers to the normal circumstance in which supervision has been properly carried out and the works have also been properly signed off by the RISC forms. One can count on the available RISC forms that the works have been duly constructed and supervised, in compliance with the contractual and ITP requirements.

(b) *Poor Record Scenario*

In this scenario, although the works have been properly supervised, the RISC forms are not duly signed off. The relevant RISC forms may either be unavailable, or grossly irregular. The absence of proper RISC form record renders it difficult to differentiate this scenario from the *Faulty Scenario*. Consequently, even if the works have been properly carried out and supervised, one is still uncertain as to whether this is the case.

(c) Faulty Scenario

This occurs when the required supervision is not properly carried out and proper RISC form record of supervision is not available. The relevant RISC form is either unavailable, or available but grossly irregular. In this scenario, the site supervision and control required under the ITP have broken down. Consequently, it is uncertain as to whether the works have been duly constructed in compliance with the requirements.

(d) *Misleading Scenario*

This happens when the works are not properly supervised but RISC form record on the supervision and signing off of the works is available. As in the *Faulty scenario*, due to the lack of proper supervision, the required monitoring and control has broken down and consequently, it is uncertain as to whether the works have been duly constructed. Even worse, the availability of the RISC form record would mislead all to believe that this is the *Normal Scenario*, i.e. the works have been properly constructed and supervised. Hence, the contractual and ITP requirements are contravened and the possibility of other illicit anomalies cannot be ruled out.

137. In the Hung Hom Site, a significant proportion of the RISC forms are either missing or irregular. Evidently, this falls under either the *Poor Record Scenario* or *Faulty Scenario*. Given the difficulty in differentiating which scenario is the actual situation, there is doubt about the quality of the works and supervision. This illustrates the importance of proper RISC form documentation in site supervision and control, as well as the dire consequences when it is not properly done. As stated in the Final Report by the Commission, the RISC process is a "*primary source of certification and was therefore of fundamental importance. It should have been the subject of full – and contemporaneous - compliance*."[71]

138. Much effort was made by MTRCL during the Holistic Assessment and Verification Study in reviewing the other available records, such as site diaries and photographs, with a view to checking whether site supervision has been carried out in those cases where the RISC forms are either missing or irregular. This is an attempt to check whether the cases belong to the *Poor Record Scenari*o or *Faulty Scenario*. Obviously, if it is indeed the *Poor Record Scenario*, the problem will be confined to deficient record keeping. It will not be as bad as the *Faulty Scenario*, in which the required site supervision is missing and the quality of works may be in doubt.

139. While checking the other available records would help fill some of the gaps, it remains difficult to ascertain whether the site supervision has indeed been properly carried out. In this respect, the Commission accepted the views of its independent management expert and stated in paragraph 646 of its Final Report the following:

> *"Moreover, site photographs, while no doubt they may have their uses, cannot in themselves constitute acceptable records going to quality assurance. They should only be used to support properly prepared quality records. Photographs may show that particular works were being carried out on a particular day but they cannot demonstrate that such works were properly inspected."*

[71] See paragraph 462 of the Final Report

140. Separately, the physical investigation works, e.g. opening up the concrete for inspection and measurement of the condition of coupler connections, carried out in the Holistic Assessment and Verification Study have helped provide supplementary information. The multitude of construction irregularities found from the investigation indicate that the relevant works have not been properly carried out. In many of these cases, e.g. unconnected couplers and missing shear links, the irregularities should have been noticed and rectified, had the works been properly supervised following the RISC process for hold point inspection. This suggests that the relevant cases probably belong to the *Faulty Scenario*, and not the *Poor Record Scenario*. The irregularities in the stitch joints and shunt neck joint fall evidently into the *Faulty Scenario*.

141. In this connection, it is stated in paragraph 24 of the Executive Summary of the Final Report that "*The Commission was of the judgement, therefore, that both MTRCL and Leighton were responsible for serious deficiencies in their management and supervision systems*".

142. The *Misleading Scenario*, which is most undesirable, might have also happened in the Hung Hom Site. The inconsistent records of the coupler connections between the EWL slab and D-wall provided by MTRCL to HyD on 13 July 2018 are examples involving illicit records. Also, where it was found from the physical investigation that the works had not been properly carried out but the relevant RISC form which signed off the works were available, the *Misleading Scenario* might be involved if the defective works could be readily noticed from a proper hold point inspection. Arguably, unconnected couplers and missing shear links, which should not be difficult to identify in inspections, fall into this category.

143. From the perspective of project management, the existence of cases of *Misleading Scenario* is worrying. It undermines the credibility of record-keeping, and erodes the confidence in the site supervision and control system. Even if records, such as RISC forms, are available certifying that hold point inspection has been duly carried out and the works have been found to be satisfactory, one may still doubt whether this is *Normal Scenario* or *Misleading Scenario*.

144. Indeed, as in the case of the HUH Site, the RISC forms of other SCL stations also showed similar problems, though with varying degrees of deficiencies ranging from missing to incomplete or inaccurate. This will be discussed in ***Section 8***.

Quality Supervision Plan

145. While BD is not directly involved in the supervision of the construction works at the HUH Extension, by imposing various conditions through the Instrument of Exemption [72] ("IoE") and specifying requirements via the acceptance letters, there is a building control mechanism in place to govern the proper execution of the works.

146. The Competent Person ("CP") of MTRCL and the Authorized Signatory ("AS") of Leighton have to submit documents including the Site Supervision Plan ("SSP"), Quality Assurance Scheme ("QAS") and QSP to BD, setting out measures in respect of the quality assurance and control of the rebars and coupler installation works at the D-walls and platform slabs.

[72] Pursuant to the Mass Transit Railway Ordinance (Cap. 556), the Building Authority may issue the Instrument of Exemption to exempt the MTRCL from parts of the requirements under the Buildings Ordinance.

147. The SSP sets out the management structure for site supervision of building works in compliance with the Code of Practice for Site Supervision 2009[73] and the Technical Memorandum for Supervision Plans 2009[74].

148. The QAS is a set of quality control documentation related to, amongst others, the production and testing of the couplers.

149. The QSP is a document prepared by the CP and the AS, setting out the supervisory personnel appointed (i.e. QCS/QCC) and the supervision and inspection requirements for the coupler works. This is in addition to the requirements under the SSP and QAS. For ductility couplers, the QSP has a checklist which sought confirmation that each and every coupler connection has been properly completed.

150. A summary of the requirements of QSP on the installation of couplers for steel rebars for Contract 1112 is given in the table below.

[73] This Code of Practice is published by BD which gives guidance to practitioners in the building industry for the preparation of supervision plans, carrying out their respective supervision duties and other site supervision matters.

[74] This Technical Memorandum is the Technical Memorandum for Supervision Plans issued by the Secretary for Development under section 39A of the Buildings Ordinance. It sets out the principles, requirements and operation of the supervision plans.

Table 3-5 Summary of requirements of QSP on the installation of couplers

	Ductility couplers		**Non-ductility couplers**	
	Leighton	**MTRCL**	**Leighton**	**MTRCL**
Minimum qualifications of QCS/QCC	Grade T3 TCP	Grade T3 TCP	Grade T1 TCP	Grade T3 TCP
Frequency of supervision/ inspection	Full time continuous supervision	Not less than once a week	Full time continuous supervision	Not less than once a week
Extent of supervision/ inspection	All splicing assemblies	At least 20-50% of splicing assemblies depending on location	All splicing assemblies	Not specified
Need to complete inspection record sheet[75]	Yes (record in record sheet)	Yes (countersign on record sheet)	No	No
Inspection log book	The date, time, items inspected and inspection results should be clearly recorded in the log book. The log book should be kept on site for inspection by officers of BD.			

151. Chapter 12 of the Final Report has explored the various uncertainties concerning the QSP. They include: (1) whether the QSP was applicable to the construction of the platform slabs, (2) whether the staff of Leighton are aware of the QSP, and (3) the meaning and effect of "full time continuous supervision".

[75] Items to be checked and recorded on record sheets include : (1) whether coupler is fully screwed and fitted, (2) whether coupler has been cleared of foreign materials (e.g. concrete gels), (3) whether thread has been cleared of foreign materials (e.g. concrete gels), and (4) whether there is complete splice between coupler and rebar.

152. Paragraph 604 of the Final Report does give the Commission's view on the failure of the hold point inspection system which have a close bearing on the effectiveness of QSP.

> "*On the basis of all the evidence heard during the full inquiry – as set out elsewhere in this report in considerable detail – it is apparent to the Commission, indeed is accepted, that the system of hold point inspections verified by contemporaneous documentation, namely, completed and signed RISC forms, is not always made the subject of rigorous adherence. Indeed, the opposite was on occasions the case.*"

153. Although some structural engineering experts in the Inquiry held the view that use of ductility couplers in the platform slabs was not necessary, it should be noted that the requirements of adhering to the QSP have been stipulated in the acceptance letters of the BA to MTRCL. As a matter of fact, the use of ductility couplers is specified in the accepted drawings for various areas of HUH Extension. Hence, it is a statutory requirement under the Buildings Ordinance ("BO") that the works should be completed in accordance with the accepted drawings.

154. MTRCL had engaged in the compilation of retrospective records for the coupler installation works at the EWL slab, as noted in paragraph 605(d) of the Final Report:

> "*During the course of final submissions, counsel for the Government submitted that the fact that, after May 2018, MTRCL and Leighton had both engaged in the compilation of retrospective record sheets for the coupler installations was itself an indication that they were or ought to have been aware of the need, at the time that the installation work was done, to compile full and accurate contemporaneous records. Clearly, that had not been done.*"

Quality testing of rebars

155. It is a regulatory requirement under the BO[76] that all rebars delivered to site have to be tested by a laboratory accredited under the Hong Kong Laboratory Accreditation Scheme ('HOKLAS'), in addition to manufacturer's certification.

156. Leighton admitted in the Extended Inquiry that approximately 7% of the rebars delivered to site under Contract 1112 was not sampled for testing by a HOKLAS accredited laboratory. It was found that based on the delivery summary, the rebars without sampling for test amounted to about 4,000 tonnages. Records show that most of the untested rebars were used in the NAT and HHS areas, but not in the accommodation blocks.

157. Evidence heard in the Inquiry showed that the majority of the rebars delivered to the site were tested and passed the HOKLAS tests. The Commission was satisfied that the reinforcement that was not HOKLAS tested would not threaten the integrity of the structures on this project.[77]

158. The use of untested rebars in the works is a major non-conformance with the contractual specifications and the statutory requirements. It also reflects a serious flaw in site supervision and control.

159. It is established practice in civil engineering works in Hong Kong to exercise stringent control of rebars delivered to site. Untested rebars are quarantined before they are tested and found to be acceptable. Only after the testing would the rebars be allowed to be used in the works. It is alarming that as many as 4,000 tonnages untested rebars, which amounts to 7% of the rebars delivered to site under Contract 1112, could be used in the works unnoticed by the site supervision and control system.

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[76] Section 17(1)6 of the BO empowers the BA to impose requirements for testing of rebars. BD adopts Construction Standard CS2:2012 (CS2) as an acceptable standard for compliance with such requirements.

[77] See paragraph 33 of the Executive Summary of the Final Report

Maintaining contemporaneous construction records

160. In the SCL Project, MTRCL is obliged to submit as-built drawings and other records to the Government upon completion of works. This requires contemporaneous recording of what has been built.

161. Typically, records to be compiled contemporaneously include RISC forms and QSP, given the purposes of compiling these records. These records are cumulative, voluminous and involve different personnel in completing them.

162. RISC forms constitute primary evidence of works inspected (at hold point inspections) and certified as being correctly done. If the RISC forms are not completed contemporaneously, it would be difficult to trace who have inspected the works and whether the works have been found to be satisfactorily.

163. QSP is another type of construction record that has to be completed contemporaneously. The QCC of Leighton will certify on the record sheet that the necessary items about the installation of couplers have been checked. The QCS of MTRCL will select a certain number of splicing assemblies (not less than 20% or 50% of the total number, depending on the location) in accordance with the QSP for inspection. If the installation is found to be satisfactory, the QCS will countersign the record sheet. The record sheet, completed with the date, time and items inspected, will then be entered into the inspection log book. The inspection log book has to be kept on site for inspection by BD officers.

164. The review report of the EWL slab construction by MTRCL dated 15 June 2018[78] is an example where the number of couplers used in connecting the rebars was subsequently found to be inconsistent with the site records previously provided by MTRCL and Leighton for reason that the QSP was not available in the first place.

[78] https://www.mtr-shatincentrallink.hk/pdf/multimedia-gallery/report/report_20180614_e.pdf

165. The lack of contemporaneous records has called for physical opening up of parts of the built structure in the Holistic Assessment to verify the as-constructed EWL slab to D-wall connections against the contractor's amendment drawings.

166. Further to the irregularities in site-record keeping, the problem in site supervision and control in the Hung Hom Site is also exemplified in the two major design changes at the HUH Extension.

Design Changes

167. Chapter 4 of the Final Report has described in detail the two design changes made to the top of the east D-wall in Areas B and C during the construction of the EWL slab.

168. To cope with the workmanship issues at the construction joint, drilled-in dowel bars and local thickening of slabs were proposed to be installed in the areas of high utilization in the package of *suitable measures* in the *Holistic Report.*

169. The issue of structural implication aside, these two incidents of design change have exposed other problems as follows:

(a) Due to the change in detail at the top of the east D-wall, the actual number of couplers used has been significantly reduced. This is one of the major errors of the June 2018 report by MTRCL.

(b) Similar to the change from lapped rebar connections to coupler connections in the NAT, SAT and HHS, there was a heated debate as to whether the changes are "minor changes" as put forward by Leighton and MTRCL. The Government considered that these changes required prior consultation with BD.

(c) Lack of contemporaneous records of what had been constructed has led to the opening up works in the Holistic Assessment. It also caused difficulties for Leighton and MTRCL in preparing the as-built drawings for submission to the BA for application of Certificate of Completion.

(d) The unavailability of documents such as RISC forms and QSP, in supervising and inspecting the built structures has cast doubt on the quality of the works done.

(e) Apparent lack of communication between MTRCL and Leighton, and between the design management team and construction team of MTRCL.

(f) Possible mishandling between the different teams of Atkins working for MTRCL and Leighton in handling the design changes.

170. The multitude of construction irregularities and the related irregularities in site supervision and control have raised concerns as to the safety and integrity of the built structures in the Hung Hom Site. The necessary remedial measures and associated issues will be discussed in ***Section 4***.

Section 4 Safety and Compliance of Built Structures in Hung Hom Site

Cause for Concern

171. The diverse types and significant extent of the construction irregularities found in the Hung Hom Site are very unusual. Throughout their professional careers, the members of the EA Team have not encountered in any other major construction projects in Hong Kong with a comparable scale of irregularities.

172. These irregularities, compounded by the anomalies in the site supervision and control, are casting doubts about the quality and integrity of the built structures in the Hung Hom Site. In practice, the concern is threefold, which involves the following issues to be dealt with:

(a) *Safety* – whether the built structures are structurally safe for them to be used as intended, and if not, what remedial measures are required. This is denoted as the "*First Issue*" in this Section.

(b) *Code Compliance* – whether the completed works, i.e. the built structures together with the remedial measures for dealing with the irregularities, are in compliance with the applicable codes. Code compliance ensures that the established standard of good engineering practice is met. Code compliance also forms part of the regulatory requirements. This is denoted as the "*Second Issue*".

(c) *Contract Compliance* – whether the completed works are in accordance with the contractual requirements based on the Entrustment Agreements between the Government and MTRCL. This is denoted as the "*Third Issue*".

173. In the Inquiry, the *First Issue* was addressed at length during the hearings, under the subject denoted as "*safe and fit for purpose*" by the Commission. The Commission's determinations are given in Chapter 8 and Chapter 10 of its Final Report, for the HUH Extension structure under the Original Inquiry and for the NAT, SAT, and HHS under the Extended Inquiry respectively.

174. The Commission has heard evidence and made observations about the poor workmanship, lax site supervision and deficient management in the Hung Hom Site.[79] However, in view of its remit, the Commission did not explicitly examine the *Second* and *Third Issues*.

175. In the Holistic Assessment and Verification Study for the Hung Hom Site by MTRCL, the *Second Issue* was the principal subject for examination.

176. There are different views among the parties involved in the Inquiry on whether *safe and fit for purpose* (i.e. *First Issue*) should be examined on the basis of code compliance (i.e. *Second Issue*). However, it has not been disputed at all that, if the *Second Issue* is addressed, the *First Issue* will not be a concern. The *Third Issue* is a matter of contractual consideration, which is outside the scope of the *Holistic Proposal* and *Verification Proposal*.

177. EA Team's analysis of the three issues is presented in the ensuing paragraphs, with account taken of the determinations of the Commission and the findings of the Holistic Assessment and Verification Study. Particular attention is given to addressing the matters pertinent to code compliance, given that the built structures in the Hung Hom Site are dealt with by MTRCL and the Government primarily based on code compliance consideration.

[79] See paragraph 415 of the Final Report

First Issue – Dealing with Safety

178. In essence, the *First Issue* is addressing a pragmatic question commonly asked by the public as to whether the built structures are safe to be used and would serve their intended functions, day in and day out. In examining the matter, the Commission has adopted the term "*safe and fit for purpose*", with the following definition:

> *"…capable of being used and functions as a station safely and without any physical restrictions on its operations and as anticipated by MTRCL during its intended design life."*[80]

179. While the question appears to be simple and direct, the answer is less straightforward. The complication lies mainly in the different approaches adopted for evaluating whether the structures are *safe and fit for purpose*.

Compliance Approach vs Forensic Approach

180. Two distinctly different approaches were adopted by the independent engineering experts who gave evidence in the Inquiry. The Commission named these as *compliance approach* and *forensic approach.*[81]

181. The expert appointed by the Government held the views that *safe and fit for purpose* should be benchmarked with the established standard of good engineering practice stipulated in the applicable codes. The expert considered that these were the minimum requirements reflecting the standard required in Hong Kong for the purpose of ensuring safety. This is denoted as *compliance approach* by the Commission.

182. The *compliance approach* has been the basis for the design, and acceptance, of modern-day engineering structures in Hong Kong and elsewhere. Under this approach, the key design criteria stipulated in the

[80] See paragraph 314 of the Final Report

[81] See paragraph 19 of the Executive Summary of the Final Report

codes, such as the design loads, material properties and required minimum factors of safety, are adopted in design. The designer has to demonstrate by engineering analysis that the requirements stipulated in the codes are met. It is advocated in this approach that the requirements given in the codes are the objective yardstick for determining whether the structures are *safe and fit for purpose*. The use of *compliance approach* in code-compliant analysis will be further discussed under the *Second Issue*.

183. The approach adopted by the independent engineering experts appointed by the Commission, MTRCL and Leighton was noted by the Commission as *"an essentially 'forensic' approach."* [82]

184. As opposed to the *compliance approach*, the *forensic approach* does not consider code compliance essential in establishing whether the structures are *safe and fit for purpose*. Instead, this is assessed by expert experience and judgement, with account taken of the condition and performance of the structures as they stood. Where considered necessary, the expert may either demonstrate or calibrate his judgement with calculations. However, the calculations do not necessarily follow the design criteria stipulated in the codes. The calculation results may also fall short of the code requirements. Notwithstanding these, the structures could still be concluded to be *safe and fit for purpose*, if the expert is satisfied that this is the case based on his experience and judgement.

Determinations of Commission

185. The Commission received expert evidence about whether the built structures in the Hung Hom Site was *safe and fit for purpose* based on the two different approaches. In gist, based on the *forensic approach*, it was the joint opinion of the experts of the Commission, MTRCL and Leighton that the built structures, as they stood notwithstanding the known irregularities, were *safe and fit for purpose*. However, the Government's expert opined that the built structures did not comply with the applicable codes and would require remedial works to render them *safe and fit for purpose*.[83]

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[82] See paragraph 19 of the Executive Summary of the Final Report

[83] See paragraph 17 of the Executive Summary of the Final Report

186. A suite of *suitable measures* was recommended in the *Holistic Report* and *Verification Report*. The *suitable measures* included, among other provisions, remedial works on the built structures for code compliance purposes. Further discussions about the *suitable measures* are given in *paragraphs 202* to *204* below.

187. Despite their different views that the built structures as they stood were *safe and fit for purpose*, the experts of the Commission, MTRCL and Leighton all agreed that *"the suitable measures would add to the robustness of the structures or at least would not result in the structures being in any way less safe."*[84]

188. The Commission came to the following conclusions regarding the safety and fitness for purpose of the HUH Extension structure:

> *"there was consensus among all the experts and the three involved parties (the Government, MTRCL and Leighton) that, whatever their conflicting views as to the need for remedial measures, with those measures in place, the station box structure will be safe and will also be fit for purpose."*
>
> *"In the view of the Commission, that consensus, reached after many months of investigation and debate, constitutes a compelling body of opinion. In light of that opinion, the Commission is fully satisfied that, with the suitable measures in place, the station box structure will be safe and also fit for purpose."*[85]

189. Similar conclusions were also reached by the Commission for the built structures at the NAT, SAT and HHS.[86]

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[84] See paragraphs 411 and 564 of the Final Report

[85] See paragraphs 412 and 413 of the Final Report

[86] See paragraphs 563 to 565 of the Final Report

Views of EA Team

190. In the opinion of the EA Team, the *compliance approach* and *forensic approach* represent two different, and perhaps complementary, schools of thought for dealing with the complex question about "how safe is safe". Under its present ambit, the EA Team has not further deliberated which one is the more appropriate approach to adopt in evaluating the built structures as they stood without remediating the irregularities. In fact, with the implementation of the *suitable measures*, the structures would no longer be standing on their own without the remedial works.

191. What matters, as far as the *First Issue* is concerned and as determined by the Commission, is that the built structures with the remedial works in place are *safe and fit for purpose*. This is the consensus of all the experts who testified before the Commission. The EA Team was not a party in the Inquiry. However, with its close involvement and knowledge of the case, the EA Team is in agreement with this position. The EA Team is convinced that, with the implementation of the required remedial works, it is safe in practical terms to use the built structures for their intended purposes.

Second Issue – Dealing with Code Compliance

192. The *Second Issue* is concerned about whether or not the works meet the requirements of the applicable codes.

193. In the present case, the Code of Practice for Structural Use of Concrete ("Concrete Code") issued by BD and the New Works Design Standards Manual ("NWDSM") of MTRCL are the applicable codes.

194. The Concrete Code is the *de facto* design standard for concrete building structures in Hong Kong. It forms part of the regulatory requirements.[87]

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[87] It is stated in the Foreword of the Concrete Code that *"Although this Code of Practice is not a statutory document, the compliance with the requirements of this Code of Practice is deemed to satisfy the relevant provisions of the Buildings Ordinance and related regulations."*

195. According to the Entrustment Agreements, the SCL structures shall be designed to comply with the NWDSM. The NWDSM embraces the requirements for compliance with the Concrete Code.[88] However, given the specific nature and requirements of railway structures, the NWDSM also contains additional specifications for such structures.

196. Hence, to be exact, the "applicable codes" for the structures in the Hung Hom Site is the NWDSM. Compliance with the NWDSM serves to meet the established standard of good engineering practice for railway structures. Since the NWDSM embraces the requirements of the Concrete Code, compliance with the NWDSM implies compliance also with the Concrete Code.

Code-compliant analysis and suitable measures

197. The *Second Issue* was the principal theme in the Holistic Assessment and Verification Study. The investigation of the irregularities and built details of the structures helped establish the governing material parameters for use in the analysis. The analysis conducted was aimed primarily at code-compliant checking, i.e. to check whether the built structures comply with the NWDSM, and if not, the remedial works required for achieving compliance. In this connection, the BA is mandated to require MTRCL to demonstrate compliance with the Concrete Code as a necessary condition for regulatory approval for usage of the structures under the BO.

198. It is the position of both the Government and its independent engineering expert that the *First Issue* is inseparable from the *Second Issue*, i.e. *safe and fit for purpose* should be assessed with the *compliance approach*. As such, the Government has not required the subject of *safe and fit for purpose* to be separately evaluated in the Holistic Assessment and Verification Study.

199. Although there were different views in the Inquiry regarding whether *safe and fit for purpose* should be assessed based on the *compliance approach*, it was evident to all that the Holistic Assessment

[88] See Clauses 4.2.2.7 and 4.2.2.8 of Section 4 of the NWDSM

and Verification Study were addressing code compliance, and that the *suitable measures* were also proposed for this purpose.

200. In this connection, regarding the HUH Extension structure, the following was stated in the *Holistic Report*:

> *"It is proposed that suitable measures are carried out to cater for the poor workmanship issues found and 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."*[89]

201. This was noted by the submissions of MTRCL's counsel to the Commission, as follows:

> *"The purpose of the Holistic Report had not been to address structural safety simpliciter but had been to ensure that the as-constructed works achieved compliance in light of issues concerning poor workmanship and missing records."*[90]

202. It was proposed in the *Holistic Report* and *Verification Report* that a suite of *suitable measures* should be provided in the Hung Hom Site. The term *suitable measures* was coined in the *Holistic Report* and *Verification Report* with the following meaning:

> *"Suitable measures means actions which are deemed necessary to address the issues identified in this Report and achieve the safety level required in the Code for meeting established good practice of engineering design. The term covers a wide range of actions and may include structural modifications, remedial works, long term monitoring of the structure and the surrounding areas, and the restrictions/ precautionary arrangements on future modifications to the structure, and future usage of the site and development in its*

[89] See paragraph 4.1.8 of the *Holistic Report*

[90] See paragraph 18 of the Executive Summary of the Final Report

vicinity. Furthermore, in view of the updated design requirements adopted in the Assessment, some restrictions and precautionary arrangements in Table 5[91] *[of the Holistic Report] will be imposed on the future use of the site but these will neither hamper the operation of the structure nor usage of the site."*[92]

203. The proposed *suitable measures* comprise principally remedial works to the built structures in the Hung Hom Site, together with other provisions. The remedial works include structural strengthening works to cater for the irregularities and other repair works for defects found on site. The Commission also noted the purpose of the *suitable measures* proposed in the *Holistic Report* as follows:

"In the result, 'suitable measures' – essentially remedial building measures – were proposed in order to achieve the safety level required in the Code of Practice for Structural Use of Concrete 2004, for meeting the requirements of the Buildings Ordinance, the established good practice of engineering design and MTRCL's 'New Works Design Standard Manual'."[93]

204. The implementation progress of the *suitable measures* at the time of preparation of this report is summarized in ***Appendix 4-1***. Readers may refer to the *Holistic Report* and *Verification Report* for further information of the need and scope of the *suitable measures*. Two items of the *suitable measures*, viz. the remedial works required on the "OTE ducts and walls" and "voids in concrete backfilled areas"[94], were agreed between MTRCL and the Government after the finalization of the *Holistic Report* and *Verification Report*.

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91 Table 5 of the *Holistic Report* is reproduced in ***Appendix 4-2*** of this report.

92 See paragraph 4.1.8 of the *Holistic Report* and paragraph 4.1.3 of the *Verification Report*

93 See paragraph 11 of the Executive Summary of the Final Report

94 See *paragraphs 114* to *122* in ***Section 3***

205. While the purpose and scope of the *suitable measures* have been agreed, the EA Team considered it useful to elaborate on some aspects pertinent to code compliance and the ramifications given the circumstances of the case. These include:

(a) relevance of code compliance;

(b) uncertainty in code-compliant analysis;

(c) *Original Design* vs *Updated Design*;

(d) implications of *Updated Design;* and

(e) further attention required on *suitable measures*.

Relevance of code compliance

206. As the Commission has determined that the built structures with the remedial works in place are *safe and fit for purpose*, why is there a need to deliberate the issue of code compliance? In EA Team's view, code compliance serves several useful purposes.

207. Firstly, the *forensic approach* and the way it was applied to the evaluation of *safe and fit for purpose* was disputed by the Government and its independent engineering expert in the Inquiry. Without benchmarking with code compliance, the Government and its expert would not have agreed that the built structures upon implementation of the remedial works are *safe and fit for purpose*. The Commission has not based its *safe and fit for purpose* determination on code compliance. However, the code-compliant analysis did provide a basis for the involved parties to resolve their differences in opinion and reach the consensus view.

208. Secondly, MTRCL has to demonstrate that the completed works comply with the Concrete Code as a necessary condition for regulatory approval under the BO.[95] Hence, code compliance is part of the

[95] Although the Concrete Code is not a statutory document, compliance with the Concrete Code is deemed to satisfy the relevant provisions of the BO. Designs based on other standards or

regulatory requirement that the structures must meet before they are accepted for use in operation.

209. Thirdly, the requirements specified in the codes are the recommended good engineering practice to ensure that a high standard of quality and safety required of an important railway structure is met. Code compliance is an instrument for conforming to the established good engineering practice, aside the regulatory requirements. The Government's independent engineering expert explained this in his evidence to the Commission as follows:

> *"the requirements contained in those instruments reflected the community's expectations and a consensus reached among industry practitioners over many years that take into account circumstances particular to Hong Kong."*[96]

210. Code compliance is related to, but different from regulatory compliance. As explained in *paragraph 196* above, the NWDSM is the applicable code for the structures in the Hung Hom Site. The code contains supplementary requirements for the recommended good standard for railway structures, in addition to the regulatory requirements (i.e. Concrete Code) of the BO.

211. Fourthly, codes also contain requirements about supplementary design provisions, such as structural detailing. These provisions encompass a wealth of empirical engineering principles and experience in the established standard of good practice for ensuring satisfactory structural performance, durability and robustness. Many of these provisions are by nature not readily amendable to verification by routine engineering analysis based on simplified calculation models. This implies that one could not readily count on routine calculations to show the need for, or to justify the omission of, such provisions. However, failure

technical criteria may be approved if they can be shown to achieve the performance requirements. However, for the Hung Hom Site, given that MTRCL has adopted the Concrete Code for satisfying the BO, compliance with the Concrete Code is therefore a necessary condition for regulatory approval.

[96] See paragraph 409 of the Final Report

to comply with the requirements may cast doubt on the quality of the structures in such aspects as their durability and robustness.

212. Last but not least, the Hung Hom Site is a case which has attracted major concern from the public and other stakeholders about the integrity of the structures. Code compliance provides an objective assurance to all that the structures meet the established standard of quality and safety. This will help restore confidence.

213. It is therefore the Government's position that the structures, with the necessary remedial works, should comply with the applicable codes. The EA Team supported this position.

Uncertainty in code-compliant analysis

214. For a properly designed and constructed engineering structure, there is normally little uncertainty in its as-constructed details. The vast majority of such details should be readily known from the design drawings and works specifications, since the structure should normally have been constructed in accordance with the design drawings and works specifications. Where material changes in some of the design details are required on site during construction, these changes should also have been duly designed, checked and recorded. Compilation of as-built drawings is an established and routine task on site. Hence, in sites where the works are properly executed and supervised, rarely would any major difficulty be encountered in ascertaining the as-constructed details.

215. Unfortunately, this is not the case in the Hung Hom Site. A large quantity of the construction records in this site are either missing or of doubtful reliability (e.g. being retrospectively compiled and inaccurate).[97] Not only are there material deviations in the construction works from the design drawings, but many of the changes are also not properly recorded, and some may even be illicit. In consideration also of the multitude of construction irregularities as revealed from the physical investigation, one could not be confident that the works would necessarily have been constructed as designed, or in accordance with the specifications.

[97] See paragraph 23 of the Executive Summary of the Final Report

216. The uncertainty in the as-constructed condition and quality of the built structures poses a major difficulty in code-compliant analysis. To tackle this difficulty, in the Holistic Assessment and Verification Study, much effort was given to collation of construction records and to physical investigation for examining the as-constructed details of the built structures.

217. In the Inquiry, the Commission noted the observation made by one of the independent engineering experts as follows:

> *"Few structures have been subjected to the degree of post-construction survey, inspection and opening up, or subjected to the sophisticated independent analysis and testing which has been carried out on the structures [the station box structure] by a number of different parties."*[98]

218. This might be taken as a positive remark about the effort given in the investigation of the irregularities in the Hung Hom Site. Indeed, the EA Team agreed that the post-construction investigation was extensive. The EA Team was also satisfied that, on the whole, the investigation was devised and conducted in a professional manner, amid the inevitable site, time and resource constraints. Overall, the investigation has helped establish the key design parameters that reflect the as-constructed condition of the structures with account taken of the identified extent and severity of the irregularities. These design parameters provided an objective basis for the code-compliant analysis.

219. However, it should be noted that despite the extensive investigation, there remains much uncertainty in the actual condition of the built structures. The investigation has reduced the uncertainty to a more manageable level that enables the code-compliant analysis to be carried out objectively. It does not fully eliminate the uncertainty. Even with the findings of the extensive investigation at hand, the residual level of uncertainty in this case cannot be underestimated, and this needs to be properly managed.

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[98] See paragraph 310 of the Final Report

220. In theory, the level of uncertainty may be further reduced by conducting more investigation works, e.g. physical opening up at more locations and retrieving more samples for testing. In practice, this is often limited by the need to strike a balance with the practical constraints, with avoidance of undue damage that may be caused by the physical investigation works to the built structures, and also with the possibility of diminishing returns in furthering the investigation.

221. From time to time during the investigation, decisions had to be made by MTRCL and the Government on when and where to draw a line about whether further investigation of a certain aspect in question should be pursued. The EA Team participated, and offered independent advice, in many of these decisions.

222. Dealing with uncertainty in design and analysis is part and parcel of professional engineering practice. After all, an important objective of engineering design is to ensure that the chance of failure is acceptably small, given the uncertainty. For this purpose, part of the recommended good practice for design stipulated in the codes are to manage uncertainty. For instance, the required minimum factors of safety to be adopted serve to ensure the availability of an adequate margin of safety to guard against unsatisfactory structural performance which may arise from unfavorable combinations of factors subject to uncertainty. Also, the loading and material parameters to be adopted in design should be suitably conservative (e.g. the 95^{th} percentile value), to cater for the uncertainty involved.

223. Similar principles were adopted in deriving the design parameters (e.g. reinforcement layout and defective rate of the coupler connections) that represent the as-constructed condition of the structures for use in the code-compliant analysis. These design parameters need to be suitably conservative to cater for the possible uncertainty. In an unusual case like the Hung Hom Site, the derivation at times called for professional judgement, aside the application of established engineering and statistical approaches. Some examples are given below as an illustration:

(a) *Coupler connections*

In determining the defective rate of coupler connections, based on binomial statistical approach, the 95th percentile value calculated from the findings of the physical opening up investigation was adopted. This followed the advice of Government's statistical experts.

(b) *Concrete strength*

The concrete strength specified in the design, and not the strength assessed from the concrete cube samples prepared on site was used. This is in line with the established design practice for code-compliant analysis. Furthermore, the concrete cube samples were prepared in a controlled environment for concrete quality assurance purposes. The actual strength of the bulk of the concrete in the built structures are affected by other factors, such as workmanship, segregation and less favorable curing environment.

(c) *Shear links*

Presence of shear links was neglected in the analysis of some parts of the built structures. This assumption was made in the light of the major irregularities, including missing shear links, smaller bar sizes and insufficient anchorage lengths, at all of the physical opening up locations. MTRCL proposed, and the Government agreed, to adopt this assumption to avoid further, extensive opening up of the built structures.

224. In the Inquiry, views were given by the experts who adopted the *forensic approach* on the conservatism of these design parameters for assessing whether the structures were *safe and fit for purpose*. The Government's expert, however, opined that these were suitable assumptions and parameters to adopt, which followed the established good engineering practice.

225. On the one hand, as the issue of *safe and fit for purpose* has eventually been settled in the Inquiry, there is no need to further deliberate whether these assumptions and parameters are most appropriate for the *safe and fit for purpose* assessment.

226. On the other hand, it was the consensus among MTRCL and the Government that the assumptions and parameters concerning the condition of the built structures adopted in the Holistic Assessment and Verification Study were representative and appropriate for the purpose of code-compliant analysis. The EA Team supported this. The EA Team considered that the approach adopted in deriving the assumptions and parameters for use in the code-compliant analysis was prudent and pragmatic, given the uncertainty involved.

Original Design vs Updated Design

227. The code-compliant analysis undertaken in the Holistic Assessment and Verification Study involved engineering analysis conducted on the built structures for assessing whether the requirements of the applicable codes are met. In case the code requirements are not satisfied, the type and scope of the remedial works required for meeting the code requirements were determined, also from analysis.

228. For the code-compliant analysis, in broad terms, the following three sets of parameters are required:

(a) the design parameters that reflect the as-constructed condition of the structures with account taken of the irregularities (e.g. reinforcement layout and defective rate of coupler connections);

(b) other relevant design assumptions and models (e.g. loading condition and parameters); and

(c) the yardstick against which code compliance is assessed through engineering analysis (e.g. the factors of safety to be applied to different material parameters and load parameters).

229. It is an established practice that code-compliant analysis is conducted, and accepted, before commencement of the construction works. Where there are major design changes during construction, the revised design will also be checked to ensure code compliance. If construction is in accordance with the design and works specifications, as is normally the case, parameter set (a) of *paragraph 228* above would be the same as that adopted in the accepted design. Therefore, conducting post-construction code-compliant analysis is normally unnecessary, given that parameter sets (b) and (c) also remain unchanged.

230. However, for the Hung Hom Site, due to construction irregularities, parameter set (a) became less favorable for achieving code compliance, than that adopted in the accepted design. Hence, code-compliant analysis is required on the built structures.

231. Set (a) of the design parameters for the Hung Hom Site was derived from the investigation carried out in the Holistic Assessment and Verification Study. These are essentially material parameters that reflect the as-constructed condition of the structures.

232. For parameter set (c), the requirements specified in the applicable codes were followed, i.e. no change to the yardstick in this respect.

233. Parameter set (b), however, involved two scenarios. These were denoted as *Original Design* and *Updated Design* in the *Holistic Report* and *Verification Report*, as described as follows:

> *"For the* ***Original Design****, Atkins [MTRCL's Detailed Design Consultant] assessed the safety and integrity of the structure based on the original design assumptions and models with consideration of the findings of as-constructed conditions from Stages 1 and 2 Investigations. It was based on these original design assumptions and models that the proposed works were accepted as achieving the safety level required in the Code for meeting established good practice of engineering design."*[99]

[99] See paragraph 4.1.4 of the *Holistic Report*

> *"For the* ***Updated Design****, MTRCL, together with the external consultants, have reviewed the original design assumptions. It is considered that a number of the design assumptions and extra flexibilities/provisions can be 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. After review, MTRCL and the external consultants recommended a set of updated design criteria for the Updated Design to be used in the Assessment. MTRCL and the external consultants consider that the adoption of these updated criteria together with the findings of the Stages 1 and 2 investigations on the as-constructed conditions and the relevant material/strength reductions generally complies with the NWDSM and achieves the safety level required in the Code."*[100] **[Emphasis added]**

234. In essence, in respect of parameter set (b), under the *Original Design* scenario, the code-compliant analysis was conducted based on the use of the design assumptions and models originally adopted in the accepted design. Under the *Updated Design* scenario, the code-compliant analysis was conducted with the use of some revised design assumptions and models. These revised design criteria would result in a less demanding design, given the adoption of the same sets of parameters in (a) and (c).

235. As a result, less extensive remedial works are required under the *Updated Design* scenario, as stated in the *Holistic Report*:

> *"Analysis Assessment of the structure using the updated design criteria still shows areas where suitable measures need to be taken, but these are less than those identified using the original design."*[101]

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[100] See paragraph 4.1.5 of the *Holistic Report*

[101] See paragraph 4.3.2 of the *Holistic Report*

236. The difference between the *Original Design* and *Updated Design* scenarios was not deliberated in detail in the Inquiry. However, the Commission noted the following in connection with the reduction of the required remedial works under the *Updated Design* scenario:

> *"The extent of the required extra construction works – the 'suitable measures', as they were called – were materially reduced from those that had been originally determined. The decision to reduce the extent of the works lay in the decision to base calculations on a set of revised design assumptions. The revised criteria, it was decided, complied with MTRCL's 'New Works Design Standard Manual' ('NWDSM') and also met the requirements of the Code."*[102]

237. Notwithstanding the changes in the design criteria adopted in the *Updated Design*, the *Updated Design* was still aimed at achieving code compliance. Hence, the scope and extent of the remedial works found necessary based on the *Updated Design* still meet the code requirements, even though the works are less extensive than those which would otherwise be required under the *Original Design*. This is understandable, as the code only specifies the minimum requirements for compliance.

238. It is not uncommon that a project would have its own design provisions which are over and above the minimum requirements of the code, due to the specific circumstances of the project. Code compliance may not be affected even if these additional provisions are removed. However, removal of the provisions could have other implications, as is the case in the Hung Hom Site.

Updated Design of HUH Extension structure and its implications

239. A total of ten key changes were made in the design assumptions and models under the *Updated Design* of the HUH Extension structure. These were denoted as *updated design criteria* in the *Holistic Report*. The ten changes in the *Updated Design*, together with the restrictions and

[102] See paragraph 51 of the Final Report

required precautionary arrangements arising from the changes, are listed in Table 5 in the *Holistic Report*. This Table is reproduced in ***Appendix 4-2*** of this report.

240. It is stated in the *Holistic Report* that the adoption of these *updated design criteria* "*generally complies with the NWDSM and achieves the safety level required in the Code*".[103] The following considerations are given by MTRCL in the *Holistic Report* for the changes in the design criteria adopted in the *Updated Design*:

> *"a number of the design assumptions and extra flexibilities/provisions can be rationalised as some of the uncertainties at the early design stage are either more certain or no longer need to be accommodated",* and
>
> *"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."*[104]

241. The EA Team supported the commitment of both MTRCL and the Government to take code compliance as the yardstick for acceptance of the built structures and determination of the required remedial works. The EA Team noted that MTRCL's adoption of the *updated design criteria*, which was accepted by the Government, was primarily aimed at containing the scope and extent of the required remedial works, while still maintaining code compliance.

242. In this respect, in the *Holistic Report*, MTRCL denoted the *updated design criteria* as *"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."*[105]

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[103] See paragraph 4.1.5 of the *Holistic Report*

[104] See paragraph 4.3.3 of the *Holistic Report*

[105] See paragraph 4.1.6 of the *Holistic Report*

243. On the premise that code compliance is not compromised, the EA Team had no objection to the adoption of *updated design criteria*. This is a pragmatic solution, agreed between MTRCL and the Government, for addressing the engineering concerns about the structural integrity, so as to render the structures acceptable for being put into their intended use for the benefit of the community.

244. In its Final Report, the Commission recorded the views given by MTRCL in its closing submissions to the Commission as follows:

> *"These actions are known as the Suitable Measures which are being implemented for the purpose of obtaining the ultimate approval of the works by the approval authorities so that the railway can be put into operation for use by the general public."*[106]

245. Notwithstanding this, the restrictions and required precautionary arrangements (see ***Appendix 4-2***), which are consequential to the adopting of the *updated design criteria*, should not be overlooked. These fall into two board categories.

246. First, many changes in the design criteria involved adjustment of the design loading provisions (i.e. Items 1, 2, 3 and 8 in ***Appendix 4-2***). This means that the HUH Extension structure with the required remedial works will comply with the code requirements, but up to the revised loading limits adopted in the *Updated Design*. The revised loading limits are lower than those adopted in the *Original Design*, which are provided in other SCL stations.

[106] See paragraph 410 of the Final Report

247. Second, there was one key item of change (Item 10 in ***Appendix 4-2***) under which a maximum of 30% moment redistribution[107] was adopted in the *Updated Design*. In the *Original Design*, as is normally the case in the prevailing design practice for other new engineering structures in Hong Kong, no moment redistribution was adopted in the design. Likewise, no moment redistribution was adopted in the design of the other SCL stations.

248. For the first category of the *updated design criteria* described in *paragraph 246* above, MTRCL has confirmed that adoption of the revised loading limits in the *Updated Design* would not affect the functionality and performance of the structures. The Government was also satisfied that this did not violate the code requirements. However, the HUH Extension structure has a reduced load capacity, in comparison with the provisions in its *Original Design*. The reduced loading limits may affect the flexibility of future alteration or other works[108], within or outside the station. Furthermore, in connection with the curtailed provisions for differential water pressure (Item 8 of ***Appendix 4-2***), groundwater and related loading condition, say arising from future construction activities in the vicinity of the site, need to be controlled accordingly.

249. In Hong Kong, during the service life of a station, modification works are at times required and there may also be nearby construction activities that could result in adverse engineering effects on the station. It is vital that the restrictions arising from the *Updated Design* are duly observed in the long term. Suitable provisions should be made in the relevant management plans and monitoring schemes to cater for the restrictions and precautionary arrangements.

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[107] In this case, adoption of a maximum of 30% moment redistribution means that at locations where the calculated bending moment exceeds the available structural capacity, the excess bending moment up to an amount of 30% of the capacity will be allowed to be re-distributed to other parts of the structure based on consideration of plastic deformation in the analysis. 30% is the maximum limit of moment redistribution allowed by the Concrete Code. Redistribution of moment, when occurs in practice, will result in large structural deformation with consequential damage. However, the structure is deemed to comply with the code, if the analysis shows that it would not collapse after the moment redistribution.

[108] Item 9 of the updated design criteria in ***Appendix 4-2*** also affects the flexibility of future alteration works, although this item involves the use of an updated structural model in the analysis instead of a revised loading provision.

250. Regarding the second category of the *updated design criteria* as described in *paragraph 247* above, the 30% moment redistribution is the maximum limit allowed in the Concrete Code. Hence, adopting this in the *Updated Design* does not contravene code compliance. However, moment redistribution is rarely adopted in the design of new structures in Hong Kong, nor is it the practice adopted by MTRCL in its new works. Moment redistribution utilizes the reserve capacity that is commonly provided in a new structure. As a result, it reduces the reserve capacity of the structure, say, in accommodating future alteration or extension works, and in withstanding unforeseen, accidental conditions.

251. While the use of moment redistribution does not violate code compliance and there are reasons for its adoption, in EA Team's opinion, this is an important change arising from the *Updated Design*.

252. One of the revised design criteria involved seismic load (Item 5 in ***Appendix 4-2***). In the *Original Design*, the seismic load adopted in design was calculated based on the approach of pseudo-static acceleration. This is not consistent with the requirements of the NWDSM. This anomaly was identified during the Holistic Assessment. It was rectified in the *Updated Design* with the use of dynamic analysis, in accordance with the requirements of the NWDSM.

253. Further discussion of the subject of seismic design is given in *paragraphs 370* to *384* in ***Section 7***.

Updated Design of NAT, SAT and HHS structures and its implications

254. Likewise, similar *updated design criteria* were adopted in the *Update Design* of the structures in the NAT, SAT and HHS. The changes made in the design criteria were listed in Tables B1, B2 and B3 of the *Verification Report*, which are extracted and reproduced in ***Appendices 4-3, 4-4*** and ***4-5*** respectively.

255. The adoption of the *updated design criteria* in the NAT, SAT and HHS structures does not affect code compliance. However, the implications are similar to those in the *Updated Design* of the HUH Extension structure.

Further attention required on suitable measures

256. At the time of preparation of this report, the vast majority of the required *suitable measures* had been completed (see ***Appendix 4-1***), and the remainder was being pursued. However, some areas warrant further attention.

257. Firstly, the EA Team noted that MTRCL could only carry out remedial works at locations where the defects and their locations were known. The possibility remains that similar or other types of defects may be present elsewhere in the structures but at unknown locations. Hence, suitable provisions should be made in the future maintenance plans and monitoring schemes for timely identification and rectification of the defects should their telltale signs become noticeable.

258. Secondly, as described in *paragraphs 97, 103, 291* and *294* of this report, detailed proposals in dealing with water seepage, corrosion, long-term monitoring, and additional undertaking of quality assurance from MTRCL are yet to be finalized. MTRCL and HyD should speed up the required follow-up actions.

259. Thirdly, in connection with the code-compliant analysis and proposed *suitable measures*, BD's checking of the compliance with the Concrete Code was completed. However, HyD's checking of the compliance with the additional requirements[109] of the NWDSM was still in progress at the time of preparation of this report. The EA Team would iterate the importance of timely completion of the checking. Separately, EA Team's observations on the lessons learnt and areas for improvement in design checking are given in *paragraphs 355* to *369* in ***Section 7***.

[109] For example, seismic design and design life of 120 years, which are required by the NWDSM but not covered by the Concrete Code.

Third Issue – Dealing with Contract Compliance

260. The *Third Issue* on whether the completed works are in accordance with the contractual requirements based on the Entrustment Agreements was not explicitly addressed in the Holistic Assessment and Verification Study, nor in the Inquiry. Clearly, none of these are intended to be a forum for deliberation of contractual liability.

261. However, the investigation conducted as part of the Holistic Assessment and Verification Study has confirmed the physical presence of a multitude of construction irregularities, which were not in compliance with the works specifications.

262. The following conclusions were given in the *Holistic Report* concerning the unsatisfactory workmanship and need for *suitable measures* to address concern about the structural integrity arising from the deficiencies:

> *"Stage 1 Desktop Exercise and Stage 2 Physical Investigation were completed in December 2018 and June 2019 respectively. These identified a number of defects, such as insufficient engagement length for a number of reinforcement couplers, deficiencies in the concrete quality and shear link placement. An assessment of the results would suggest these issues were due to unsatisfactory workmanship which was not identified during supervision and inspection of the construction works."*[110]

> *"Suitable measures including structural modifications and remedial works are proposed to address the deficiencies identified in Stage 2, including defective coupler connections, honeycombing, gaps between wall/column/ hanger wall and slab, localised unconnected couplers identified in some of the gaps, shear link defects, rusting of coupler connections, water seepage and workmanship issues in horizontal*

[110] See paragraph 5.1 of the *Holistic Report*

construction joints between the EWL slab and D-wall area."[111]

263. In the Final Report of the Commission, upon stating *"the Commission is fully satisfied that, with the suitable measures in place, the station box structure will be safe and also fit for purpose"*, it was asserted that *"The Commission at all times recognised, however, that there had been failures in respect of the construction process."*[112] In this regard, it said:

> *"In coming to this determination, however, the Commission recognises that in a number of respects, in the course of construction of the station box structure, there were unacceptable incidents of poor workmanship on site compounded by lax supervision and that in a number of respects also, management of the construction endeavour fell below the standards of reasonable competence."*[113]

264. These alluded to the question about the compliance of the built structures with the contractual requirements.

265. The *suitable measures* proposed in the *Holistic Report* and *Verification Report* are aimed at ensuring code compliance. As described in *paragraphs 245 to 251* above, even with the implementation of the required *suitable measures*, restrictions and precautionary arrangements would still have to be put in place in future. Furthermore, the completed structures would have a reduced reserve of structural capacity, as compared with that which should be available in the *Original Design* and in the design of the other SCL stations. In other words, even with the implementation of the *suitable measures* that were required for code compliance, there remains the question about compliance with the requirements of the Entrustment Agreements.

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[111] See paragraph 5.3 of the *Holistic Report*

[112] See paragraphs 21 and 22 of the Executive Summary of the Final Report

[113] See paragraph 415 of the Final Report

266. The gap between the completed structures and the requirements under the Entrustment Agreements is apparent. However, examination of the extent and degree of the possible discrepancies is outside the remit of the EA Team. This is a matter for the Government to follow up with MTRCL.

Section 5 Long-term Monitoring

Background

267. Hitherto, the term "*monitoring*" has primarily been taken as referring to the use of sophisticated instruments for measuring, tracking and observing the performance or responses, such as ground movement and structural deformation. In this report, "*monitoring*" refers to a broader range of actions, such as inspections, measurement, surveys and surveillance, for monitoring purposes. In this context, "*long-term monitoring*" herein denotes these kinds of provisions to be made in the long term for monitoring the ongoing integrity, durability and reliability of the built structures in the Hung Hom Site.

268. MTRCL first reported in its *Holistic Proposal* of December 2018 that "*the EWL slab is currently being monitored for any sign of movement by an Automatic Deformation Monitoring System (ADMS). As part of the holistic study for the EWL and NSL slabs and the D-walls, a long-term instrumentation & monitoring programme of the structure would be proposed based on the results of the above staged investigation. Attention will be paid to the measurement of small structural strains and deformation.*"[114]

269. In the Interim Report of the Commission dated February 2019, the Commission "*recommends ongoing monitoring of the station structure during operation of the station, so as to provide reassurance to the public. However, the Commission notes the advice it has received that it is unlikely that any significant movement will occur*."[115]

270. It was then stated in MTRCL's Holistic Report of July 2019 that "*As part of the suitable measures, a long-term structural monitoring scheme including instrumentation and inspection will be developed to monitor the ongoing structural integrity of the structure*."[116]

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[114] See paragraph 8.1 of the *Holistic Proposal*

[115] See paragraph 391 of the Interim Report of the Commission

[116] See paragraph 4.1.9 of the *Holistic Report*

271. In its Final Report of March 2020, the Commission recommended that "*regular visual inspections should take place in order to monitor those areas in the station with the highest assessed stress levels. The monitoring should take the form of a planned preventive inspection regime, a regime that should be in existence for an extended period, perhaps five years*."[117]

Monitoring by Sensitive Instruments

272. Sensitive instruments are available for monitoring of minute deformation (e.g. fibre optic sensors for small strain measurement) of engineering structures. Electronic sensors with automatic data loggers and remote data transmission are normally adopted, which helps overcome difficulty in accessing concealed or inconvenient locations. These have been successfully used in monitoring, and further advances are being made in both the research and application aspects. However, their successful application hinges not only on the resolution of the instruments but also other factors, such as the nature and magnitude of the structural behavior to be monitored, robustness of the monitoring system and response plan, and recognition and management of possible false alarms.

273. In this respect, the EA Team shares the views of the Commission in paragraph 419 of its Final Report that "*should such instrumentation be installed, there is a real problem that – being highly sensitive, including a proclivity to be triggered by 'noise' factors – it may set off false alarms*." Such instruments should be used with caution, and in circumstances where they could serve the purpose.

Monitoring in Broader Sense

274. It is normal practice to conduct regular monitoring of an important engineering structure throughout its service life. Such monitoring provides useful information for evaluating the performance of structure, assessing its structural condition and identifying any necessary routine maintenance, preventive maintenance and repair works for upkeeping the

[117] See paragraph 420 of the Final Report

condition of the structure. Depending on such factors as the nature of the structure and its operational environment, the monitoring may include inspections, measurement, surveys and surveillance. This may or may not require the use of sensitive instruments.

Scope of Long-term Monitoring in Hung Hom Site

275. Such regular monitoring will be undertaken by MTRCL in the Hung Hom Site, as would MTRCL do so in other stations. Given the particular circumstances of the Hung Hom Site, the long-term monitoring should address the following specific aspects, in addition to the normal scope of the regular monitoring programme:

(a) restrictions and precautionary arrangements associated with the *Updated Design*;

(b) potential concerns in long-term performance and durability of built structures; and

(c) supplementary provisions for other irregularities.

Restrictions and precautionary arrangements associated with Updated Design

276. In adopting the *Updated Design* in the structural assessment and determination of the required remedial works, some of the changes in design criteria from the *Original Design* involve restrictions and precautionary arrangements to be put in place in the future use of the station. The restrictions and precautionary arrangements known at the time of preparation of the *Holistic Report* are summarized in Table 5 of the Report (see ***Appendix 4-2***). The long-term monitoring should include provisions for checking whether the restriction and precautionary arrangements are observed, ascertaining the validity of the relevant changes in design considerations under the *Updated Design*, and identifying any necessary follow-up actions if there is a cause for concern. For instance, Item 8 of Table 5 of the *Holistic Report* states that "*Groundwater and loading*

conditions, say arising from future construction works in the vicinity of the site, will be controlled accordingly. Long term monitoring scheme to be further developed."

277. This aspect should be addressed by MTRCL through suitable provisions in the long-term monitoring programme. This may include, among other provisions, standard instrumentation and monitoring measures (e.g. continuous groundwater monitoring using pneumatic piezometers).

Potential concerns in long-term performance and durability of built structures

278. To address the construction defects, *suitable measures* are carried out by MTRCL with a view to complying with the applicable codes. However, even with the detailed review and comprehensive assessment carried out, it is inevitable that some potential concerns may remain in the long-term performance and durability of the built structures. Such concerns could arise from a number of areas.

279. First, given the deficiencies in construction control and record-keeping, and in view of the limitation of the retrospective review and assessment, uncertainties exist both in what is actually constructed and in the quality of the construction of the built structures.

280. Second, it is known from the Holistic Assessment that some of the works did not comply with the required specifications (e.g. coupler connections) and established engineering good practice in detailing (e.g. reinforcement details). Also, other defects, such as inadequate concrete cover and excessive water seepage, were found. While compensatory provisions for compliance with the applicable codes have been made through the agreed *suitable measures*, it is not known whether the long-term performance and durability of the structures may still be adversely affected.

281. Thirdly, as noted in *paragraph 257* in ***Section 4***, MTRCL could only carry out remedial works at locations where the defects and their locations were known. The possibility remains that similar or other types of defects may be present elsewhere in the structures but at unknown locations. Hence, suitable provisions should be made in the future maintenance plans and monitoring schemes, for timely identification and rectification of the defects should their telltale signs become noticeable.

282. Fourthly, the EA Team noted that both independent structural experts appointed by the Government (Prof Francis Au and Dr James Lau) had expressed major reservation about the structural integrity and long-term durability (e.g. possible concrete cracking issues) of the connection between the EWL slab and the east D-wall (see *paragraph 90* in ***Section 3***). While some prescriptive strengthening works were carried out, given the concern of the experts, the EA Team had recommended HyD to carry out further analysis in consultation with the experts. This is a technically complex subject for conventional engineering analysis. In case of unresolved concerns, it may be prudent to include suitable provisions in the long-term monitoring for addressing the concerns.

283. Indeed, Dr James Lau has recently advised HyD in the course of design checking that the finite element analyses conducted so far were still unsatisfactory and he remained concerned about the likelihood of development of tension cracks on the top and outside faces of the D-walls. These cracks are subjected to fluctuating groundwater conditions. There is a possibility of corrosion and long-term durability problem. He opined that this should be addressed in the long-term monitoring programme. The monitoring should include provisions to look for signs of water seepage and corrosion in the relevant parts of the HUH Extension structure.

284. In this respect, the EA Team suggests that a list of the potential concerns should be identified and drawn up by MTRCL for agreement with the Government, so that suitable provisions are made in the long-term monitoring to address the concerns. In particular, attention should be given to the more vulnerable parts of the structures, based on consideration of the degree of utilization of the structural capacity, the known extent and

nature of the construction deficiencies, the degree of uncertainty in the built quality, the sensitivity of the long-term structural performance and durability to such uncertainties, etc.

285. Apart from the long-term performance and durability of the connection between the EWL slab and the east D-wall, water seepage and corrosion problems[118] are other examples of such potential concerns to be listed and addressed in the long-term monitoring. In connection with the concern about water seepage, it is stated in the *Holistic Report* that "*At locations where water infiltration and water seepage are of concern, it is recommended to carry out grouting or other water seepage prevention measures with continuously monitoring for the water seepage condition. Detailed proposals will be submitted to the Government*."[119]

286. The material expert commissioned by MTRCL also advised in his investigation report on corrosion that "*to ensure that no further rusting would take place in the future, the couplers should not be left immersed in any water ponds, and some grouting or other water seepage prevention measures should be conducted to minimize/control ingress of water flow into the concrete panels and ensure no water flow into the couplers*."[120]

287. HyD should also seek advice from its independent structural experts in compiling the list of potential concerns and in deliberating suitable provisions for addressing these concerns in the long-term monitoring.

Supplementary provisions for other irregularities

288. The built structures in the Hung Hom Site were thwarted by some other irregularities, e.g. missing records and deficient RISC forms, aside the construction defects. These irregularities may be dealt with through

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[118] See *paragraphs 91* to *104* in ***Section 3***

[119] See paragraph 3.6.18 of the *Holistic Report*

[120] See paragraph 3.4 of "Investigation Report on Apparent Corrosion found on Rebars Embedded into Coupler Shatin to Central Link Hung Hom Station Extension" dated 4 June 2019 by Ir Dr Eric C.H. Lim

a suite of follow-up measures, for remedy of the deficiencies due to the irregularities and for resolution of the relevant compliance and contractual requirements. Inclusion of suitable provisions in the long-term monitoring may be a pragmatic and effective follow-up measure to cater for some of the irregularities. Such provisions may include more frequent and detailed inspections of the elements in question, expanded scope of maintenance, extended maintenance period and additional preventive maintenance works, etc.

Personnel Involved in Conducting Long-term Monitoring

289. Given the particular circumstances of the Hung Hom Site and the role of the long-term monitoring programme as part of the *suitable measures* for dealing with the irregularities and uncertainty, it is imperative that the personnel involved in conducting the long-term monitoring for MTRCL should be of sufficient knowledge and experience in the work.

290. Likewise, it is recommended that HyD should enlist independent and experienced experts in vetting the long-term monitoring submitted by MTRCL and in reviewing the required follow-up actions. The experts should also provide HyD with advice on any changes required to the long-term monitoring provisions in the light of the findings of the monitoring.

Additional Quality Assurance

291. As a side note, in addition to the long-term monitoring, MTRCL has undertaken to explore options for providing the Government with additional undertaking of quality assurance for the built structures in the Hung Hom Site.[121] The scope and details of the additional quality assurance provisions may be related to, and thereby should be deliberated in connection with, the arrangement for the long-term monitoring.

[121] See paragraphs 4.4.13 and 5.7 of the *Holistic Report*

Latest Situation

292. The EA Team has conveyed the above advice on long-term monitoring to MTRCL via HyD since early June 2020 for their consideration.

293. Subsequently, MTRCL submitted draft technical proposals for long-term monitoring for the Hung Hom Site to HyD on 31 July 2020 and 31 August 2020. Dialogues are being held between HyD and MTRCL on the contents of the draft technical proposal. No conclusion has been reached in finalizing the long-term monitoring programme at the time of writing this report.

294. It is recommended that MTRCL and HyD should finalize the programme and details of the long-term monitoring for implementation, with account taken of the relevant considerations given in this Section.

Section 6 Spare Capacity in Design

Puzzle

295. The issues about the safety, code-compliant and contractual aspects of the built structures in the Hung Hom Site were addressed in ***Section 4***. Some related matters deserve further deliberation.

296. One of these concerns the puzzle about why the structures in the Hung Hom Site with a host of construction irregularities could be reasoned as *safe and fit for purpose* as it stood. In this connection, one may also query why the structures could be retrofitted to code-compliant through structural strengthening works, without calling for large-scale remediation or re-construction.

297. In EA Team's view, the clue to the puzzle involves two factors. First, the spare capacity in the *Original Design* of the structures. Second, the changes in design criteria adopted in the *Updated Design*. This in turn brings about the question of whether the spare capacity in the *Original Design* was excessive, be it arising from the code requirements being overly conservative or over-provision on top of the code requirements.

Factor No. 1 – Spare Capacity in Original Design

298. Back in the Original Inquiry, the Commission received expert advice on the redundancy, i.e. spare capacity, of the HUH Extension structure, as follows:

> *"… the design of the EWL and NSL slabs was 'conservative' and provided a high degree of under-utilisation as compared to that required to properly withstand the loads incurred by the structure. The experts also referred to this under-utilisation as 'redundancy' or 'spare capacity'. In layman's terms, these descriptions demonstrate that the structure has been specifically designed so as to increase its structural reliability. In this regard, for example Atkins, Ove Arup and*

> *COWI all agreed that there is* ***at least 40% spare capacity***[122] *at the top mat of the EWL slab at the connection with the* diaphragm wall."[123] **[Emphasis added]**

299. The experts of MTRCL and Leighton both came to the conclusion of the safety of the structure based on its ample spare capacity:

> *"It is evident so far as I am concerned that the structure of the station box has large degrees of redundancy and robustness and, consequently, a comfortable margin of safety which supports my opinion that the structure is safe for its intended lifespan."*[124]

> *"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."*[125]

300. The main rebars at the top mat of the EWL slab at its connection with the D-wall were required to provide tensile resistance for withstanding the bending moment at this location. This was a critical location in the structural design. As discussed earlier in ***Section 4***, the Government's expert held different views about the approach for assessing whether the structure was *safe and fit for purpose* in the Inquiry. Notwithstanding this, there was no dispute that redundancy in the rebars at the top mat of the EWL slab would result in spare structural capacity. This would help

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[122] As the expert advice was given in the Original Inquiry, the "40% spare capacity" was the redundancy over and above the code requirements under the *Original Design*, and not under the *Updated Design*. The hearing in the Original Inquiry was held from October 2018 to January 2019. The term *Updated Design* was first adopted in the Holistic Report issued in July 2019.

[123] See paragraph 353 of the Final Report

[124] See paragraph 8.10 of Dr Glover's expert report dated 7 January 2019 discussed in the Original Inquiry

[125] See page 6 of Mr Southward's expert report dated 7 January 2019 discussed in the Original Inquiry

compensate the structure for some, if not all, of the reduced structural capacity arising from irregularities in the coupler connections.

301. The EA Team was not provided with the details about how the "*at least 40% spare capacity at the top mat of the EWL slab at the connection with the diaphragm wall*" (see *paragraph 298* above) was derived. However, the EA Team considered that 40% spare structural capacity, if available, was indeed a significant amount. From EA Team's experience, it is uncommon that such a significant spare capacity is provided at critical locations (e.g. with maximum calculated bending moment) in structural design.

Factor No. 2 – Revised Design Criteria in Updated Design

302. Apart from the available spare capacity in the *Original Design*, the changes in design criteria in the *Updated Design* have also helped the structures meet the code requirements with less extensive remedial works. It was with the combination of the spare capacity in the *Original Design* and the changes in design criteria in the *Updated Design* that some parts of the built structures were found to be code-complaint without the need for remedial works, despite the reduced structural capacity due to construction irregularities. At other parts of the structures not complying with the code requirements, the required remedial works were determined in the Holistic Assessment with account taken of the spare capacity in the *Original Design* and the changes in design criteria in the *Updated Design*.

303. In this regard, the Commission noted the reduction of the remedial works required for code compliance under the *Updated Design* scenario:

> *"The extent of the required extra construction works – the '**suitable measures**', as they were called – **were materially reduced** from those that had been originally determined. The decision to reduce the extent of the works lay in the decision to base calculations on a set of revised design assumptions. The revised criteria, it was decided, complied*

with MTRCL's 'New Works Design Standard Manual' ('NWDSM') and also met the requirements of the Code."[126]
[Emphasis added]

Contribution of the Two Factors

304. It was evident from the Holistic Assessment that, for code compliance purpose, the available spare capacity in the *Original Desig*n alone was not sufficient in some parts of the structures to cover the reduced structural capacity due to the construction irregularities. Otherwise, remedial works to the structures as included in the proposed *suitable measures* would not have been required for code compliance.

305. The EA Team did not directly take part in the detailed structural analysis, nor in Government's checking of the analysis, in the Holistic Assessment. After completion of the Holistic Assessment, the EA Team has made an attempt to spot-check the *Original Design* of the EWL slab at four selected locations at its connection with the D-wall. Two of these are located in Area A, while the other two are in Area B and C.

306. MTRCL and its DDC i.e. Atkins, provided information and assisted in the spot-check. They also advised that the four selected locations, in terms of the available spare capacity at the connection between the EWL slab and D-wall, were reasonably representative.

Findings of spot-check

307. The findings of the spot-check are summarized in ***Appendix 6-1***.

308. From the spot-check, the spare capacity in the top mat in Areas B and C, where no remedial works were assessed to be required for code compliance, was found to be at least 40%. The findings indicated that a significant spare capacity could indeed be generally available in the *Original Design* at the connection between the EWL slab and D-wall.

[126] See paragraph 51 of the Executive Summary of the Final Report

309. However, the available spare capacity might only be marginal at other parts of the EWL slab. For instance, the spare capacity in the top mat in Area A, where remedial works were found necessary for code compliance, was found to be 10%.[127] This suggested the possibility that the significant spare capacity was not consistently provided throughout the whole stretch of the connection of between the EWL slab and D-wall. Apparently, the notion "*there is at least 40% spare capacity at the top mat of the EWL slab at the connection with the diaphragm wall*" (see *paragraph 298* above) might apply to the majority, but not to all, of the rebars at the top mat of the EWL slab.

310. The changes in design criteria in the *Update Design* has helped reduce the extent of the remedial works required for rendering the structures in compliance with the code. MTRCL has indicated that the remedial works required under the *Updated Design* are "*less than those identified using the original design*."[128] As MTRCL had not disclosed the relevant details in the *Holistic Report*, the exact extent of the reduction was not known to the EA Team. However, the EA Team believed that the reduction would not be small, in view of the adoption of a maximum 30% moment redistribution together with reduced load limits in the *Updated Design*.

311. As the NSL slab was not covered in the spot-check, the EA Team did not have data at hand on the NSL slab for validation. From the Holistic Assessment, it was found that no remedial works were required at the connection between the NSL slab and D-wall for code compliance, despite the significant irregularities in the coupler connections. This suggested the likelihood that a significant spare capacity was present in the *Original Design* of the NSL slab at its connection with the D-wall, possibly similar to the circumstances in Areas B and C of the EWL slab.

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[127] See Table 6-1-1 (a) of ***Appendix 6-1***

[128] See paragraph 4.3.2 of the *Holistic Report*

Over-provision in Design

312. In the *Original Design*, at the connection between the EWL slab and the D-wall, there was significant spare capacity not only in the rebars at the top mat, but also at the bottom mat. There is a question about whether the significant spare capacity in the top and bottom mats of the EWL slab was due to the code requirements being overly conservative, or due to designer's conservative provision over and above the code requirements.

Rebars at top mat of EWL slab

313. The "*at least 40% spare capacity at the top mat of the EWL slab at the connection with the diaphragm wall*" as reported by the experts in the Original Enquiry is probably attributed to over-provision in the *Original Design*. It tallies with the findings of the spot-check that this spare capacity was provided over and above the code requirements. Hence, the spare capacity was the designer's conservative provision (i.e. over-provision) on top of the code requirements, and was irrelevant to any conservatism in the code requirements.

314. Over-provision of 40% in a finalized design is significant.[129] The EA Team could not find any justifiable reasons from MTRCL that called for this conservative provision, which was in excess of the code requirements when the design was finalized for acceptance and tendering.

Rebars at bottom mat of EWL slab

315. At the connection between the EWL slab and D-wall, the main rebars in the bottom mat are not required for providing structural resistance against the design loading conditions. However, requirements are given in the Concrete Code about the minimum amount of rebars to be provided in the bottom mat, in line with the good practice in design for ductility and detailing.

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[129] The *Original Design* of the HUH Extension structure was the finalized design, which was accepted by the BA. The proposed works based on the *Original Design* were shown in the accepted drawings for tendering and construction.

316. In the spot-check, the EA Team noticed some ambiguities in the interpretation of the requirements relating to whether the connection between the EWL slab and the D-wall should be designed as a *beam-column* connection or a *slab-wall* connection.

317. It was agreed among all the independent experts who testified to the Commission that, to comply with the code requirements, at least 50% of the amount of the rebars required in the top mat of the EWL slab should be provided at the bottom mat. This 50% requirement was brought up by the experts in the Original Inquiry, as recorded in the Final Report:

> *"The Commission was advised by the experts that, in order to* ***comply with the Code****, the amount of reinforcement steel in the bottom of the EWL slab needed to be at least equivalent to 50% of the reinforcement steel in the top of the slab."*[130]
> **[Emphasis added]**

318. This arises from the detailing requirements specified in the Concrete Code on the main rebars to be provided in the bottom mat at the connection between the EWL slab and the D-wall, based on the consideration that this is a *beam-column* connection.[131] From the spot-check, it was found that the over-provision on top of this requirement was substantial, i.e. 225% and 467% in the bottom mat at the connection in Areas B and C respectively.[132] The over-provision was irrelevant to any conservatism in the code requirements.

319. As in the case at the top mat, the EA Team once again could not find any justifiable reasons from MTRCL that called for the conservative provision of the rebars at the bottom mat, which was significantly over and above the code requirements.

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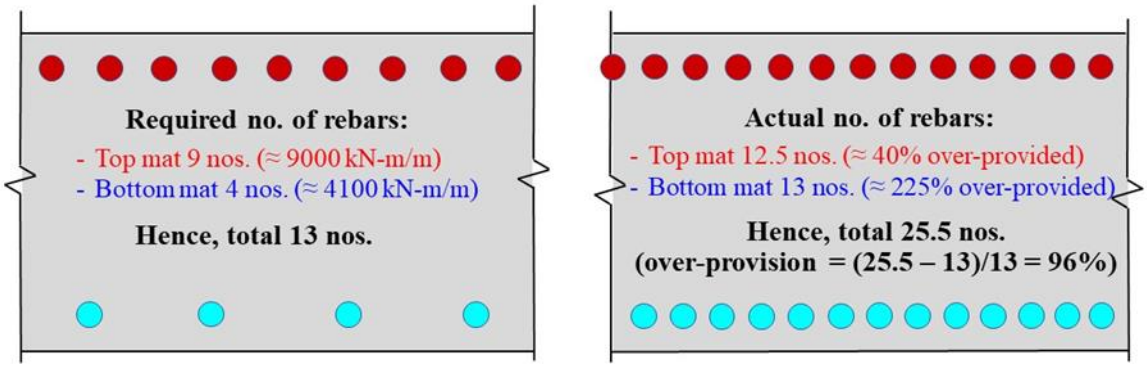
130 See paragraph 331 of the Final Report

131 See paragraphs 15 to 20 of ***Appendix 6-1*** for further discussion about this matter, including the views given by the independent experts to the Commission

132 See Table 6-1-1 (b) of ***Appendix 6-1***

Diagrammatic illustration

320. A diagrammatic illustration of the code's requirements versus the actual provision of the main rebars at the connection between the EWL slab and D-wall is shown in ***Figure 6-1***.[133] In this example, the net over-provision was 96%, i.e. the actual provision is almost twice as much as that required by the code.



(a) Code requirements ***(b) Actual provision***

Figure 6-1 Diagrammatic illustration of over-provision in excess of Code's requirements at the connection between EWL slab and D-wall

Implications of over-provision

321. As codes are stipulating the minimum requirements for meeting the recommended standard of good practice, it is not unusual for the actual design to include some conservative provisions exceeding the minimum code requirements. Normally, such conservative provisions are made through the adoption of more stringent design loads or material parameters, to cater for the particular circumstances of the case. It is uncommon that, upon finalizing the design loads and material parameters to be adopted in the design, the actual amount of rebars being provided is so significantly over and above that found to be required from the design analysis.

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[133] This diagrammatic illustration is based on the findings of the selected spot-check location at Grid Line 19 of Area B, see Tables 6-1-1(a) & (b) of ***Appendix 6-1***. To satisfy the code requirements, 9 nos. of rebars (which represent 9,000 kN-m/m) are required at the top mat as tension reinforcement and 4 nos. of rebars (which represent 4,100 kN-m/m) at the bottom mat due to detailing requirements. In the actual provision, the rebars at the top mat and bottom mat are over-provided by 40% and 225%, respectively. The net over-provision over above the code requirements is 96% i.e. (25.5 – 13) / 13.

322. The design intent of providing the structures with the significant spare capacity is unclear. Furthermore, as discussed in *paragraph 309* above, the spare capacity was not consistently provided at all parts of the EWL slab. Hence, there is a possibility that the significant spare capacity may simply be an inadvertent "over-provision", rather than a deliberate "conservative design". Furthermore, it appears that the detailing of rebars in the design has not generally followed the good practice for curtailment of the main rebars in the top and bottom mats. This might have aggravated the over-provision of the main rebars.

323. Incidentally, the over-provision of the rebars at the EWL and NSL slabs has helped reduce the adverse consequences of the construction irregularities. However, as the presence of the irregularities would not have been foreseen in the design stage, it should not have been the design intent to introduce the significant over-provision to cater for the irregularities.

324. The over-provision has cost implications. In the present case, perhaps of even greater practical concern, it adversely affected buildability. Congestion of rebars at the top and bottom mats of the EWL and NSL slabs had resulted in construction difficulty in rebar fixing, connection of couplers and concreting. The significant over-provision of rebars could have aggravated the difficulty.

325. The concern about buildability and cost-effectiveness will be addressed in ***Section 7*** of this report. Relating to the issue of over-provision in design, it is recommended that MTRCL should review and improve its prevailing design practice and checking provisions, so as to avoid overly conservative design and ensure proper detailing following the good practice given in the design codes.

Is the Concrete Code Overly Conservative?

326. The over-provision in excess of the code requirements, which resulted in the significant spare capacity, was discussed in the previous paragraphs. To wrap up the discussion of the spare capacity in design, the

question about whether or not the Concrete Code is overly conservative, is addressed.

327. The focal point of the question, as raised in the Inquiry, rested in the detailing requirements specified in the Concrete Code for 50% of the required main rebars in the top mat to be provided at the bottom mat in the EWL slab at its connection with the D-wall. This matter was brought up by the experts in the Original Inquiry, in connection with whether the HUH Extension structure is *safe and fit for purpose*.

Detailing requirements for rebars at bottom mat

328. It is evident from structural analysis that the main rebars in the bottom mat of the EWL slab at its connection with the D-wall are not required for directly providing structural resistance for withstanding the design loading conditions. The consensus among the experts on this was recorded in the Final Report as follows:

> *"All agreed that, irrespective of the code requirement the EWL slab does not, in theory, rely on steel at the interface, at the bottom, for flexure and shear capacity."*[134]

329. In this regard, some of the experts opined that there was no need to consider the main rebars at this location in evaluating whether the HUH Extension structure was *safe and fit for purpose*. The Government expert, however, held different views. In his submission to the Original Inquiry, he stated that:

> *"Whilst the provision of flexural strength for hogging moment at the EWL slab adjacent to the connection between the EWL slab and the east diaphragm wall (the slab-wall joint) does not necessarily require bottom reinforcement, provision of bottom reinforcement is a mandatory requirement under the Code of Practice for Structural Use of Concrete 2004, Second Edition (Buildings Department 2004) (the Concrete*

[134] See paragraph 335 of the Final Report

> *Code) [H8/2818-H8/3015] and it still helps to ensure ductility, serviceability, etc. Therefore, the proper connection of the bottom reinforcement of the EWL slab to the diaphragm wall by way of mechanical couplers was required and would also serve useful purposes."*[135]

330. In gist, this 50% requirement, which is specified in the Concrete Code, is not intended for directly resisting the calculated bending moment or shear force under the design loading conditions. Instead, the rebars are required for enhancing the ductility and robustness of the structure, which is prudent for ensuring structural integrity and preventing uncontrolled collapse in accidental conditions.

331. This principle is well accepted by the engineering profession. The requirement is incorporated in the Concrete Code, as well as in similar codes elsewhere, as part of the recommended good practice. The EA Team understood that the difference in opinion among the experts on this matter in the Inquiry hinged not on the structural engineering principle, but on whether this provision is essential to evaluating *safe and fit for purpose*.

332. Setting the *safe and fit for purpose* evaluation aside, the EA Team believed that this requirement was consistent with the consensus among the profession about the good practice to adopt in structural design and detailing.

333. As to whether the provision of rebars should be set at a minimum level of 50%, this is a matter of technical details. After all, the significant spare capacity in the bottom mat at the connection between the EWL slab and D-wall, which is in excess of the code requirements, was unrelated to any conservatism in the code requirements.

[135] See paragraph 3.1.1 of Prof Francis AU's expert report dated 7 January 2019

Other aspects of the Concrete Code

334. The EA Team had not studied whether the other aspects of the requirements of the Concrete Code were overly conservative. It was noteworthy that the Concrete Code was prepared by BD jointly with the engineering profession, after extensive consultation. The code stipulates the recommended good practice as agreed among the profession. Account was taken of the practices in other places, and overall, the requirements of the Concrete Code are similar to those of the state-of-the-art practice elsewhere.

335. The Concrete Code was first published in 1987. The current version was updated and published in 2013, with further amendments made in 2017. As in the case of other engineering standards and codes of practice, the Concrete Code has been updated from time to time to incorporate the experience gained.

Section 7 Design and Checking

Issues Relating to Design and Checking of Design

336. The design issues, such as code compliance and spare capacity, of the built structures in the Hung Hom Site are addressed in ***Section 6***. Further discussions of the lessons learnt and areas for improvement in the design and checking of design are given in this Section. These cover the following areas:

(a) avoiding conflict of interest;

(b) plugging gap in Government's design checking;

(c) gearing up for seismic design;

(d) using couplers judiciously; and

(e) ensuring cost-effectiveness in design.

Avoiding Conflict of Interest

Potential conflict of interest in the SCL Project

337. In the early stage of EA Team's participation in the review of the SCL Project, the EA Team noted that Atkins, MTRCL's DDC was also engaged by the contractor as the design consultant for the HUH Extension structure under Contract 1112. Atkins served the contractor in designing the site works, including changes to MTRCL's engineering design (which was originally designed by Atkins). Atkins, being also the DDC of MTRCL, was also responsible for checking the contractor's design (which was prepared by Atkins).

338. The EA Team was concerned about the potential conflict of interest, either actual or perceived, under such an arrangement. The EA Team considered that this should be avoided, particularly in the Hung Hom

Site, where irregularities were to be dealt with and sensitive liability and public perception issues were involved. Likewise, MTRCL should also examine whether similar circumstances might exist in the other sites of the SCL Project.

339. Hence, in its Interim Report issued on 19 October 2018, the EA Team recorded one of its preliminary recommendations as follows:

> *"The EA Team recommends that MTRCL examine whether their consultants or other service providers in the Hung Hom Station Extension and in other sites of the SCL Project may have potential conflict of interest, either actual or perceived, and take any necessary actions to ensure that this will not adversely affect, or may be perceived to adversely affect, the management and delivery of the SCL Project."*[136]

340. The potential conflict of interest that might arise from the dual role of Atkins in the Hung Hom Site could be illustrated by a case, with the relevant details examined in the Commission's hearings. The case involved two changes[137] to the design and construction details that were made by the contractor at the top of the east D-wall during construction. Atkins prepared the detailed design for the HUH Extension structure for MTRCL. The design included, among other aspects, the structural connection of the EWL slab with the top of the east D-wall. During construction, the contractor made the two changes, which involved alteration of the steel reinforcement provisions at the connection between the EWL slab and east D-wall and trimming down of the top portion of the east D-wall. At the time, Atkins was aware of and agreed with the changes.

341. Atkins, in its role as the contractor's designer, was tasked to prepare design for the contractor to substantiate the acceptability of the changes. However, being also MTRCL's DDC, Atkins was responsible

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[136] See PR 2.10 of ***Appendix 2-1***

[137] The two changes, denoted as the First Change and Second Change, are described in Chapter 4 of the Final Report. See also *paragraph 86* in ***Section 3*** of this report.

for providing MTRCL with advice on the acceptability of the changes. Hence, there was a concern about the potential conflict of interest arising from the dual role of Atkins. Even worse, in this case, the two changes were made by the contractor on site without seeking the necessary agreement from MTRCL's design management team nor the BA.

342. Atkins relied on the deployment of two different design teams, viz. Team A working for MTRCL and Team B for the contractor, to address the concern about potential conflict of interest arising from their dual role in the Hung Hom Site. However, it transpired that the arrangement was not robust. In this regard, the following were recorded by the Commission in its Final Report:

> *"During the course of the hearings, it was initially asserted that Atkins kept both teams independent of each other with no conflict of interest. However, both the project director and design team leader were the same persons for Team A and Team B. More than that, Justin Taylor, Leighton's Risk Manager / Revenue Recovery Manager, said that, as he saw it, the same people at Atkins were handling the work for MTRCL and Leighton and there was no practical difference in the teams. In the end, John Blackwood, Director of Transport of Atkins, accepted that "in retrospect, it probably would have been better to have totally separate people [in two teams]."*[138]

343. The Commission noted the opinion of its independent project management expert, Mr Rowsell, as follows:

> *"As pointed out by Mr Rowsell, with Team A and Team B under the same leadership, there was the risk that Team A may be reluctant to identify faults in designs approved by Team B or may not review submissions from Team B as thoroughly as they might otherwise have done."*[139]

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138 See paragraph 636 of the Final Report

139 See paragraph 637 of the Final Report

344. The Commission concluded its views as follows:

> *"The Commission is of the view that it is not good practice for the same design firm to provide services both to the employer, in this case MTRCL, and the contractor, in this case Leighton. As illustrated, such an arrangement carries with it the immediate potential of both real and perceived conflict of interest."*[140]

Follow-up actions taken by MTRCL

345. MTRCL has been looking into possible improvements to make in response to the recommendations from the EA Team and the Commission concerning avoidance of conflict of interest. The following were recorded in the May 2020 report of the Independent Audit Panel:

> *"MTRCL reported that it had corporate-level documentation in place to guard against conflict of interest. In general, the same design consultant would not be employed by MTRCL and its contractor to work on the same contract. In* ***exceptional circumstances*** *where there is an* ***advantage to the safe and efficient production of designs*** *(as in Contract 1123 where the same consultant has, since January 2015, been designing both permanent and temporary works for MTRCL and its contractor respectively), MTRCL has introduced a procedure which clearly defines and separates the workflows of the respective consultant teams. By so doing, all communications must route through the teams of MTRCL and the contractor on site to provide a meaningful and effective firewall. Team membership must be subject to approval to ensure that the same staff are not working for both teams."*[141] **[Emphasis added]**

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[140] See paragraph 638 of the Final Report

[141] See paragraph 88 of the May 2020 report of the Independent Audit Panel. The Independent Audit Panel was set up by the Government to review whether the recommendations by the Commission in the Inquiry have been duly implemented. The Panel prepared a report in May 2020, on its review of the implementation of the recommendations made in the Commission's Interim Report of February 2019 following the Original inquiry.

346. In order to find out more about the corporate-level documentation mentioned in *paragraph 345* above, the EA Team had requested for further information from MTRCL such as the relevance of the corporate-level documentation on the subject case, scope of services and selection processes of the design consultant in Contract 1123 of the SCL Project. The EA Team was concerned about the consideration taken for Contract 1123 to fall into the "*exceptional circumstances where there is an advantage to the safe and efficient production of designs*", given that the nature of works in Contract 1123 was apparently typical of that in many other SCL station sites. However, detailed information was not received at the time of preparation of this report. Under the circumstances, the EA Team would like to caution that the "*exceptional circumstances*" should only apply to cases which are truly "*exceptional*". Otherwise, "*exception*" would become the norm as many other cases may well be also taken as "*exceptional*" based on the same yardstick.

347. MTRCL has made provisions to strengthen the firewall in the ongoing case of Contract 1123, in which the same design consultant was employed by MTRCL and the contractor. However, the EA Team would caution against overconfidence in the reliability and effectiveness of the firewall. Even if the firewall does help reduce the actual or potential conflict of interest, its efficacy against perceived conflict of interest remains in question.

348. This aside, after putting in place a strong firewall, the two teams would effectively work as independent units, as if they were from different consulting firms. It is doubtful then whether there would remain such an overriding "*advantage to the safe and efficient production of designs*" that justifies the exceptional arrangement.

Government's requirement and practice

349. Avoidance of potential conflict of interest, actual or perceived, is vital in upholding the necessary checks and balances. In this respect, the following requirements are given in the Government's Stores and Procurement Regulations ("SPR"):

> *"Departments must be alert to the potential conflict of interest which may arise from the different roles or assignments a consulting firm or contractor may take up, whether in relation to the same project for which that consulting firm or contractor was or remains engaged by the Government in the first place, or other related projects."*[142]

350. It is stated in Clause 192 of the SPR that "*To ensure that Government receives from consulting firms objective professional advice which is not tailored or fashioned with regard to promoting that consulting firm's or its associate's products and/or services, and to maintain a level-playing field in the procedures for government procurement*", departments must undertake the following among other actions:

> *"debar the selected consulting firm and its associate(s) from participating in any subsequent exercise for the procurement arising out of or which was the very subject of the consultancy, save for the circumstances specified in SPR 194."*[143]

351. Following the requirements of Clause 192 of the SPR, a standard Special Conditions of Employment clause is given in the *Handbook on Selection, Appointment and Administration of Engineering and Associated Consultants* issued by the Civil Engineering Development Department, for incorporation into all consultancy agreements under the purview of the *Engineering & Associated Consultants Selection Board*.[144] This clause serves "*to debar the selected consultants from participating in any subsequent exercise for the procurement of any goods and/or services arising out of or which was the very subject of the Consultancy.*"[145]

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142 See Clause 190 of the SPR

143 Clause 194 of the SPR stipulates the actions to be taken by the department under the circumstanced that "*for reasons acceptable to the relevant consultants selection board, a department would not want to debar a firm which has acted as its consultant and/or the consultant's associates from participating in exercises for the procurement arising out of or which was the very subject of the consultancy*".

144 The Engineering & Associated Consultants Selection Board approves the selection and appointment of engineering and associated consultants for Government projects.

145 See paragraph 2 of Appendix 4.13 of the Handbook on Selection, Appointment and Administration of Engineering and Associated Consultants

352. This debar requirement has long been applied to engineering consultants appointed by Government departments, including HyD, for public works projects. The EA Team is not aware of any reports of notable negative impact of the requirement on the smooth delivery of public works projects.

353. Railway projects undertaken by MTRCL for the Government under entrustment arrangements are funded by public finance. It would be prudent for the established good practice for avoidance of conflict of interest in public works projects to be also adopted in Government-funded projects undertaken by MTRCL. It is recommended that HyD should look into this in future railway projects.

354. It is also recommended that MTRCL should consider adopting similar requirements for avoidance of conflict of interest in its own projects. In this connection, it is advisable for MTRCL to take concrete actions in more explicitly debarring its consultants from working for the contractor under the same contract, unless in circumstances that are truly exceptional due to other overriding considerations.

Plugging Gap in Government's Design Checking

Gap in checking

355. As described in ***Section 4***, in the Holistic Assessment and Verification Study, MTRCL carried out code-compliant analysis on the built structures in the Hung Hom Site following the principle and criteria agreed with the Government. Based on the findings of the analysis, the scope of the remedial works (i.e. *suitable measures*) proposed by MTRCL in the *Holistic Report* and *Verification Report* for the code compliance was accepted by the Government.

356. Following the finalization of the *Holistic Report* and *Verification Report*, MTRCL proceeded with the detailed engineering design and finalization of the exact extent and details of the required remedial works. The completed design was then submitted to the Government for checking.

As the Hung Hom Site falls under the remit of IoE, the design was submitted to the BA for regulatory checking.[146]

357. The BA, being the regulatory authority, is mandated to check the design in respect of compliance with the BO. MTRCL has adopted the Concrete Code for meeting the relevant requirements of the BO. Hence, the BA's checking was confined to compliance with the Concrete Code, which applies to buildings in general. As explained in *paragraphs 195* and *196* in ***Section 4***, the structures in the Hung Hom Site were designed to meet the requirements of the NWDSM, which not only embraces the Concrete Code but also contains additional design requirements pertinent to railway structures. This means that the structures, apart from complying with the statutory requirements for buildings under the BO, should also satisfy the NWDSM in order to meet the specific requirements for railway structures.

358. HyD has counted solely on the BA's regulatory checking, without making further arrangement for checking MTRCL's design for compliance with the additional NWDSM requirements. There has all along been a gap in Government's design checking, in that the compliance with the additional NWDSM requirements not included in the BO were not examined. Most notably, the performance of the structures under seismic condition (i.e. seismic design) which is specified in the NWDSM but not in the Concrete Code, was not attended to. Moreover, a design life of 120 years is stipulated in the NWDSM which is more stringent than the 50-year design life adopted in the Concrete Code.[147] This has been the case in the checking of the structural design in the Hung Hom Site since the beginning of the project.

359. EA Team's specific observations about seismic design are further addressed in *paragraphs 370 to 384* below.

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[146] The regulatory checking by the BA is done via a team of professional staff seconded from BD to HyD to handle matters relating to the IoE.

[147] See Clause 4.2.2.4 of the NWDSM and Clause 2.1.5 of the Concrete Code.

Need of plugging the gap

360. For the structures in the Hung Hom Site whose structural integrity were in question due to the known irregularities, the EA Team considered it imperative that Government's checking should encompass compliance with the NWDSM, rather than confining only to the Concrete Code. Since the start of the code-compliant analysis during the Holistic Assessment and Verification Study, the EA Team has repeatedly reminded the relevant Government departments of EA Team's recommendation that Government's checking should deal with full compliance of the relevant codes, i.e. both the NWDSM and Concrete Code.

361. In response to EA Team's recommendation, HyD undertook to separately conduct the design checking for ensuring compliance with the NWDSM, in additional to the BA's checking against compliance with the Concrete Code.

362. By November 2019, the BA has completed its regulatory checking of, and accepted, the design of MTRCL's proposed remedial works[148] based on the requirements of the Concrete Code. The remedial works were then commenced on site upon BA's acceptance of the design.

363. At the time of preparation of this report, HyD's checking has yet to be completed. The EA Team was concerned about the progress of the checking.

364. Specifically for the Hung Hom Site, it is recommended that HyD should complete the outstanding design checking against compliance with the NWDSM as soon as possible. It is also recommended that HyD should document the approach for and the findings of its checking. This will help demonstrate HyD's accountability with transparency on not only the due completion of the checking but also on how it has been conducted to meet the intended objective.

[148] The remedial works are referring to those identified in the *Holistic Report* and *Verification Report*.

365. To fill the gap in Government's checking in general, it is recommended that for Government-funded railway projects undertaken by MTRCL in future, HyD should ensure that compliance with all the applicable codes, rather than confining only to the regulatory requirements, is covered in Government's checking.

366. While the additional design checking being undertaken by HyD would help fill the gap in Government's checking, the EA Team considered the arrangement not entirely satisfactory.

367. Firstly, the structures were designed to comply holistically with all the requirements of the NWDSM. Truncating the design into two parts for checking separately by the BA and HyD may not only result in duplication of checking effort but also potential ambiguity in the scope of and accountability for the checking.

368. Secondly, as MTRCL has to separately seek the acceptance from two different parties for the same piece of structural design, this would inevitably lengthen and complicate the process. In the case of the Hung Hom Site, by the time of preparation of this report, the vast majority of the remedial works have been completed. Yet, HyD's checking of the additional NWSDM requirements was still in progress. This situation is undesirable.

369. In the interest of streamlining procedures and providing one-stop service as far as practicable, it is recommended that HyD should explore the possibility of having the compliance checking against the regulatory requirements and NWDSM carried out under one roof in future. For instance, for Government-funded railway projects undertaken by MTRCL under IoC, HyD's checking should address compliance with the whole of the NWDSM, instead of confining to the Concrete Code. Likewise, for IoE cases, consideration should be given to extending BD's checking to cover the NWDSM in addition to checking against the regulatory requirements.

Gearing Up for Seismic Design

Anomaly in seismic design

370. As noted in *paragraph 252* in ***Section 4***, an anomaly in seismic design was identified during the Holistic Assessment. The EA Team considered this a major anomaly, in that both the approach and procedures specified in the NWDSM for seismic design were not duly followed in the original design of the HUH Extension structure.

371. The NWDSM specifies the use of a state-of-the-art approach in seismic design with account taken of the combined effects of the horizontal and vertical accelerations as well as the dynamic responses of the ground and structures under seismic actions. This is an established approach for seismic design that involves soil-structure interaction under dynamic loading conditions. However, a rudimentary approach based on consideration of a pseudo-static horizontal force to represent the seismic effects on the structures was adopted in the original design of the HUH Extension structure. This neither meets NWDSM's requirements for seismic design, nor would necessarily result in a safe design.

372. Apart from the design approach, specific seismic design procedures are also stipulated in the NWDSM. These include, in particular, preparation of a *design philosophy statement* which shall be submitted in the Approval in Principle Document for the approval by MTRCL. Specifically, the following, among other requirements, are specified in the NWDSM in connection with the *design philosophy statement*:

(a) *For above-ground structures*, it is specified in the NWDSM that "*The design and analysis philosophy shall follow the proposals laid down in the New York City Seismic Code*", and that a list of seismic design considerations and procedures proposed to be adopted shall be included in the *design philosophy statement.*

(b) <u>*For underground structures*</u>, it is specified in the NWDSM that "*The design and analysis philosophy shall follow the proposals laid down in the paper published by the Earthquake Engineering Committee of Japan Society of Civil Engineers - Earthquake Resistant Design Features of Submerged Tunnels in Japan*". Likewise, the *design philosophy statement* shall include a list of the proposed considerations and procedures[149] for the seismic analysis and design of the underground structures, subject to the approval of MTRCL.

373. The procedures specified in the NWDSM constitute part of the good practice in ensuring that due consideration is given to the evaluation and acceptance of the governing seismic design assumptions and parameters. Unfortunately, these procedures were not duly followed in the original design. Had the procedures been properly followed, the anomaly in seismic design would not have occurred in the original design.

374. The EA Team was concerned about not only the non-compliance with the seismic design approach and procedures specified in the NWDSM, but also about the fact that this major deviation from NWDSM's requirements in the original design was neither identified in the internal checking by MTRCL's DDC nor by its design management team which was tasked to certify the design. As seismic design is part of the NWDSM's requirements which are not specified in the Concrete Code, the anomaly also slipped through the BA's checking.

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[149] Regarding the proposed procedures and considerations for seismic design of underground structures, the following are stated in paragraph 4.8.3.12 of the NWDSM:
"The design philosophy statement shall include, but not be limited to, the following:
i) a description of the proposed procedure for the analysis and design of the structure;
ii) consideration of the forces induced in structural elements by the structure tending to follow the shear deformation of the surrounding ground mass;
iii) consideration of the forces induced in structural elements by the structure tending to resist the shear deformation of the surrounding ground mass;
iv) consideration of the forces induced at any interfaces between structures of different stiffness and seismic response such as station to tunnel connections and the like;
v) consideration of the forces induced in structures founded in ground with significant variations in stiffness;
vi) discussion of soil liquefaction potential and resultant effects;
vii) discussion of ground movements - vertical and horizontal; and
viii) any other effects relevant to the particular structure, adjacent Corporation structures or other infrastructure under consideration."

375. Furthermore, in the course of following up this matter, the EA Team gained a general impression that the involved parties, including representatives from MTRCL, MTRCL's DDC and HyD, were apparently not conversant with seismic design and the relevant NWDSM requirements.

376. It is noteworthy that the seismicity of Hong Kong is "*low to moderate*" and the seismic risk in Hong Kong cannot be regarded as negligible.[150] Although the statutory requirements for seismic design have not yet been included in the BO by the BA, it has been the established practice to make project-specific provisions for seismic design of important infrastructure facilities, e.g. important buildings and bridges. The recommended minimum requirements for seismic design of highways and railways have also been stipulated in the *Structures Design Manual for Highways and Railways* ("SDM") issued by HyD.[151] It is prudent for the NWDSM to contain seismic design requirements, given the importance of mass transit railway structures. In EA Team's opinion, circumstances exist in Hong Kong's condition that the seismic condition[152] may control the structural design, even for structures that are partly or wholly embedded in the ground. An obvious example is where the structure is situated in reclamation area and embedded in soils which are susceptible to seismic liquefaction.[153]

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150 See GEO Information Note 21/2020

151 The SDM provides guidance and sets standards for the design of highway and railway structures in Hong Kong. It has been widely used by practitioners as a reference for local highway and railway structural works since its first publication in August 1993. Revised editions of SDM were issued in 1997, 2006 and 2013.

152 Regarding earthquake loads, the paragraph 4.4.13.1 of the NWDSM specifies that "a bedrock induced motion equivalent to a peak horizontal ground acceleration of 15% g and a peak vertical ground acceleration of 7.5% g shall be adopted in design". These "represent approximately a 1 in 1000 year return period earthquake event in the Hong Kong region", with approximately a 10% probability of being exceeded during the 120 years design life of the structures.

153 In this connection, the following are specified in paragraph 4.4.13.6 of the NWDSM under the requirements for seismic design of underground structures: "As a general rule structures shall not be constructed in ground conditions with a low factor of safety against liquefaction (<1.5). However where this is not possible, stabilisation measures such as densification shall be adopted as well as consideration of bulk weight compaction and horizontal pressures (i.e. Ko = 1). Consideration shall be given to induced loads due to ground movement and pile buckling due to liquefaction of the supporting ground mass." Also, in paragraph 4.8.3.12 of the NWDSM, "discussion of soil liquefaction potential and resultant effects" is one of the items to be included

Required follow-up actions

377. Specifically for the Hung Hom Site, the EA Team would iterate its recommendation that HyD should ensure that, as part of its design checking described in *paragraph 361* above, NWDSM's seismic design requirements are complied with in the structures in the Hung Hom Site.

378. The EA Team has also advised HyD to take stock of whether the approach and procedures specified in the NWDSM for seismic design were followed in the design of the other SCL stations. At the time of preparation of this report, the EA Team has not received any information from HyD about the progress and findings of the stock-taking. It is recommended that HyD should speed up the stock-taking to ascertain whether any further follow-up actions are required.

379. There is room for the engineering profession in Hong Kong to gear up the competence in seismic design. It is recommended that HyD, BD and MTRCL should review the need and formulate training and development plans for enhancing their competence in dealing with seismic design.

380. Furthermore, sourcing external support could be a useful provision in case of insufficient in-house resources or expertise in dealing with the checking of seismic design. There are merits in engaging an Independent Checking Engineer ("ICE") for this purpose, particularly in the early stage when local experience in seismic design is being built up.

381. Hence, it is recommended that consideration should be given by MTRCL in engaging an ICE to deal with the checking of seismic design, as the need arises such as in case of insufficient in-house resources or expertise.

in the design philosophy statement to be submitted in the Approval in Principle Document for the approval of MTRCL.

382. In this connection, the EA Team noted the requirements specified in the PIMS that, "*where sophisticated analysis is required for complex/ unconventional structures*", the Engineer's design of permanent and major temporary works should be subject to independent design check by MTRCL's ICE.[154]

383. Moreover, requirements are also set out in HyD's SDM for an independent check of the design of different categories of highway and railway structures. For complex structures[155], it is stipulated that the independent check of the design shall be carried out by "*a checking team from a separate independent organization*", i.e. an ICE.

384. There is scope for HyD to examine whether its future railway projects undertaken by MTRCL should also follow this requirement of the SDM for independent design check by an ICE. If so, the scope of the ICE's design check may cover the whole of the design in compliance with the applicable codes, instead of confining to the seismic design aspects. There is also an option as to whether the ICE is to be appointed on MTRCL's side or on HyD's side. It is recommended that HyD should look into the need and possible arrangement for this in the delivery of its future railway projects.

Using Couplers Judiciously

Workmanship and buildability issues relating to use of couplers

385. Defective coupler connections of the rebars between the platform slabs and D-wall in the HUH Extension structure are arguably most striking among all the irregularities uncovered in the Hung Hom Site. As described in ***Section 3***, it involved not only works failing to meet the required specifications and workmanship quality, but also non-conformities in site supervision and control, record-keeping and

[154] See Exhibit 7.4/2 of PIMS/PN/09-3/A2

[155] These complex structures are denoted as "Category III" structures. They refer to structures requiring sophisticated analysis or with any one of the features listed under the Category in Table 2.2 of the SDM.

rectification works on defective works. The consequences are serious, in that the improper coupler connections become the weakest link in the chain, rendering the integrity of the built structures in question despite all the other key constituents such as the main rebars and concrete have been duly provided and constructed.

386. The platform slabs and D-wall of the HUH Extension structure are cast-in-situ reinforced concrete construction. Since they are designed to form a monolithic box structure, the main rebars required for reinforcing the concrete have to continuously go through the structure (i.e. between the platform slabs and D-wall). Where two rebars need to be connected to ensure adequate load transfer, this may either be achieved by lapping the rebars for an adequate length, or by threading the ends of the two rebars and connecting them with a steel coupler. According to the accepted design drawings, couplers were to be adopted in the connections between the rebars of the platform slabs and D-wall (see ***Figure 3-1***). Couplers were also used to connect the vertical rebars within the D-walls, between different bays of concrete in the platform slabs, as well as in the NAT, SAT and HHS generally.

387. In terms of structural performance, a properly connected coupler would behave as satisfactory as connecting the rebars with an adequate lapped length.[156] Use of couplers in connecting rebars does offer a distinct advantage. When the rebars are very closely spaced, connecting the rebars by couplers could avoid lapping the rebars, which would otherwise result in more congested rebars at the lapped location and thereby increase the difficulty in steel fixing and concreting.

388. However, one should never lose sight of the fact that coupler connection is a much more delicate piece of construction works than lapping rebars. Lapping rebars is simply putting two rebars side by side with an adequate lap length, which is easy to arrange and check. Proper coupler connection is dependent on a series of actions which need to be duly executed on site:

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[156] See paragraph 523 of the Final Report

(a) the ends of the rebars have to be correctly threaded to match with the type of the coupler used;

(b) the couplers and rebars have to be accurately aligned, lest adjacent rebars to be connected with the couplers may cross one another making it difficult for them to be properly screwed into the couplers;

(c) damaged couplers or threaded ends of the rebars have to be replaced;

(d) the couplers and threaded ends of rebars have to be thoroughly cleaned, given that presence of debris, be it of a small amount, could hinder the coupler connection;

(e) the rebar has to be properly screwed into the coupler, strictly following the relevant installation procedures and requirements;[157] and

(f) after installation, and given the presence of multiple layers of rebars connected by couplers, it is difficult to ascertain by visual inspection as to whether the coupler connections have been made properly. Close supervision and workmanship checking are required during installation of individual coupler connections, in addition to the usual checking after completion of all the rebar fixing works.

389. Hence, it is necessary to adopt rigorous site supervision procedures (e.g. full-time supervision) and control requirements (e.g. the RISC form process and SSP/QSP requirements).

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[157] In the case of the BOSA couplers used in the Hung Hom Site, it has to be fully and tightly screwed in, according to the "butt-to-butt" requirement. The Government's independent expert has testified in the Inquiry that this was required not only for ensuring sufficient strength capacity but also control elongation at the connection (see paragraph 387 of the Final Report).

390. Even when the above actions are carefully undertaken in coupler installation, it is not uncommon that a few percentages of the coupler connections may still be found to be unsatisfactory, and consequentially have to be rectified by replacing the couplers or using alternative means of connection (e.g. substituted by a drilled-in bar to lap with the rebar that is to be connected). In case the works fall into the critical part of the construction works programme (e.g. in top-down construction as further described in *paragraph 401* below), the rectification works would be subject to enormous time pressure.

391. In summary, coupler connection is an involved process of works which needs to be meticulously undertaken and closely supervised. Otherwise, particularly under the relatively unpleasant working environment on site, it is vulnerable to defects in installation and could result in serious implications for the structural performance. Hence, in EA Team's view, it should be used with caution.

Vigilance in use of couplers

392. Coupler connections have become widely used in the construction works in Hong Kong.[158] The EA Team would caution that designers and contractors should use coupler connections judiciously, with account taken of their advantages and constraints.

393. On the one hand, where it is necessary or preferable for coupler connections to be used, due provision should be made in the works process and in site supervision and control to ensure compliance with the installation specifications and workmanship quality.

394. On the other hand, where there are no particular reasons for couplers to be adopted in favor of connection by simply lapping the rebars, it would be rash to use couplers indiscriminately, without due consideration of the possible risk of construction irregularities, their adverse consequences and the need for more stringent site supervision and control.

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158 For example, the health-check audits in ***Section 8*** of this report have revealed that, with the exception of HIK, a significant number of couplers were used in all of the SCL stations audited.

In this regard, it is noted that a very large amount of couple connections have indeed been used in the Hung Hom Site.[159] Many of these were apparently out of the contractor's decision, with neither prior acceptance by MTRCL nor contemporaneous and complete records on whether the installation works were properly carried out and supervised.[160]

395. It is recommended that MTRCL and HyD should be vigilant of the judicious use of coupler connections, particularly in avoiding their inadvertent use and in implementing effective site supervision and control to ensure that the required specifications and workmanship quality are met.

Attending to buildability

396. Furthermore, the above observations point also to the wider issue about accounting for buildability in design and construction, in that the judicious use of coupler connections does call for proper buildability consideration. In some cases, such as where the rebars are congested, using coupler connections instead of lapping rebars may provide an effective solution for enhancing buildability. In other cases, inadvertent use of coupler connections may unnecessarily introduce buildability problems due to the vulnerability of the installation to workmanship defects and the knock-on effects on the construction arising from misaligned or defective coupler connections.

397. One should also bear in mind the possibility that the buildability problem that may arise from coupler connections could be aggravated by a combination of other unfavorable factors. The circumstances in the east D-wall of the HUH Extension structure may serve as an illustration.

398. Firstly, the headroom restriction due to construction underneath the existing HUH resulted in the need for connecting (also by couplers) the vertical reinforcement cages of the D-wall at short sections. This

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[159] At the connections between the EWL slab and D-wall in the HUH Extension structure alone, there were some 21,500 coupler connections. See *paragraph 62* in ***Section 3***.

[160] See *paragraphs 105 to 112* on the unauthorized change from lapped bar connections into coupler connections in the NAT, and *paragraphs 114 to 119* on the OTE ducts and walls in ***Section 3***.

increased the difficulty in maintaining an accurate alignment of the horizontal couplers provided at the reinforcement cages of the east D-wall for connection with the main rebars of the platform slab.

399. Secondly, in the HUH Extension structure, the connection between the platform slabs and the D-wall was designed as a moment joint. This necessitated the connection with the horizontal couplers of the D-wall to be placed at the top and bottom mats of the platform slab, where multiple layers of congested main rebars were present.[161] Slight misalignment of the horizontal couplers could result in significant difficulty in the connection with the main rebars of the platform slab.

400. Thirdly, due to the over-provision in design possibly related at least partly to the lack of curtailment of the main rebars, the amount of the rebars at the top and bottom mats was significantly more than that which was required (see ***Appendix 6-1***). This worsened the rebar congestion problems and the buildability difficulty arising from misaligned couplers.

401. In addition, the use of the top-down construction method inevitably put the casting of the platform slab in the critical path of the box structure construction programme. When the bulk excavation was carried out to the platform slab level with the horizontal couplers at the D-wall exposed, defective couplers found to require rectification works would adversely affect the works programme.[162]

402. This alludes to the possible buildability problem in the coupler connections during the construction of the HUH Extension structure. In EA Team's opinion, it may have been an important prelude to the irregularities found in coupler connections, steel fixing, illicit design changes and cutting of threaded bars on site.

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[161] As a comparison, the platform slab and D-wall connection in TKW was designed as a pinned joint. The couplers for connecting the platform slab and the D-wall were placed in the mid-depth of the platform slab, and thereby avoiding encroachment on the top and bottom mats where congested rebars were present.

[162] In comparison, the EXC station structure was constructed in a bottom-up manner. After exposure of the horizontal couplers at the D-wall, ample time is available for rectification works on defective couplers, before the platform slab is to be cast.

403. Addressing buildability [163] in design and construction is an established requirement of the PIMS, which states:

> "*a design for safety and constructability review process shall be followed in each design stage to engage competent reviewers with experience of constructing similar works to review and identify the construction risks associated with the design*", and
>
> "*Further details relating to design for safety and constructability are provided in Practice Note PIMS/PN/04-3 'Design for Safety & Constructability'.*" [164]

404. Up to the time of preparation of this report, the EA Team has not been provided with detailed information about the *"design for safety and constructability ["DSC"] review*" process adopted in the SCL Project, nor about whether the review process had addressed any of the coupler connections and other buildability issues relating to the irregularities[165] by now revealed in the Hung Hom Site. However, MTRCL has noted that rebar fixing for diaphragm walls and slabs casting were considered typical for the construction of reinforced concrete structures and were not highlighted in the DSC review.

405. The EA Team considered that there might be areas for improvement in the light of the lessons learnt from the Hung Hom Site. For instance, it is evident that buildability difficulty was encountered in coupler connections during construction of the HUH Extension structure. Had the matter been brought up for attention in the regular DSC reviews during construction, all parties would have had the opportunity to timely

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[163] The term "constructability" is adopted in the PIMS. For the purpose of this report, the EA Team has taken "buildability" as a synonym of "constructability".

[164] See Section 9.3 of PIMS/P/09/A2. Further details relating to design for safety and constructability are provided in Practice Note PIMS/PN/04-3/A3, which is "*applicable to all railway projects, from detailed design, through to construction, testing and commission stages*" as stated in Section 2.1 of the Practice Note.

[165] The difficulty in shear link placement in the EWL and NSL slabs is another example of potential buildability issue.

address and thereby avoid degradation of the problem. It is recommended that MTRCL and HyD should review the adequacy of their prevailing practice in addressing the buildability aspects of the design and construction, with a view to enhancing the identification and resolution of major buildability issues in their future railway projects.

Ensuring Cost-effectiveness in Design

406. The significant spare capacity in the *Original Design* of the HUH Extension structure was discussed in ***Section 6***. It apparently arose from the over-provision in design over and above the code requirements. The over-provision had unfavorable cost and buildability implications.

407. The issue of buildability has been discussed in *paragraphs 396* to *405* above. Cost-effectiveness in design is under much deliberation in recent years, amid the fact that the cost of construction works in Hong Kong is among the highest in the world.[166] Cost-overrun in some major development projects, including the SCL Project, has also aroused concern about the cost management in construction projects.

Prevailing provisions

408. Specifically for large-scale construction works like the HUH Extension structure, cost-effectiveness needs to be addressed in all stages throughout project delivery. Due consideration of cost-effectiveness should be made in the project inception, feasibility study and preliminary design stages, as the formulation of the scope, scheme, alignment, etc. of the project has profound cost-effective implications. In the detailed design stage, attention should be given not only to structural detailing (e.g. curtailment of the main rebars as noted in *paragraph 400* above) and avoiding overly conservative design, but also the wider issues about adoption of suitable structural form and construction methodology.

[166] As noted in Development Bureau's paper No. EC(2018-19)26 of January 2019 to the Establishment Subcommittee of Finance Committee, the construction cost in Hong Kong has been ranked the third highest in the world in 2018 by several international reports.

409. The objective of achieving cost-effectiveness in design is embedded in the Manuals of the PIMS, in which the management responsibility for this by different Departments and Sections of the Projects Division of MTRCL is set out. Some examples are given below:

> "*Provide a civil engineering overview of railway extension conceptual studies to ensure appropriate* ***cost-effective solutions*** *are achieved consistent with safety, quality and environmental standards*" under the Civil Engineering Section of Civil & Planning Department,[167]
>
> "*Prepare the overall Master project schedule and critical path in the most time and* ***cost effective way*** *to meet the needs and requirements of new railway projects*" under the Programming Department,[168] and
>
> "*Secure input from contractors and/or consultants in adopting partnering concepts to ensure that projects are designed to enable completion in a* ***cost effective*** *and timely manner*" under the Project Management Department.[169] **[Emphasis added]**

410. Regarding the management of preliminary design, the following provisions are given in the Practice Notes of the PIMS:

> *"The purpose of preliminary design is to establish the project scope,* ***cost*** *and programme, to produce the Project Definition Documents*[170]*, to enable a final decision to be made on*

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167 See paragraph 3.3.4 a) of PIMS/MAN/004/A4

168 See paragraph 3.9.1 a) of PIMS/MAN/004/A4

169 See 5th bullet point of paragraph 3.21.3 b) i) of PIMS/MAN/004/A4

170 As stated in paragraph 6.1 of PIMS/MAN/005/A3, Project Definition Documents is "*developed and approved at the Preliminary Design Stage setting out the performance requirements to be achieved at the completion of the project, and the standards, specifications and other requirements to be observed during project delivery*". The development of the Project Definition Documents is managed by the Project Definition Documents Control Committee (PDDCC). The terms of reference of PDDCC is given in Appendix A/1.2 of PIMS/MAN/005/A3.

progressing with the project and to enable the project to be split into manageable packages for the purposes of detailed design and construction"[171], and

"Major decisions on scope or programme shall be made using value engineering (VE) techniques, with major issues confirmed at Project Control Group (PCG).[172] *The **cost estimate** and programme at the end of the preliminary design shall be approved by PCG."*[173] **[Emphasis added]**

411. In respect of the management of detailed design undertaken by MTRCL's consultants, it is stated in the Practice Notes of the PIMS that:

*"The initial period of detailed design, usually termed scheme design, is used to verify the findings of the preliminary design and for the new consultant to take ownership of the design … The **cost estimate** and programme at the end of scheme design must be approved by PCG."*[174], and

*"During the production stages of detailed design the emphasis should be directed towards ensuring that the developed design is translated into clear, accurate, co-ordinated and unambiguous drawings, and that it adheres to the **cost forecasts** made at scheme design stage."* [175] **[Emphasis added]**

PDDCC is tasked to, among other duties, "*ensure the appropriateness, adequacy, consistency and cost effectiveness of the contents of the project definition documents in meeting the Corporation's objectives, customer needs and project requirements, and to initiate new project definition documents where required*". PDDCC is chaired by the Head of Project Engineering.

171 See paragraph 5.1.7 a) of PIMS/PN/09-3/A2

172 The terms of reference of PCG are given in Appendix C/2 of PIMS/MAN/005/A3. PCG is tasked to, among other duties, "*control the cost of all new Projects within the powers delegated by the Executive in order to ensure that the Projects are completed on time and within budget to an approved quality*". PCG is chaired by the Projects Director, with meetings held at weekly intervals.

173 See paragraph 5.1.7 c) of PIMS/PN/09-3/A2

174 See paragraph 5.1.8 a) of PIMS/PN/09-3/A2

175 See paragraph 5.1.8 b) of PIMS/PN/09-3/A2

412. For design management of entrusted works, it is stated in the Practice Notes of the PIMS that:

> "*Government works entrusted to the Corporation for design and/or construction shall be carried out in accordance with Government design standards and specifications, but in accordance with the Corporation's design process and procurement practices. It is essential that acceptance by the end user is obtained continuously throughout the project delivery to avoid problems at the handover stage.*"[176]

413. There are no explicit conditions relating to the cost-effective aspect in the Entrustment Agreements between the Government and MTRCL. As regards the standards of the SCL Project, HyD has required the following:

> *"the Shatin to Central Link shall be designed to standards and in accordance with a specification which is consistent with and not materially in excess of those applicable to comparable completed railway projects in Hong Kong."*[177]

414. Although cost-effectiveness is a broad objective of design, neither any specific requirements nor details of the implementation process for achieving this objective are given in the PIMS. The EA Team was given an impression that in the detailed design stage, the main focus of MTRCL's cost management was on controlling the cost within the cost estimate. This is different from enhancing the cost-effectiveness of design. In order to find out whether there are other requirements set out by MTRCL for cost-effectiveness in design and about the exact provisions made in the SCL Project, the EA Team has requested for further information on this from MTRCL. However, up to the time of preparation of this report, the EA Team has not received any relevant information on this subject matter.

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176 See paragraph 5.1.10 b) of PIMS/PN/09-3/A2

177 See Clause 5.1(b)(i) of the Entrustment Agreement for Design and Site Investigation in Relation to the Shatin to Central Link between the HKSAR Government and MTRCL dated 24 November 2008

415. The prevailing design checking by the Government on the SCL Project, viz. IoE and IoC cases by the BA and HyD respectively, was to deal with compliance with the Concrete Code. The design would be accepted if it is found to be code-compliant, irrespective of whether or not the design is cost-effective.

416. While the scope of the work of HyD's M&V consultant was focused on cost, programme and public safety, the EA Team understood that the M&V consultant had not explicitly looked into the cost-effectiveness aspects of the design.

417. The above may shed some light on the possible context that the significant over-provision in design, as observed from the spot-check of the original design of the HUH Extension structure (see ***Appendix 6-1***), could slip through the prevailing project management of MTRCL and the checking by the Government. In MTRCL's project delivery process, there is apparent room for enhancing cost-effectiveness in design.

Enhanced cost-management in public works projects

418. In comparison, more comprehensive provisions, including new initiatives introduced in recent years, are in place for improving the cost-effectiveness of public works projects. Three examples, which cover different aspects of cost management for uplifting cost-effectiveness in the project delivery process, are described below.

Institutional set-up

419. Relating to the institutional aspect, a dedicated team *Project Cost Management Office* ("PCMO") was set up in the Development Bureau ("DEVB") in 2016 for enhancing the cost management of public works projects. PCMO's work dealt not only with managing the cost of the projects to within budget, but also improving cost-effectiveness leading to better value for money and cost-saving. It has been reported that, in between 2016 and 2018, PCMO has scrutinized 230 projects and saved

$55.6 billion, amounting to 13% of the original project cost.[178] In 2019, PCMO was upgraded and expanded to the *Project Strategy and Governance Office* ("PSGO") to formulate strategies and take forward new initiatives to strengthen project governance for uplifting project performance.

420. Two distinct requisites for the work of PCMO (and now PSGO) are notable. Firstly, it is a dedicated and independent unit in DEVB, separated from the project delivery teams and reporting directly to the senior management. Secondly, its cost management initiatives and processes for scrutinizing the scope, design and cost estimate of the projects cover the whole of the project delivery process. This is aimed at capitalizing on all opportunities for cost-saving from project inception to the design and construction stages.

Design optimization through project-by-project vetting

421. Aside the institutional set-up, the relevant works policies and implementation arrangements for promoting innovative and fitness-for-purpose design have been put in place. For instance, the policy and procedures for enhancing the cost-effectiveness of permanent geotechnical works in Government's capital works projects with piling or foundations works or other geotechnical works exceeding $500 million are set out in Technical Circular (Works) No. 3/2018 issued by DEVB. It introduces the requirements for conducting review in the schematic design stage on optimization of the geotechnical design from the perspective of cost-effectiveness. Also, works departments' detailed design submissions of major geotechnical works are required to be examined by a Design Vetting Panel based on a holistic approach with due consideration of the cost-effectiveness of the project. The roles and responsibilities of the key parties to take part in the process have also been set out.

[178] See the blog of Financial Secretary of 15 September 2019 in https://www.fso.gov.hk/eng/blog/blog20190915.htm

Other cost-management initiatives

422. Furthermore, a suite of strategic initiatives for improving cost management practice, capability and culture in project delivery are being pursued. For example, the *Project Surveillance System* is launched for monitoring the cost and time performance of projects during the construction stage, and the *Centre of Excellence for Major Project Leaders* is established for providing high-level leadership development programmes for major project leaders.[179]

423. Among these initiatives, the EA Team noted that DEVB is exploring enhancements to consultancy agreements, in particular, to solicit expert input for the formulation of innovative schemes for more cost-effective designs. The EA Team is aware that MTRCL has appointed expert panels to review certain aspects of its railway projects. MTRCL may look into the need and arrangement for introducing enhanced initiatives in cost-effectiveness evaluation and cost management initiatives in its project delivery and checking process.

424. In view of the above, the EA Team considers that there is scope for improvement by MTRCL in ensuring that the objective given in the PIMS on cost-effective design are achieved in project delivery. It is recommended that MTRCL should review its relevant practices and provisions with a view to seeking improvement.

425. It is recommended that HyD should strengthen its management of future Government-funded railway projects undertaken by MTRCL, so that these projects are at least on a par with Government's public works projects in the quest for improvement in cost management. Consideration may also be given by HyD to inclusion of the cost-effective aspects in Government's design vetting and in the audits by the M&V consultant.

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[179] See paragraphs 12, 15 and 16 of Development Bureau's paper No. EC(2018-19)26 of January 2019 to the LegCo's Establishment Subcommittee of Finance Committee

Section 8 Assessment of Other SCL Stations

Background

426. Given the irregularities found at the HUH Extension, the EA Team is tasked under its Terms of Reference, to "*advise on possible measures to ascertain if there are other irregularities in the construction of key structures in the SCL project (i.e. not limited to Hung Hom Station Extension)*".

427. In January 2019, when the Holistic Assessment had begun to reveal the possible nature and severity of the irregularities at the HUH Extension, the EA Team recommended that a "health-checking" assessment be carried out for the other SCL stations. This aimed to review whether the works might have been affected by any irregularities with potentially significant structural safety implications, with account taken of the findings of the on-going investigations at the HUH Extension.

Three-tier Audit

428. Following this, the Government announced in March 2019[180] the implementation of a three-tier audit of all relevant stations in the SCL Project (other than HUH Extension), as part of the preparation for the commissioning of the Tai Wai to Hung Hom Section.

429. The three-tier audit is comprised of the following:

(a) firstly, the Government has asked MTRCL to conduct an internal audit on these SCL stations in order to ensure that the construction details are in compliance with the design and acceptable standards;

(b) secondly, HyD would conduct an audit on these SCL stations, with focus on records about quality control of works and site supervision; and

[180] See paragraph 34 of the paper submitted to the Subcommittee on Matters Relating to Railways of the LegCo Panel on Transport (LC Paper No. CB(4)687/18-19(05)) https://www.legco.gov.hk/yr18-19/english/panels/tp/tp_rdp/papers/tp_rdp20190329cb4-687-5-e.pdf

(c) finally, for the purpose of vetting, MTRCL has to submit to the Government the Certificates of Completion together with the relevant documents including record drawings, test reports on construction materials and certificates. The Government will then perform the necessary site inspection/audit and site witness. If the works were completed to the Government's satisfaction, a no-objection letter would be issued by the relevant authority (BA or HyD as appropriate) to acknowledge the Certificates of Completion.

430. The first- and second-tier audits by MTRCL and HyD in Items (a) and (b) of *paragraph 429* above serve the purpose of a "health-checking" assessment. The last tier of vetting by the relevant authority in Item (c) follows the regulatory requirements for the Certificates of Completion prior to the built structures being put in use.

Comparison between HUH Extension and Other SCL Stations

431. In addition to the audits carried out by MTRCL and HyD, the EA Team recommended HyD to compare a number of key factors identified in the HUH Extension with the other SCL stations to be audited as follows:

(a) whether a similar structural form involving D-walls with the use of couplers for connection with the platform slabs was used;

(b) whether the main contractor and steel-fixing subcontractor were the same as that for the HUH Extension; and

(c) whether there might be potential conflict of interest between MTRCL's DDC and the main contractor's design consultant.

432. The comparison was aimed to identify, early on, any potential areas for special attention by the audit consultants given possible similarity in the key circumstances as the HUH Extension.

433. There are ten stations, including new or extension of existing stations, in the SCL Project. Three of the stations have no major civil engineering works under the SCL Project, viz. Tai Wai Station ("TAW"), Ho Man Tin Station ("HOM") and Admiralty Station ("ADM"), as their station structures had been completed under other previous projects. Hence, aside the HUH Extension, only six stations are included in the comparison exercise. They are Hin Keng Station ("HIK'), Diamond Hill Station ("DIH"), Kai Tak Station ("KAT"), Sung Wong Toi Station ("SUW"), To Kwa Wan Station ("TKW") and Exhibition Centre Station ("EXC"). With the exception of EXC which is on the NSL, the other five stations are on the EWL.

434. The comparison shows that three stations (i.e. DIH, TKW and EXC) have similar construction form as the HUH Extension. Two stations (i.e. DIH and EXC) have the same design consultants serving both MTRCL and the main contractor. None of the stations are using the same main contractor or steel fixing subcontractor as the HUH Extension. The results of the comparison are summarized in ***Appendix 8-1***.

435. It should be noted that while three SCL stations have similar construction form as that of the HUH Extension, the difficulty and complexity in the coupler connections between the platform slab and D-wall in the three stations are considerably less demanding than the HUH Extension. The platform slabs in the three stations are thinner[181], with less congested rebars. The site conditions are less challenging when compared with the HUH Extension, which has to be constructed underneath the existing HUH with limited headroom. Furthermore, DIH and EXC are constructed in a bottom-up manner[182], whereas top-down construction is adopted in the HUH Extension.

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[181] The typical thickness of the platform slabs for DIH is ranging between 1.5m and 2.4m; TKW is between 1m and 2m; and EXC is between 1m and 1.5m. The EWL slab in the HUH Extension is 3 m thick.

[182] In bottom-up construction, ample time is available for rectifying damaged or misaligned couplers, before fixing the rebars of the platform slabs and connecting them with the D-wall.

436. Regarding the employment of MTRCL's DDC by the main contractors as their design consultants in DIH and EXC, it is noted that the consultants in DIH and EXC were mainly advising the contractors for part of the temporary works design of the excavation and lateral support works. In addition, the consultant in EXC was also involved in alternative designs for piling works at the station and some other design work.

437. The findings of the comparison exercise provide some assurance that the circumstances of the HUH Extension in respect of the combination of its demanding setting of coupler connections and its construction and design teams are unique among the SCL stations. Hence, there is no obvious basis for direct extrapolation of the irregularities found in the HUH Extension to the other SCL stations. Nevertheless, it is prudent to have the first two tiers of audits conducted in parallel by HyD and MTRCL on these SCL stations, to provide further assurance in addition to the normal vetting by the relevant regulatory authority.

Internal Audit by MTRCL

438. As the first-tier audit described in *paragraph 429* above, WSP (Asia) Limited ("WSP") was engaged by MTRCL to carry out an independent audit on the six new SCL stations to assess whether the construction works were properly supervised and documented.

439. The audit was conducted in two rounds. The first covering the five EWL stations was carried out between February and June 2019. The second covering EXC was carried out between July 2019 and April 2020. The results of these audits were contained in two audit reports submitted by MTRCL to HyD.

440. As this is an internal audit by MTRCL, the EA Team has had limited involvement in the work of WSP except for a few briefing meetings arranged by MTRCL, before receiving the audit reports from MTRCL. A summary of the audit findings by WSP is at ***Appendix 8-2***.

Independent Audit by HyD

441. HyD employed its M&V consultant, PYPUN, to conduct the second-tier audit for the same six SCL stations. The field inspections and sample checks of supplementary evidence of the audit on the five EWL stations was conducted between January and May 2019. The audit for EXC was carried out between March and April 2020.

442. The EA Team took part in overseeing PYPUN's audit, and had frequent interaction with PYPUN during the process, including giving advice on the audit approach, assessment methodology and review of findings. The EA Team also participated as an observer in several occasions of PYPUN's on-site auditing work. A summary of the audit findings by PYPUN is at ***Appendix 8-3***.

Observations by EA Team

RISC forms

443. Properly completed RISC forms are important documents in that they record the inspection results of the construction works on site, which forms part of the hold point control process.

444. Although the scope and extent of WSP's and PYPUN's audits are not exactly the same, their findings are collaborating with each other in many areas such as the availability of RISC forms for the stations (***Table 8-1***).[183] It is the intended objective that the two audits conducted in parallel and independently by MTRCL and HyD would help benchmark and supplement the findings of each other. It should also be noted that the details of the results of the two audits may not exactly be the same, due to the different approaches and samples taken in the audits.

[183] Reference has been made to page 6 of PYPUN's Executive Summary of Health-check Exercise covering SCL TKW, DIH, HIK, KAT, SUW Stations (November 2019); sections 3.2 to 3.12 of PYPUN's Review Report of Exhibition Centre Station Audit (3rd Draft) (July 2020) and section 3.1 of MTRCL's Audit Report on Quality Supervision of 1123 Exhibition Centre Station dated 21 April 2020.

Table 8-1

Percentage of the required RISC forms found to be available

Station		WSP's audit	PYPUN's audit
HIK		95%	83%
DIH		93%	91%
KAT		82%	84%
SUW		95%	95%
TKW		88%	83%
EXC	Paper form	77%	91%
	iSuper system	100%	100%

445. WSP's audit of RISC forms comprised two phases of review. While the overall availability of RISC forms may appear not exceedingly unsatisfactory, an analysis of the results of the two-phase review process by WSP revealed that the handling of unavailable and inconsistent RISC forms would deserve a closer examination. In WSP's Phase 1 check, the availability and consistency of the available RISC form were audited. Next, the cases of unavailable and inconsistent RISC forms were reviewed by WSP in its Phase 2 check for assessing whether they could be regarded as closed cases, i.e. deemed to be acceptable provided that the case has two or more pieces of supplementary materials as supporting evidence. These supplementary materials comprise photographs, site diaries, drawings, WhatsApp/Email messages, test reports and piling records (see ***Figure 8-2-2*** *of* ***Appendix 8-2***).

446. The overall findings of the audit on RISC forms for the five EWL stations by WSP[184] is summarized in ***Table 8-2*** below.

[184] Reference made to Figures 8 to 11 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019.

Table 8-2 Overall findings of the audit on RISC forms for the five EWL stations by WSP

<table>
<tr><td colspan="4">Total RISC forms required for the five EWL stations
3,823 (100%)</td></tr>
<tr><td colspan="3">Available
3,460 (90.5%)</td><td>Unavailable
363 (9.5%)</td></tr>
<tr><td rowspan="2">Consistent
2,646
(69.2%)</td><td colspan="2">Inconsistent[185]
814
(21.3%)</td><td rowspan="2">Regarded as closed cases after Phase 2 check

289
(7.6%)</td></tr>
<tr><td>Regarded as closed cases after Phase 2 check[187]

587
(15.4%)</td><td>Insufficient evidence, i.e. remained not closed after Phase 2 check[188]
227
(5.9%)</td></tr>
<tr><td></td><td></td><td></td><td>Insufficient evidence, i.e. remained not closed after Phase 2 check[186]

74
(1.9%)</td></tr>
</table>

447. The combined number of "*inconsistent*" and "*unavailable*" RISC forms as found from Phase 1 check was 1,177 (i.e. 814 + 363), which implies that 30.8% (i.e. 21.3% + 9.5%) of the required RISC forms were deficient. After Phase 2 check, 876 out of these 1,177 deficient cases were closed, based on consideration of the supplementary materials. As a result, the number and percentage of deficient cases (i.e. cases remained not closed) were reduced to 301 (i.e. 1,177 – 876) and 7.9%, respectively.

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185 "Inconsistent" refers to RISC forms which have not been properly signed, incorrect information on the title, description of works, etc. shown on the RISC forms, and inconsistent dates of construction processes. See *Figure 8-2-1* and *paragraph 6* of ***Appendix 8-2***.

186 See Figure 10 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019

187 See Figure 11 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019. These cases are supplemented by two or more pieces of supporting evidence.

188 See Figure 11 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019

448. Also based on this approach, out of the 1,218 required paper RISC forms in EXC, the number and proportion of deficient cases after Phase 2 check were 48 and 3.9%, respectively.

449. In the meetings with the audit consultants, HyD and MTRCL during the audit exercise, the EA Team queried whether the supplementary materials would be able to "*close the gaps*" for the *unavailable* or *inconsistent* construction records such as the RISC forms. While the checking of site photographs and other supporting information like site diaries or material delivery notes may show that some activities have taken place on site, it is difficult to ascertain whether the necessary supervision has been properly carried out or the works are up to the required quality. Indeed, the Commission has determined in paragraph 646 of its Final Report the following:

> *"Moreover, site photographs, while no doubt they may have their uses, cannot in themselves constitute acceptable records going to quality assurance. They should only be used to support properly prepared quality records. Photographs may show that particular works were being carried out on a particular day but they cannot demonstrate that such works were properly inspected."*

450. WSP has applied a *7-day rule* which acknowledges that, if the RISC form is received within 7 days of the activity under inspection, the RISC form is deemed acceptable (i.e. not regarded as *inconsistent*). WSP has given the benefit of the doubt that the work schedules of the front-line inspectors might not allow them to attend office until a later time and the review of RISC form submission status by the SIOW was conducted on a weekly basis. Without the *7-day rule*, the number of *inconsistent* RISC forms will be more than 21.3% as assessed at present. In fact, such situation as contemplated by WSP should have been avoided with proper planning in the construction programme and staff resources. The next phase of the works being controlled by the hold point should not be allowed to proceed without signing off the relevant RISC form.

451. In contrast, PYPUN has not applied the *7-day rule* or similar relaxation in its audit of RISC forms.

RISC form register

452. Section 10.1.2 of MTRCL's PIMS/P/11/A3 states that –

> *"The SIOW and his Inspectorate Team shall work closely with the Contractor's site supervision team to ensure that inspection or witnessing of critical actions is undertaken at the required time.* ***The SIOW shall maintain a database of Requests for Inspection and Survey Checks (RISC) from the Contractor****, the results of which shall be available for review as required. The SIOW shall produce regular status reports of the inspection results."* **[Emphasis added]**

453. Section 5.1.2 of PIMS/PN/11-4/A5 also states that:

> *"Request for inspection, test or survey check of site works shall be made by means of a standardised RISC form (see Exhibit 7.3). The SConE/SIOW/SLS shall ensure an administration system is set up to receive, log and monitor the status of inspections and tests…* ***If possible the project specific ePMS system should be used to administer this process*** *[RISC numbering system],* ***otherwise the SIOW should set up an independent register to control and monitor the RISC process****…"* **[Emphasis added]**

454. PYPUN's audit revealed that all of the five EWL stations did not meet the requirements stipulated in the above PIMS Practice Notes. Instead of setting up an independent register for RISC forms of their own, MTRCL had relied on the contractors' RISC form registers.[189] Even worse, as the contractors failed to keep the RISC form registers updated and complete, this was not timely rectified by MTRCL.

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[189] See page 7 of PYPUN's Executive Summary of Health-check Exercise covering SCL TKW, DIH, HIK, KAT, SUW Stations (November 2019)

455. For EXC, MTRCL did follow the PIMS requirements by keeping an independent register for the paper RISC forms.

Use of couplers

456. The audits revealed that, with the exception of HIK, couplers are used in all of the SCL stations audited. As described in ***Section 3*** of this report, there are non-ductility (Type I) and ductility (Type II) couplers, which are subject to different supervision requirements.

457. The Commission heard evidence that "*in order to avoid error, only ductile couplers - 'Seisplice' couplers - were ordered by Leighton*"[190] in the Hung Hom Site although both Type I and II couplers for different elements of the station structures are shown in the design drawings. This has resulted in some arguments in the Inquiry about whether QSP would be applicable to areas designed to use Type I couplers but with Type II couplers actually adopted instead.[191]

458. Couplers are commonly used in construction works in Hong Kong. Its judicious use warrants attention. This is discussed under the subject of *using couplers judiciously* in ***Section 7*** of this report.

Frequency of SSP inspections

459. Notwithstanding the high percentage of SSP inspection records found to be available in WSP's audit for the five EWL stations (92%, i.e. 17,534 records of SSP inspections were available, out of 19,054 required inspections)[192], WSP discovered that the inspection records for certain grades of Technically Competent Persons ("TCPs") and certain elements of the structures in individual stations were well below this average figure of availability. For example, there was no record of the 60 required inspections by the Grade T4 TCP of the CP stream for the pile cap

190 See paragraph 141 of the Final Report

191 See paragraphs 575 to 584 of the Final Report

192 See Section 3.3 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019

construction at HIK (i.e. 0% availability). In another case, only the records of 141 inspections out of the 250 required inspections by the Grade T5 TCP of the CP stream for the basement construction of KAT can be identified (i.e. 56% availability).[193]

460. PYPUN's audit also revealed anomalies in the inspection records of TCP. For example, in KAT, the inspection records of TCP T4 for 15 months, from February 2014 to May 2015, were not available. Similarly, the inspection records for the CP and TCP T5 were also not available for a substantial period of time.

Deficiencies in keeping contemporaneous construction records

461. Both of the audits by WSP and PYPUN have revealed inadequacies of keeping contemporaneous construction records in all of the SCL stations audited, albeit to varying extents. Most notably, these include RISC forms and SSP inspection records. In a number of cases, they involved late submissions of records and dates of action not tallying with one another, e.g. date of pouring concrete before the pre-pour inspection date.

462. Although the supplementary materials per se cannot be treated as reliable evidence of quality assurance, the painstaking checking and verification by WSP and PYPUN in the audit exercises did help reduce some uncertainties in site supervision and control.

The iSuper system

463. The new digital RISC form system ("iSuper") launched in EXC since February 2019 has improved the availability of RISC forms. However, the long-term effectiveness of this system should be further examined. As discussed in ***Section 3*** of this report, there are many aspects relating to the carrying out of hold point inspections and completion of RISC forms. The change from paper form to digital form alone may not be a panacea for all the problems.

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[193] See Appendix B3 of MTRCL's Audit Report on Quality Supervision of EWL Stations dated 6 November 2019

464. Furthermore, the iSuper was launched after the irregularities in the Hung Hom Site had come to light. One would expect that all parties would exercise greater attention on site supervision, while this matter was under scrutiny.

Summary

465. The EA Team recognized the positive response of MTRCL and HyD to EA Team's recommendation in conducting the health-checking assessment. The audits by WSP and PYPUN have provided additional and useful information about the works and site supervision and control in the relevant SCL stations.

466. The EA Team had visited most of these SCL stations, prior to the audit by PYPUN. Its observations and understanding about the status of the RISC forms and site records were enriched by PYPUN's audit. The audit carried out by WSP also provided supplementary and collaborating information.

467. The first two of the three-tier audit described in *paragraph 429* above have been carried out as planned. Despite the irregularities identified in RISC forms and other site records, both WSP and PYPUN have not identified any major deficiencies or abnormalities with potentially significant structural safety implications.

468. The irregularities in the site records observed in the audits revealed that the deficiencies exist in all the audited stations. This is a cause for concern regarding the overall management of the SCL Project. The EA Team will further address this concern as a project management issue in ***Section 10***.

469. The deficiencies in site records cast doubt on the assurance of the quality of the works. MTRCL has reiterated its conclusion that there is "*no sign of any distress or structural issue which would affect safe operation of the railway*", and "*no report showing any problem which would affect safe operation of the railway from any party either.*"[194] While reasons to dispute this are not apparent to the EA Team, it would caution that workmanship defects and deficiencies in built quality may take time to surface as a noticeable problem. These may affect the long-term durability and performance of the built structures, even though signs of structural safety issues are currently not observed.

470. In this connection, it should be borne in mind that 7.9% of the required RISC forms in the five EWL stations were found by WSP as deficient (i.e. remained not closed), after the two phases of check in the audit. In EXC, the deficient cases amounted to 3.9%. Also, various anomalies in the available QSP and NCR records were found in WSP's audit.

471. Therefore, it is recommended that MTRCL should take due account of the concern about the deficiencies in site records and their possible implications in devising the future maintenance plans and monitoring schemes for these SCL stations. As described in *paragraph 281* in ***Section 5*** on a similar concern in the Hung Hom Site, such provisions should facilitate timely identification and rectification of the defects should their telltale signs become noticeable in future.

472. Similar to that for the HUH Extension, it is recommended that MTRCL should explore options for providing the Government with additional undertaking of quality assurance in respect of the built structures of these SCL stations (see *paragraph 291* in ***Section 5***).

[194] See paragraph 17 of the Executive Summary of MTRCL's Audit Report on Quality Supervision of EWL Stations submitted to HyD on 8 November 2019

473. In the last tier of the audit, the relevant authority (BA or HyD as appropriate) has acknowledged the Certificates of Completion together with relevant documents including record drawings, test reports on construction materials and certificates submitted by MTRCL for the five EWL stations audited. This signifies the acceptance by the authority, in the public interest, for the completed works of these stations to be safely put in use. Likewise, EXC will also be vetted by the relevant authority in due course.[195]

[195] The construction works of EXC have not been completed at the time of writing this report

Section 9 Settlement Audit

Monitoring and Control in Underground Construction

474. The SCL Project involves the construction of various underground structures. As is the case in other major excavation and underground construction works in an urbanized setting, the works need to be cautiously carried out, together with the implementation of a monitoring and control system. This is to ensure that the adverse impacts on the nearby facilities are kept within an acceptable level.

475. In the SCL Project, the "adverse impacts" to be controlled are principally construction-induced ground movement, which may result in settlement, distortion and damage to the nearby facilities.[196] Among a wide range of works under the SCL Project, ground excavation and dewatering for the construction of underground structures are particularly prone to inducing ground movement in the vicinity of the works. Tunneling works can also result in settlement in the overlying ground.

476. In the design stage of the project, MTRCL assesses the effects of the works on the surroundings, prepares drawings and site-specific monitoring plans, and consults the relevant Government departments and stakeholders to establish the monitoring and control system.

477. During construction, following the accepted monitoring and control plan, MTRCL conducts regular monitoring, tracks the impacts brought by the works to the surroundings, and takes the response actions as the need arises.

[196] Typically, building structures, pavements, utilities, etc. are vulnerable facilities which may be adversely affected by construction-induced ground movement. The settlement and distortion of these facilities are often subject to monitoring and control. For simplicity, this is commonly denoted as "settlement monitoring and control", although in practice it may also cover other aspects, such as building tilting and drawdown of groundwater level.

Alert-Action-Alarm Mechanism

478. As part of the monitoring and control plan, a three-tier activation mechanism is adopted in the SCL Project. The trigger criteria for activation of response actions are commonly denoted as Alert-Action-Alarm ("AAA") Levels. The monitoring parameters (e.g. ground settlement), pre-set trigger levels of the parameters (i.e. AAA Levels), and the response actions to be taken in the event of reaching each of the trigger levels are specified in the accepted drawing which presents the monitoring and control plan. This three-tier activation mechanism is also known as "AAA mechanism".

479. When the highest pre-set trigger level, i.e. *Alarm Level*, is exceeded, suspension of the construction works is typically specified among other response actions. The monitoring and control system of the SCL Project is akin to that commonly adopted in other private and public works projects of similar complexity, e.g. excavation for construction of deep basement.

Public Concern about Construction-Induced Settlement

480. There has been major public concern about ground, utility and building settlement problems arising from the SCL works, particularly in the vicinity of TKW and EXC and at the Fleet Arcade near EXC.

TKW

481. TKW was built underneath Ma Tau Wai Road.[197] The construction works commenced in late 2012. The bulk excavation works and construction of the station structure were substantially completed by the end of 2016 and mid-2017, respectively. The ground settlement in the vicinity of the works was recorded to have exceeded the *Alarm Level* since August 2013.

[197] See *Figure 9-2-1* of ***Appendix 9-2*** for layout plan of TKW

482. Towards the end of 2014, complaints were received about building damage, such as loosening of plaster and cracks on walls, in the vicinity of the site. Since then, suspected damage to buildings, pavements, and utilities due to ground movement induced by the works has attracted much public concern.

EXC

483. The construction of EXC station structure and the associated cut-and-cover western approach tunneling works[198] commenced in 2015. The ground settlement in the vicinity of the works was recorded to have exceeded the *Alarm Level* since November 2015.

484. In August 2018, MTRCL disclosed to the public that the *Alarm Level* had been exceeded at 49 settlement monitoring points in the vicinity of the EXC site. The construction works[199] at the EXC site were suspended by MTRCL on 10 August 2018. The subject was discussed in subsequent meetings in the Subcommittee on Matters Relating to Railways of the LegCo Panel on Transport on 31 August 2018, 7 December 2018, 1 February 2019 and 6 December 2019.

485. On 28 September 2018, a new mechanism for enhancing monitoring and making announcement for impact of the SCL works on nearby structures and public facilities ("*Enhanced Mechanism*", see ***Appendix 9-1***) was implemented by HyD, BD and MTRCL. The works at the EXC site were resumed on the next day, together with the use of a revised set of AAA Levels which was proposed by MTRCL and accepted by HyD.

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198 See *Figures 9-3-1* and *9-3-2* of ***Appendix 9-3*** for layout plan of EXC

199 At that time, about 15% of the excavation required for the construction of the underground station structure was yet to be carried out before reaching the final excavation level.

The Fleet Arcade

486. The Fleet Arcade is a cluster of low-rise buildings[200] at about 250 m to the west of the EXC site. It is located above the alignment of the NSL Western Bored Tunnels, which comprise an up-track tunnel and a down-track tunnel constructed by tunnel boring machine ("TBM") under the SCL Project.[201]

487. The TBM for the construction of the up-track and down-track tunnels passed underneath the Fleet Arcade in April and October 2017, respectively. During the tunneling works, MTRCL recorded several occasions of exceedance of the *Alarm Level* of building settlement at the Fleet Arcade and ground settlement in its vicinity. In this connection, there was considerable public attention on the recorded settlements and suspected building damage.

Views Previously Given by EA Team on Enhanced Mechanism

488. Amid concern about the settlement-related issues of the SCL Project, the *Enhanced Mechanism* implemented by HyD, BD and MTRCL on 28 September 2018 was aimed at improving the settlement monitoring and control system of the SCL Project.

489. While that was in the early stage of EA Team's involvement in the SCL Project, the views of EA Team were sought and incorporated in the *Enhanced Mechanism* before its finalization for implementation.

490. In its Interim Report of October 2018, the EA Team summarized its input to the *Enhanced Mechanism* and views on its implementation. In particular, the EA Team noted the following:

[200] See *Figure 9-4-1* of ***Appendix 9-4*** for a view of the cluster of buildings of the Fleet Arcade

[201] See *Figure 9-4-2* of ***Appendix 9-4*** for layout plan of the Fleet Arcade and the tunnels

(a) regarding the implementation of the *Enhanced Mechanism*, "*MTRCL and the relevant government departments should thoroughly follow the principles set out therein [the Enhanced Mechanism], as well as the requirements stipulated in the accepted monitoring plans. This will ensure timely and appropriate actions, including suspension of works in the event of breaching the Alarm Level, are taken to control any further adverse impacts that may be caused by the remaining works of the SCL Project on the nearby facilities.*"[202];

(b) regarding revision of AAA levels, *"not only should the revision of the AAA Levels be made with full justifications, the number of revisions should also be minimized.*"[203]; and

(c) regarding the effectiveness of the *Enhanced Mechanism*, "*While the EA Team believes that the mechanism will improve the situation, its effectiveness will depend on whether the requirements set out therein are thoroughly followed by the relevant parties.*"[204]

491. The EA Team stated in the Interim Report that it "*plans to conduct audits of selected cases in the SCL Project, including cases before and after the implementation of the mechanism, to assess the effectiveness of the monitoring and control system*".[205] The EA Team undertook that upon completion of the audits, it "*will tender its observations on the lessons learnt and recommendations on areas for improvement*".[206]

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[202] See paragraph 4.13 of the Interim Report of the EA Team

[203] See paragraph 4.14 of the Interim Report of the EA Team

[204] See paragraph 4.14 of the Interim Report of the EA Team

[205] See paragraph 4.15 of the Interim Report of the EA Team

[206] See paragraph 4.16 of the Interim Report of the EA Team

Scope of Audit

492. In this context, a settlement audit was conducted by the EA Team to review selected cases where notable settlements have been reported and to identify lessons learnt and areas for improvement.

493. Selected incidents of exceedance of the *Alarm Level* at or in the vicinity of TKW, EXC and the Fleet Arcade sites were identified from the available information. Records from MTRCL and relevant Government departments on the incidents were reviewed. Where necessary, clarifications were sought from these parties by the EA Team.

494. The audit was based on the available records. It focused on reviewing the site activities associated with the exceedance of the *Alarm Level* and the response actions taken in the implementation of the AAA mechanism. These provided a basis for appraising whether the established requirements and good practice were followed for the monitoring and control of the site works under the AAA mechanism. Neither physical investigation works nor design analyses were carried out by the EA Team, given that the audit was not intended for assessing the effectiveness of the response actions that were taken, nor the extent of damage that might have arisen from the works.

495. The underground construction works at TKW and the tunneling works underneath the Fleet Arcade had substantially been completed when the *Enhanced Mechanism* was implemented. Hence, the audit at TKW and the Fleet Arcade covered only incidents prior to the implementation of the *Enhanced Mechanism*. At EXC, both cases before and after the implementation of the *Enhanced Mechanism* were audited.

496. The details of the settlement audits at TKW, EXC and the Fleet Arcade are presented in ***Appendices 9-2, 9-3*** and ***9-4***, respectively. The key findings of the settlement audit, particularly regarding the non-conformances observed, are summarized in *paragraphs 497* to *525* below.

Non-conformance Observed in Audit of TKW

497. Six monitoring points in the vicinity of TKW, where notable settlements were reported to have occurred during the construction of the station structures, were selected for audit. The six selected monitoring points covered ground settlement, utility settlement, building settlement and drawdown of groundwater level.

498. At the six monitoring points, a total of nine different incidents of exceedance of the *Alarm Level* were identified. These incidents occurred between 2013 and 2017, during which the D-wall construction, bulk excavation and dewatering works were in progress.[207]

499. Apart from reviewing the monitoring data at the six selected monitoring points, the available monitoring data at the other relevant monitoring points in the site in three snapshots of time, viz. February 2014, September 2014 and March 2017, were also examined in the audit. This enabled an appraisal of the spatial extent of the exceedance of the *Alarm Level*. The findings showed that the exceedance had occurred in a sizeable area, and was not confined to the selected monitoring points.

500. Six of the nine incidents involved the exceedance of the *Alarm Level* of ground settlement, utility settlement and groundwater drawdown. It was specified in the accepted drawing that all construction activities within 50 m of where the *Alarm Level* was reached shall be suspended. In all of the six incidents, the relevant construction works (i.e. D-wall construction, bulk excavation and dewatering) were not suspended after the exceedance of the *Alarm Level*. This did not comply with the requirements stipulated in the accepted drawing.

501. The other three of the nine incidents involved the exceedance of the *Alarm Level* of building settlement. Likewise, the relevant works (i.e. D-wall construction, bulk excavation and dewatering) were not suspended after the exceedance. According to the accepted monitoring and control plan, precautionary and mitigation actions should be undertaken but

[207] The nine incidents of exceedance of the *Alarm Level* are listed in *Table 9-2-3* of ***Appendix 9-2***.

suspension of works was not specified in the event of exceedance of the *Alarm Level* of building settlement. Hence, the continuation of the works after the exceedance of the *Alarm Level* of building settlement in these three incidents did not contravene the requirements of the accepted monitoring and control plan.

502. In all the nine incidents of exceedance of the *Alarm Level*, the construction works had continued to proceed for a considerable time until the completion of the relevant works without a revised and accepted AAA Levels being in place. As such, in practice, after the exceedance of the *Alarm Level*, the relevant works were continued to be carried out without the control of an applicable AAA mechanism. This was not in line with the established good practice for settlement monitoring and control in major underground construction works.

503. MTRCL acknowledged that, in the nine incidents, the construction works were continued to be carried out without suspension and also without a revised and accepted set of AAA Levels being in place.

504. While the *Alarm Level*s of ground settlement, utility settlement, building settlement and groundwater drawdown had been exceeded extensively at TKW, there were no records of exceedance of the *Alarm Level* of building tilting throughout the construction period.

Non-conformance Observed in Audit of EXC

505. The monitoring and control system adopted in EXC was similar to that in TKW. However, there was one notable difference. In TKW, suspension of works in the event of exceedance of the *Alarm Level* of building settlement was *not* specified. In EXC, in the event of exceedance of the *Alarm Level* of building settlement, suspension of all construction activities within a minimum distance of 50 m of where the *Alarm Level* was reached, was also specified in the accepted drawing.

506. Seven monitoring points in different parts of the area adjoining the EXC were selected for audit. These included six monitoring points on ground settlement and one on utility settlement. As there were no reports of excessive building settlement, building tilting and groundwater drawdown in EXC, such monitoring points were not selected for audit.

Prior to implementation of Enhanced Mechanism

507. During the construction of the D-wall, the *Alarm Level* of two of the seven selected monitoring points had been exceeded since November 2015 and September 2016, respectively. During bulk excavation, exceedance of the *Alarm Level* at the other five of the selected monitoring points began to occur from June 2017 to May 2018.[208]

508. The spatial extent of the exceedance of the *Alarm Level* was examined. The exceedance was not confined to the selected monitoring points, but covered a sizeable area.

509. In the seven incidents, the relevant works were not suspended as specified in the accepted drawing. As in the case of TKW, the relevant construction works were continued for a considerable time without a revised and agreed set of AAA Levels being in place. These were not in line with the requirements of the accepted drawing, nor with the established good practice for settlement monitoring and control in major underground construction works.

510. As described in *paragraph 484* above, the works at EXC were eventually suspended on 10 August 2018. By that time, the *Alarm Level* had been exceeded in as many as 49 monitoring points at EXC. With the introduction of the *Enhanced Mechanism* and revision of the AAA Levels, the works were resumed on 29 September 2018, almost seven weeks since the suspension of works.

[208] The seven incidents of exceedance of the *Alarm Level* are listed in *Table 9-3-3* of ***Appendix 9-3***.

511. While acknowledging that the construction works in the seven incidents were continued to be carried out without a revised and accepted set of AAA Levels being in place, MTRCL noted that *"there were two occasions of local suspension after the exceedance of AAA Levels"*. Given the sizeable spatial extent of the exceedance of the *Alarm Level*, it is evident that the suspension of *"all construction activities within a minimum distance of 50 m radius of the instrument of where the Alarmed values were reached"* as specified in the accepted drawing should be much more extensive than the two *"local suspension"*. In addition, without putting in place a revised and accepted set of AAA Levels, the suspended works should not be resumed.

512. Therefore, for the purpose of this audit, the EA Team did not consider that the "*two occasions of local suspension after the exceedance of AAA Levels"* as stated to have been made by MTRCL would have met the requirements for suspension of works stipulated in the accepted drawing in the seven audited incidents. HyD shared this view.

After implementation of Enhanced Mechanism

513. In connection with the implementation of the *Enhanced Mechanism* in September 2018, the AAA Levels for EXC were revised and accepted. Since then, none of the monitoring points of EXC were reported by MTRCL to have further incidents of exceedance of the revised *Alarm Level*.

Non-conformance Observed in Audit of the Fleet Arcade

514. Four monitoring points, including three on building settlement and one on ground settlement, were selected for audit. There were two applicable sets of AAA Levels for the TBM tunneling works, one for the up-track tunnel and the other for the down-track tunnel.

515. As in EXC, suspension of *"all construction activities within a minimum distance of 50 m radius of the instrument of where the Alarm value was reached"* was specified in the accepted monitoring and control

plan in the event of exceedance of the *Alarm Level* in the Fleet Arcade. This applied to both building settlement and ground settlement.

516. The first TBM drive for the up-track tunnel between EXC and Admiralty Station took place from March to May 2017. The second TBM drive for the down-track tunnel was carried out from September to November 2017. The TBM drives for the up-track and down-track tunnels passed underneath the Fleet Arcade in April 2017 and October 2017, respectively.

517. Soon after the commencement of the first TBM drive for the up-track tunnel, the *Alarm Levels* at all of the four selected monitoring points were exceeded in April 2017.[209] In these four incidents of exceedance of the *Alarm Level* (i.e. Incidents No. 1 to 4), the construction activities (i.e. TBM tunneling works) were not suspended. This did not comply with the requirements specified in the accepted monitoring and control plan. Also, the TBM tunneling works were continued without putting in place a revised and accepted set of AAA Levels for controlling the works.

518. MTRCL advised that the TBM tunnel excavation at the site was suspended in one occasion in the period. The following information was provided by MTRCL:

> *"For the Up-track TBM tunnelling in close proximity of Fleet Arcade in April 2017, one no. of AAA Exceedance Notification Form (i.e No. 221) was received with exceedance of the Alarm Level of the external wall tilting (1:820) for the monitoring point Nos. WCSP-CG-001-V and WCSP-CG-008-V at Main Building of The Fleet Arcade on 13 April 2017. As a result, the TBM tunnelling excavation was suspended between 14 April 2017 and 17 April 2017. The TBM tunnelling work was resumed after the concerned external wall was inspected by RSE team and the associated safety precautionary works were carried out. As the TBM tunnelling work advanced forward*

[209] The four incidents of exceedance of the *Alarm Level* are listed as Incidents No. 1 to 4 in *Table 9-4-3* of ***Appendix 9-4***.

and steadily moving away from Fleet Arcade, three no. of AAA Exceedance Notification Forms were received (i.e. No. 222, 228 & 230) due to some residual settlement effect. Site inspection by RSE team were conducted and the concerned building was in a safe condition in general. Structural Assessment with proposal of revised AAA level were submitted to RDO for review and the approval of these revised AAA levels was obtained before commencement of the Down-track TBM tunnelling work."

519. The EA Team noted that this was a brief occasion of suspension of works, which was during the Easter public holiday in 2017, in response to the exceedance of the *Alarm Level* of building tilting recorded at two other monitoring points at the time. The suspension was to deal with the recorded building tilting at that particular location. It was unrelated to, and was not addressing the audited incidents of exceedance of the *Alarm Level*, which involved building and ground settlements recorded at the four selected monitoring points. The TBM works were resumed after the brief period of suspension, but no provision was made in the revision and acceptance of the *Alarm Levels* which were exceeded in respect of the building and ground settlements at the selected monitoring points.

520. After the commencement of the second TBM drive for the down-track tunnel, the *Alarm Levels* at the selected ground settlement monitoring point and at two of the selected building monitoring points were also exceeded in October 2017.[210]

521. At the time of occurrence of these three incidents in the second TBM drive, the cutterhead of the TBM had just been advanced to a location which was more than 50 m from the relevant monitoring points. It might be argued that the requirement for suspension of works was no longer applicable to the TBM cutterhead, even though the recorded settlement was related to the TBM works. However, since the *"50 m radius"* is a *"minimum distance"* specified in the accepted monitoring and control plan,

[210] The three incidents of exceedance of the *Alarm Level* are listed as Incidents No. 5 to 7 in *Table 9-4-3* of ***Appendix 9-4***.

in EA Team's view, it should still be applicable to construction activities beyond 50 m from the instrument if the exceedance of the *Alarm Level* is related to the construction activities. Hence, while there are some ambiguities in the three incidents, the EA Team opined that the requirement for suspension of works should also be applied to the TBM works which were only marginally beyond 50 m from the monitoring points at the time.

522. The possibility that the site might be affected by other concurrent construction activities in the vicinity, apart from the TBM tunneling works, was raised at the time. EA Team's observations about this are presented in *paragraphs 555* to *557* below. There is also a question about whether suspension of the TBM works would serve much useful purpose, particularly in view of the observed delay in the response of ground and building settlements. This is discussed in *paragraphs 558* to *563* below.

Other Precautionary and Mitigation Actions in the Three Audited Sites

523. The non-conformance with the requirements specified in the accepted monitoring and control plan for suspension of works upon the exceedance of the *Alarm Level* is a major irregularity observed in the settlement audit on the three sites. Other than this non-conformance, overall, the other precautionary and mitigation actions were duly carried out by MTRCL according to the AAA mechanism. The EA Team was aware of the effort made by MTRCL and the relevant Government departments in these actions, such as conducting reviews, enhancing the monitoring and control, carrying out ground treatment and other mitigation works, inspecting buildings for confirmation of structural safety, ensuring road safety via inspections and repairing pavements when found necessary, and liaising with the affected parties.

524. The EA Team opined that these precautionary and mitigation actions should not be taken as adequately replacing the need for suspension of works, as the two are required under the AAA mechanism for different purposes. Specifically, as in the three audited sites, after the exceedance of the *Alarm Level* and in the absence of an updated *Alarm Level* applicable to the works that are yet to be carried out, suspension of works would provide the vital opportunity for the revision and acceptance of an

applicable *Alarm Level*. Otherwise, the works would continue to be carried out without the control of an applicable AAA mechanism. This is unacceptable.

525. The EA Team did not conduct an in-depth diagnosis of the causes of the recorded settlements and their inter-relationship with the construction works and with the suspected damage. It was outside the scope of this audit to evaluate the adequacy and effectiveness of the precautionary and mitigation actions that were implemented. However, the EA Team found no cause from the audit to doubt that due attention was given by MTRCL and the relevant Government departments in attending to and ensuring structural safety.

526. Notwithstanding the above, the EA Team considered that there were useful lessons to learn from the audited cases.

Observations and Lessons Learnt

527. Major underground construction and tunneling works were completed in the three sites, which were subject to considerable site constraints. These included presence of sensitive facilities in close proximity to the sites, vulnerable subsoil conditions, high groundwater level, limited working space and concurrent construction activities of other projects. They posed an immense challenge to controlling the adverse impacts of the works to the surroundings. To meet the challenge, implementation of an effective monitoring and control system is vital.

528. The settlement audit conducted on the three sites provided an opportunity for reviewing possible areas for improvement. The EA Team's observations, particularly concerning the lessons learnt in the monitoring and control of similar works in future, were summarized in the remainder of this Section.

Alarm Level unrealistically lower than predicted level

529. In the three audited sites, the monitoring and control plan was timely formulated and accepted, before the commencement of the works. Overall, the monitoring and control system was comprehensive, with the relevant monitoring parameters identified, the corresponding monitoring points proposed, and the AAA Levels and the response actions specified.

530. Notwithstanding these, there is a key area for improvement regarding the threshold limit set for suspension of works, i.e. the *Alarm Level*.

531. It was apparent from the settlements predicted at TKW and EXC by design analysis that some of proposed and accepted AAA Levels were unrealistically low. For example, at TKW, the predicted ground settlement was as much as over 45 mm. At EXC, the predicted ground settlement was even greater, which exceeded 100 mm at the locations of many of the monitoring points. However, in the accepted drawings of the two sites, an *Alarm Level* of 25 mm was specified.

532. The use of a low settlement limit as the *Alarm Level* may facilitate its acceptance, given that a small settlement would bring about lesser adverse impact on the nearby facilities. However, as this low settlement limit is much smaller than the predicted settlement, exceedance of the *Alarm Level* during construction is perceivable. When the *Alarm Level* is indeed exceeded during the works on site, it would be necessary to implement the required response actions, including suspension of works. The *Alarm Level* would then have to be revised to a higher settlement limit, with the necessary justifications, and accepted for controlling the works upon their resumption.

533. Had a more realistic settlement limit been justified for acceptance in the design stage, this would have avoided the undesirable scenario of exceedance of the *Alarm Level* during construction, disruption of the works progress due to suspension, and revision of the AAA Levels in urgency for the works to be resumed as soon as possible. The use of an unrealistically

low *Alarm Level* is deferring the problem that should have been resolved in the design stage to the construction stage. In effect, it passes a time bomb to the construction.

534. In EA Team's opinion, if a relatively large settlement is predicted in the design, the designer should assess whether the adverse impacts that may arise from the predicted settlement are acceptable to the affected facilities. If so, the *Alarm Level* which tallies with the predicted settlement should be proposed, with justifications, for acceptance. If the predicted settlement is found to be unacceptable, then the designer should revise the design with a view to reducing the predicted settlement to an acceptable level. Alternatively, the designer may propose the necessary strengthening and mitigation works, such as ground improvement or underpinning of existing buildings, to minimize the adverse effects and render the predicted settlement acceptable to be used as the *Alarm Level*.

535. If this is not properly sorted out in the design stage, it will eventually have to be dealt with during construction, unless one chooses not to comply with the accepted monitoring and control plan during construction.

536. The EA Team was aware of the view that one may choose to initially set a more stringent *Alarm Level,* and then relax it when the need arises during construction. One may even consider this a possible means to ensure that the contractor would carry out the works more cautiously. However, the EA Team has major reservation about this arrangement, in view of the following:

(a) The *Alarm Level* is the highest limit in the AAA mechanism serving as the threshold for suspension of works among other required response actions. Distorting the threshold value for such purposes is *undesirable*.

(b) The *Alert Level* and *Action Level*, being the lower and hence more stringent limits of control in the AAA mechanism are available to serve such purposes. Hence, distorting the

threshold value of the *Alarm Level* for such purposes is *unnecessary*.

(c) If an unrealistic *Alarm Level* is imposed on the contractor's works, this will unnecessarily inflate both the risk (e.g. suspension of works, which will result in delay to the construction programme) and cost (e.g. need for additional precautionary and mitigation measures to avoid reaching the stringent *Alarm Level*) of the construction. This adversely *affects cost-effectiveness*, and may also lead to *contractual disputes*.

(d) If the *Alarm Level* which has been exceeded during construction is not revised and accepted in time, all parties will be faced with the difficult consequence of either suspending the works as specified or continuing with the works without the control of an applicable AAA mechanism.

537. Indeed, there was a lack of revised *Alarm Level*s over a prolonged period in the audited sites. In facing with the dilemma when the *Alarm Level* was exceeded during construction in the three sites, it was apparently the norm rather than the exception that the requirements for suspension of works were not observed.

538. Hence, in formulating similar monitoring and control plans in future, MTRCL is recommended to set a realistic *Alarm Level* (i.e. the threshold for suspension of works) which tallies with the predicted ground response, subject to proper justification of the acceptability of this limit.

Monitoring

539. The available records of the audited sites indicated that regular monitoring was carried out in accordance with the accepted monitoring and control plans. MTRCL had made arrangement for its independent monitoring consultant to carry out spot-checking and joint survey with the contractor's surveyor. This is a good practice for ensuring the reliability

and coherence of the monitoring data, based on which the monitoring and control system is implemented.

Suspension of works upon exceedance of Alarm Level

540. A total of 23 incidents of exceedance of the *Alarm Level* were identified from the audit of the 17 selected monitoring points in the three sites, and the construction activities in the vicinity were not suspended after the exceedance. Apart from three incidents which involved building settlement in TKW, suspension of the construction activities was specified in the accepted monitoring and control plans (see *paragraph 501* above). In another three incidents which involved ground and building settlements in the second TBM drive at the Fleet Arcade site, there are some ambiguities about the applicability of the requirement for suspension of the TBM works (see *paragraph 521* above). Aside these six incidents, the lack of suspension of works in the other 17 incidents evidently did not conform with the requirements stipulated in the accepted plans.

541. It is essential for the construction of underground works in Hong Kong's urban environment to maintain a rigorous discipline in complying with the requirements stipulated in the accepted monitoring and control plans. The required response actions, including suspension of works in the event of exceedance of the *Alarm Level*, should be promptly undertaken. The requirement for suspension of works serves two essential purposes.

(a) Firstly, it avoids aggravation of the site conditions due to further adverse impacts that may arise from the continuation of the works, while the adverse impacts have already reached the pre-set threshold limit, i.e. the *Alarm Level*.

(b) Secondly, it provides an important window of opportunity, before resumption of the works, for reviewing what has gone wrong, implementing the necessary precautionary and mitigation measures, and revising the AAA Levels with justifications for acceptance. This applies in particular to the circumstances that the review and revision of AAA Levels

have not been thoroughly dealt with when the *Alert Level* and *Action Level* were previously exceeded.

542. While the need for observance of the requirement for suspension of works in the event of exceedance of the *Alarm Level* is reiterated in the *Enhanced Mechanism*, it has always been part of the established good practice for monitoring and control of construction works.

543. For other projects affecting MTRCL's facilities, their works are always strictly suspended upon reaching the *Alarm Level*. Similarly, private development works are required to be immediately suspended in the event of breaching the *Alarm Level*, and failure to comply with this requirement may be subject to follow-up actions under the BO. MTRCL should adopt a consistent approach in controlling the works of its projects affecting the facilities of other parties.

544. In this connection, it is recommended that MTRCL should rigorously observe the requirements for implementation of the response actions specified in the accepted monitoring and control plans, including suspension of the relevant construction activities upon exceedance of the *Alarm Level*. MTRCL should also enhance its project management practice to avoid recurrence of similar non-conformances.

Revision and acceptance of AAA Levels after exceedance

545. In the 23 audited incidents of exceedance of the *Alarm Level*, the works had continued to proceed for a considerable period of time, many even to their completion, without the revision and acceptance of an updated set of AAA Levels.[211] The AAA mechanism as a means for controlling the works has broken down after the exceedance of the *Alarm Level*. Continuation with the works without a revised and accepted set of AAA Levels in place, as is the case in the audited incidents, implies that the works will then be carried out without the control of an applicable AAA mechanism.

[211] Among the 23 incidents, the seven incidents in the Fleet Arcade were subject to the problem of residual settlement probably due to the delayed response of the ground and building settlements induced by the TBM tunneling works. In this connection, the lessons learnt are further discussed in *paragraph 558* to *563* of this Section.

546. This is contrary to the established good practice of instigating the AAA mechanism in the first place for the works. As the works have already resulted in a level of adverse impacts reaching the threshold limit specified in the *Alarm Level* for suspension works, it is particularly undesirable for the works to continue not only without suspension as specified, but also without the control of an applicable AAA mechanism.

547. It is recommended that the AAA Levels, particularly upon the exceedance of the *Alarm Level*, should be timely revised by MTRCL with justifications for acceptance, to ensure that the relevant works which are yet to be carried out are subject to the control of a suitable and applicable AAA mechanism. Also, after exceedance of the *Alarm Level*, resumption of works should not be allowed without an applicable and accepted AAA mechanism being in place.

Safety vs damage

548. In its Interim Report of October 2018, the EA Team stated the following:

> *"the EA Team noted that the AAA Levels were normally set with a view to both ensuring safety and avoiding damage to properties. While ascertaining the safety condition is the priority for inspection upon breaching the AAA Levels, the EA Team considered that the inspection should also include the damage aspect."*[212]

549. In the audit, the EA Team noted circumstances with potential ambiguity in whether the damage aspects had been duly accounted for, aside the safety aspects. For instance, in assessing the acceptability of the predicted building settlements for the TBM tunneling works in the Fleet Arcade, consideration was given primarily to building safety, via analysis of structural integrity. As such, the *Alarm Level* found to be justifiable from the assessment might only be acceptable for the purpose of avoiding structural failure, but not building damage in general.

[212] See paragraph 4.11 of the Interim Report of the EA Team

550. In the audited incidents of exceedance of the *Alarm Level*, although the works were not suspended, MTRCL had taken actions to review the structural integrity and ensure safety. BD also noted that, in those cases that it was involved, it "*had inspected the affected buildings and no obvious structural safety problem was found*". While ensuring safety is important, it should not be overlooked that the AAA mechanism serves not only to ensure safety but also avoid damage to properties.[213] Building damage, such as loosening of plaster, cracking of non-structural walls and leakage of water-carrying services, could become a problem even though structural integrity and building safety are not yet at stake.

551. The EA Team reiterates its view that, in addition to safety consideration, damage inspection and assessment should be thoroughly carried out by MTRCL after the exceedance of the *Alarm Level*, to provide a basis for establishing the need for any mitigation or other follow-up actions and ascertaining the acceptability of resumption of works. This has been incorporated in the *Enhanced Mechanism* (see *paragraph 6 of* ***Appendix 9-1***).

552. Likewise, in assessing the acceptability of the AAA Levels, due consideration should be given to limiting damage to properties, apart from avoidance of structural failure. This is the established practice, but was apparently not consistently followed in all cases.

Role of Government departments

553. In the three audited cases, various Government departments (viz. HyD, BD and Geotechnical Engineering Office) were involved in different capacity in the monitoring and control mechanism. The settlement audit revealed that there was room for improvement in their respective overseeing, regulatory or advisory role in the project.

[213] For example, it is stated in the Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers APP-137 that the guidelines given therein on the control of ground-borne vibrations and ground settlements, including the AAA mechanism, are "with a view to minimizing possible damage to adjacent properties and streets".

554. It is recommended that the relevant Government departments should adopt a proactive and firm approach to ensure that the response actions specified in the accepted monitoring and control plan are duly taken by MTRCL. This applies in particular to suspension of works in the event of exceedance of the *Alarm Level* and revision of the AAA levels with justifications for acceptance before resumption of works.

Effects of concurrent construction activities

555. In EXC and the Fleet Arcade, views were raised during construction that the notable settlements recorded might be caused partly by the concurrent construction activities of other projects in the vicinity. For instance, in a number of occasions when the *Alarm Level* was exceeded, MTRCL opined that the settlement was partly due to other concurrent construction activities.

556. The EA Team appreciated the possibility that concurrent construction activities might contribute to the recorded settlements in some cases. From a review of the relevant cases in the audit, the EA Team noted three areas for improvement.

(a) Firstly, despite MTRCL's view that the concurrent construction activities were contributing to the recorded settlements, further investigation to ascertain this was not thoroughly carried out at the time. If indeed the nearby facilities were suffering from the adverse effects, with the *Alarm Level* already reached, from both MTRCL's works and the other concurrent construction activities, this should have been further investigated as part of the follow-up actions. This would help ascertain the effect, if any, that the concurrent construction activities had impacted on the facilities. It would also facilitate evaluation of any further effects that may arise from the remaining works of the concurrent construction activities in addition to those of MTRCL's works.

(b) Secondly, despite the claim that the concurrent construction activities were contributing to the recorded settlements, little consideration was given to assessing the combined effects yet to be induced by the ongoing concurrent construction activities and MTRCL's proposed works. For instance, in predicting and assessing the acceptability of the further settlement which would next be induced at the affected facilities in the Fleet Arcade, consideration was given to only the settlement which would be caused by MTRCL's proposed works. No account was taken of that which might be induced by the ongoing, concurrent construction activities. This is unsatisfactory.

(c) Thirdly, the EA Team was concerned about the possibility of inadequate coordination in dealing with facilities affected by concurrent construction activities from multiple projects. Under the current, project-based monitoring and control arrangement, individual projects would separately predict the settlement induced by its works and the acceptability of its effects on the facilities. There seems to be inadequate consideration given to the combined effects from all the projects. There may also be insufficient coordination in addressing the combined effects and resolving possible disputes among the involved parties, particularly when the projects are managed by different parties.

557. Therefore, it is recommended that the Government should look into means of enhancing the coordination in dealing with facilities affected by more than one project, to ensure that the combined effects are duly accounted for in the monitoring and control plans of future railway projects. This applies to both the formulation and implementation of the monitoring and control plans. For this purpose, consideration may be given to assigning a coordinator to take an accountable and leading role in dealing with the combined effects of concurrent construction activities. For instance, the Government department managing the project which will potentially affect the facilities most may act as the coordinator.

Monitoring and control of TBM tunneling works

558. As illustrated in the case at the Fleet Arcade, the recorded ground and building settlements continued to increase for some time, after the TBM had traversed through the site (see ***Figures 9-4-4*** and ***9-4-5*** of ***Appendix 9-4***). This is referred to as "residual settlement" by MTRCL, which is related to the delay in the response of ground and building settlements induced by the TBM tunneling works. While there was a possibility that other concurrent construction activities might have partly contributed to the recorded settlements, the time lag in the response of ground and building settlements has been commonly observed in tunneling works in Hong Kong, especially in reclamation areas.

559. The delay in response could result in a scenario that when the recorded settlement reaches the *Alarm Level*, the tunnel excavation face might have already traversed, or largely traversed through the site that is affected by the settlement. This was the case in the Fleet Arcade, with two notable implications. Firstly, by the time when the *Alarm Level* is found to have been breached, the TBM that induced the settlement is about to pass through the site. As such, the suspension of works may not help as much as in the case of other types of construction works (e.g. D-wall and bulk excavation works) in containing the adverse effects that may result from furthering the works. Secondly, after the breach of the *Alarm Level*, the affected facilities would continue to suffer from further settlement due to the delay response, even though the TBM is leaving the site. This means that the situation will continue to deteriorate after the breach of the *Alarm Level*, which renders the monitoring and control system ineffective in fulfilling its intended purpose.

560. Regarding the lack of suspension of the TBM tunneling works in the audited incidents in the Fleet Arcade, MTRCL explained that "*it would not have helped the situation to suspend the TBM tunneling works*" and "*suspending the tunnelling work ahead would not be beneficial to the residual settlement condition*".

561. Given the delay in ground response, the EA Team accepted that the suspension of works might only give limited help (but still it would help to a certain extent). However, the EA Team would caution against taking this as a justification for business as usual, as if it is a non-issue. In reality, the facilities were affected by notable settlements, which exceeded the *Alarm Level.* Furthermore, before the exceedance, there was a lack of an effective mechanism to control the works with a view to avoiding the breach of the *Alarm Level*. After the exceedance of the *Alarm Level*, no provisions were available to effectively control the further increase in the settlement (i.e. the residual settlement arising from the delay response) and the consequential adverse effects. This situation is highly undesirable, and is not in line with the objective and principle of instigating the monitoring and control system for the works.

562. With the awareness of the delay in ground response, the monitoring and control system should have been revised and improved to make it more effective in anticipating the eventual exceedance of the *Alarm Level* in connection with the delay response. Also, the necessary response actions should have been taken earlier, so as to control the increase in settlement and avoid reaching the *Alarm Level*. In practice, these may call for the following provisions:

(a) introducing additional monitoring points at suitable locations in the area that the TBM would traverse before reaching the concerned facilities, in order to track the settlement trend including the pattern and magnitude of the delay response, for evaluating the eventual settlement that may occur at the facilities when the TBM traverses through them;

(b) specifying a more stringent set of AAA Levels for controlling the TBM works, with account taken of the further settlement that may eventually occur due to the delay in response; and

(c) implementing the required response actions well in advance of the breach of the AAA Levels, e.g. provision of ground treatment, gearing up the control of the TBM, suspension of works, and review of the acceptable settlement.

563. It is recommended that in formulating and implementing monitoring and control plans for future railway projects, due account should be taken by MTRCL and the relevant Government departments of the possible delay in the response of ground and building settlements induced by tunneling works.

Audits by MTRCL and HyD

564. Regular internal audits were conducted by MTRCL on the site works. MTRCL advised that, over the period when the incidents of exceedance of *Alarm Level* occurred in the audited sites, *"there were internal audits but no touching on AAA exceedance"*.

565. HyD's M&V consultant had conducted annual public safety audits of the works in the SCL sites. The audits included "*Review of procedures when instrumentation recorded exceedance of the AAA values*" as one of the items to be checked. Any non-conformances identified, among other findings, were included in the audit reports.[214] TKW and EXC had been subjected to these audits.

566. None of the available audit reports by the M&V consultant in the TKW and EXC sites covering the period of exceedance of the *Alarm Level* had identified the non-conformance with the requirement for suspension of works after the exceedance of the *Alarm Level*.

567. Instead, for TKW, it was stated in the 2014 and 2015 audit reports *"When an exceedance of the AAA Level occurred, the procedures as per MTRCL Procedures had been followed"*, and in the 2016 and 2017 reports *"When an exceedance of the AAA Level occurred, the procedures as stated in the PS [Particular Specifications] and construction drawings had been followed"*.

[214] The reports are entitled "Public Safety Audit for SCL Works – SCL Contract 1109 Sung Wong Toi and To Kwa Wan Station and Tunnels" for TKW, and "Public Safety Audit Report for SCL Works – SCL Contract 1123 Exhibition Station and Western Approach Tunnel" for EXC.

568. For EXC, all the four audit reports from 2015 to 2018 stated *"The settlement readings were monitored closely. When an instrument recorded exceedance of the AAA values, the procedures stated in the instrumentation and settlement management plan were followed"*.

569. The EA Team was concerned that the audits were not only ineffective in identifying the non-conformance with the requirement for suspension of works in the incidents of exceedance of the *Alarm Level*, but might have also given a misleading assurance in this respect.

570. The wider issue about the effectiveness of the audits by MTRCL and HyD and areas for improvement will be discussed in the topic *conducting effective audits* in ***Section 10*** of this report.

Enhanced Mechanism

571. Since the implementation of the *Enhanced Mechanism* together with the revision of the AAA Levels in September 2018, the *Alarm Level* had not been exceeded in EXC until the completion of the remaining bulk excavation and station construction works. In the audit, the EA Team did not find any major anomalies in the implementation of the *Enhanced Mechanism*.

572. Both MTRCL and HyD advised the EA Team that the implementation of the *Enhanced Mechanism* was satisfactory. While this is encouraging, the EA Team opines that the effectiveness of the *Enhanced Mechanism* and the thoroughness of its implementation by the involved parties are yet to be further tested. When the *Enhanced Mechanism* was introduced, EXC was the only active construction site of the SCL Project. The potential impacts of the remaining works in EXC were much less significant in comparison with those in the earlier stage of the works. The absence of major anomalies in the implementation of the *Enhanced Mechanism* should also be considered in this context.

573. The guidelines and procedures given in the *Enhanced Mechanism* for the response actions under the AAA mechanism are based on the established practice, which is specified in the accepted monitoring and control plans. Reiterating these in the *Enhanced Mechanism* is an explicit undertaking by MTRCL and the relevant Government departments in complying with the established practice. The *Enhanced Mechanism* also includes guidelines and procedures for enhancing the communication with the stakeholders. This demonstrates the commitment of MTRCL and the relevant Government departments in improving the transparency and accountability in dealing with settlement-related issues.

574. The *Enhanced Mechanism* was introduced for adoption in the SCL Project. Given its useful purposes and the satisfactory experience gained from its implementation so far, it is recommended that HyD, BD and MTRCL should refine the *Enhanced Mechanism* to incorporate the areas for improvement identified from the settlement audit and other experience gained, for implementation in future railway projects.

Consultation with industry

575. The successful application of the monitoring and control system calls for professional input from practitioners. It is recommended that MTRCL and the relevant Government departments should maintain a close dialogue with the industry in pursuing improvement to the monitoring and control system and soliciting their feedback.

Section 10 Project Management

PIMS

576. According to its Terms of Reference, the EA Team has to "*review the Project Integrated Management System (PIMS) of the MTR Corporation Limited (MTRCL) to identify areas for improvement, as well as enhancement in communication and check-and-balances, including, but not limited to, how hold point inspections are to be conducted by MTRCL and/or Government, possible use of smart technology for site supervision*.".

577. The PIMS is the project management system established and used by MTRCL to manage railway projects in Hong Kong for more than 20 years. It includes Manuals, Procedures and Practice Notes, which cover a wide range of project management subjects.

578. Amongst other things, the procedures for formal inspections and approval of site works, RISC form process, handling of NCR and preparation of as-built records as a continuous operation as construction proceeds are set out in the PIMS. These are matters investigated extensively in the Inquiry. The PIMS also deals with the management of the design process, which is not the main subject of the Inquiry.

579. The PIMS sets out the principles, requirements and procedures for MTRCL's project management. As in all documents of this kind, what is specified in the PIMS is one thing, what is actually carried out in practice may at times be another matter due to deviations of the implementation from the guidelines given in the PIMS. The lessons learnt from the SCL Project would provide insights into possible areas for improvement in MTRCL's project management. These may, in some cases, involve an enhancement of the guidelines given in the PIMS. In other cases where suitable guidelines have already been given in the PIMS, it may principally be the implementation of the guidelines which calls for improvement.

580. As an illustration, as far as record management is concerned, the PIMS has stipulated high level requirements in its Manual (PIMS/MAN/003/A4), which are reproduced below.

"**1.3 Records Management**

Procedures and Practice Notes identify the records to be maintained by the Projects Division throughout the duration of a project to ***provide evidence of conformity to requirements*** *and the effective operation of the PIMS.* ***Records shall be legible, readily identifiable and retrievable****. Procedures and Practice Notes are established to define the controls needed for the identification, storage, protection, retrieval and disposition of records*." **[Emphasis added]**

581. As described in ***Section 3*** of this report, it transpired that the construction records in the Hung Hom Site were significantly deficient. Therefore, it is not the case that the PIMS has not covered the important subject of record management. It is only due to some reasons that the requirements for record management have not been followed through diligently as it should be.

582. The sheer volume of the documents in the PIMS has made it difficult for anyone outside MTRCL to comprehensively evaluate its contents, not to mention the effectiveness of its implementation. Only a small part of the PIMS, primarily related to document and data management, has been examined during the hearings of the Commission. The review of the PIMS would best be placed in the hands of MTRCL as what enhancements need to be made to augment its existing provisions and what improvements are required in the implementation of the provisions.

583. The EA Team is pleased to note that MTRCL has appointed an external management consultant to carry out a full review and an update of the PIMS by the last quarter of 2020. Pending the outcome of the review, MTRCL has revised and implemented the PIMS on site supervision and inspection process in August 2019.

584. In view of the above, the EA Team has focused its attention on the identification of the lessons learnt in project management, instead of the amendments to be made to the PIMS documents.

Project Management Issues

585. The Commission has put forward a number of recommendations in its Interim Report and Final Report in February 2019 and March 2020 respectively, many of which are related to project management. In particular, Mr Rowsell, the independent project management expert appointed by the Commission, has prepared two expert reports dated 20 December 2018 and 23 August 2019 respectively.[215] The Commission has accepted all the recommendations in the two expert reports without reservation.[216] These recommendations include project management matters to be addressed by both the Government and MTRCL.

586. In October 2019, the Chief Executive appointed an Independent Audit Panel ("IAP") to audit independently from the Government the implementation of the recommendations in the Commission's Interim Report. The IAP issued a report on 26 May 2020[217], outlining the implementation progress of the recommended measures by the Government and MTRCL. Out of the 58 recommendations in the Commission's Interim Report to promote public safety and assurance on quality of works, the IAP is of the view that 14 have been fully implemented and 42 are with satisfactory progress, whereas the remaining two have also made progress.

587. The IAP will conduct a further follow-up audit 12 months from the date of the Final Report, i.e. by March 2021.

588. The EA Team has the opportunity of making observations about the project management aspects from its review of the SCL Project. In light of these, the EA Team shared similar views in many of the project management issues identified by the Commission. These cover a range of matters pertinent to construction control, site supervision, specifications,

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[215] https://www.coi-hh.gov.hk/pdf/Expert_Report_Steve_ROWSELL.pdf & https://www.coi-hh.gov.hk/pdf/Expert_Report_Steve_ROWSELL_201910.pdf

[216] See paragraph 695 of the Final Report

[217] https://www.thb.gov.hk/eng/psp/publications/transport/studies/index.htm

regulatory requirements, project delivery, competence of personnel, management leadership, etc.

589. During the course of its work, the EA Team has also noted other facets of the works in the SCL Project in general, which are not confined to the Hung Hom Site. These included assessment of the other SCL stations, settlement audit, and other aspects such as design- and audit-related issues. Some of these were relevant to project management.

590. Regarding design and checking of design, the EA Team has presented its observations about the lessons learnt and areas for improvement in ***Section 7***. Apart from the technical aspects of the design, these also involve project management issues, such as avoiding conflict of interest, plugging gaps in Government's design checking, and enhancing cost-effectiveness in design. Those relating to settlement monitoring and control have been covered in ***Section 9***.

591. In order to minimize overlapping the project management issues already dealt with by the Commission and in the previous Sections of this report, the EA Team would like to highlight several salient issues that warrant attention to supplement the subject matter. These include:

(a) maintaining discipline in compliance with design and works requirements;

(b) keeping contemporaneous and traceable site records;

(c) conducting effective audits; and

(d) probing into the underlying causes.

Maintaining Discipline in Compliance with Design and Works Requirements

The concern

592. A host of irregularities in the Hung Hom Site were found from the review and Commission's Inquiry. The manifold and extensive deviations of the works from the design and works requirements are startling. These involve an apparent lack of discipline on site in two areas:

(a) construction in conformance with the design and relevant works specifications; and

(b) compliance with the essential site supervision and control requirements.

593. Regarding Item (a) of *paragraph 592* above, the issue of non-compliance with the design may be illustrated by the incidents of the First Change and Second Change.[218] These incidents, which involved unauthorized changes to the design during construction, were examined in the Inquiry. Mr Rowsell, in his report to the Commission[219], gave the following observations about the incidents:

> "*The opinion I have formed is that the contractual procedures had at this stage broken down and the position reached could be described as build and design (rather than design and build). I do understand the pressures that can develop on site during construction and the need to maintain programme but there always comes a stage where either the Contractor or the Engineer (or jointly, particularly in a partnering environment) should halt construction activity to ensure that approved designs are clear, procedures have been followed and are being implemented in practice.*"[220]

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[218] See *paragraphs 167 to 169* of this report

[219] In paragraph 661 of the Final Report, concerning the observations given by Mr Rowsell, it is stated that "*The Commission agrees with these observations*".

[220] See paragraph 660 of the Final Report

594. The significant irregularities of shear link placement in the HUH Extension structure, including missing shear links, smaller bar sizes and insufficient anchorage lengths as described in *paragraphs 78* to *83* in ***Section 3***, is another example of major construction deviation from the design.

595. The non-compliances of the construction with the works specifications have been described in ***Section 3*** of this report. In this connection, the Commission stated the following about the HUH Extension structure:

> *"In coming to this determination, however, the Commission recognises that in a number of respects, in the course of construction of the station box structure, there were unacceptable incidents of poor workmanship on site compounded by lax supervision and that in a number of respects also, management of the construction endeavour fell below the standards of reasonable competence."*[221]

596. Regarding Item (b) of *paragraph 592* above, the irregularities in the site supervision and control have also been described in ***Section 3***. The subject has been addressed at length in the Inquiry. For instance, regarding the importance of hold point inspection and RISC form process as set out in the PIMS, the Commission noted the following:

> *"During the course of the inquiry, an issue of central importance was the efficient use of RISC forms, those forms being fundamental to MTRCL's systems of supervision, inspection and verification of work satisfactorily completed."*[222]

[221] See paragraph 415 of the Final Report

[222] See paragraph 615 of the Final Report

> *"The RISC form process is set out in MTRCL's PIMS and, by virtue of the entrustment agreement, MTRCL is obliged to adhere to that process. By extension of that obligation, the RISC form process is a contractual obligation imposed on Leighton."*[223]

597. However, this requirement which was noted by the Commission as "*fundamental to MTRCL's systems of supervision, inspection and verification of work satisfactorily completed"* was not properly followed in the Hung Hom Site. The Commission concluded that:

> "*On the basis of all the evidence heard during the full inquiry – as set out elsewhere in this report in considerable detail – it is apparent to the Commission, indeed is accepted, that the system of hold point inspections verified by contemporaneous documentation, namely, completed and signed RISC forms, is not always made the subject of rigorous adherence. Indeed, the opposite was on occasions the case.*"[224]

598. In the settlement audits conducted by the EA Team on the TKW, EXC and Fleet Arcade sites, it was found that the requirement for suspension of works was commonly not observed in the audited events of exceedance of the *Alarm Level*. It did not comply with the accepted monitoring and control plan, and resulted in the breakdown of the AAA mechanism. The relevant details are described in ***Section 9*** of this report. This is a notable example of lack of discipline in complying with the construction control requirements, which also involved the other sites of the SCL Project.

Ramifications

599. Hong Kong has long been known for the quality of its construction works, and for its established good practice for construction management and site supervision and control. The good practice is also embodied in

[223] See paragraph 616 of the Final Report

[224] See paragraph 604 of the Final Report

the PIMS, which sets out the relevant requirements for managing railway projects delivered by MTRCL. While there is scope for update and improvement of the PIMS[225], the EA Team does not consider that the PIMS has any fundamental deficiencies in its project management principles and processes. These, if properly followed, should have served to deter major deviations of the construction from the design and works specifications. As a matter of fact, MTRCL has successfully delivered railway projects in Hong Kong for long years, through its project management system.

600. What matters in the present case is the apparent lack of discipline in complying with the established good practice, both for construction according to design and specifications and for site supervision and control. Gaps in the implementation have hampered the effectiveness of the established system and processes in ensuring that the works are constructed as designed and up to the required quality and standard.

601. The situation is aggravated by the incomplete site records, rendering it difficult to trace whether the works were properly carried out and who were accountable for signing this off. The significance of keeping contemporaneous and traceable site records will be discussed in *paragraphs 607* to *628* below.

602. The serious nature of these deficiencies in project management is highlighted in paragraph 24 of the Executive Summary of the Final Report, which states:

> "*The Commission was of the judgement, therefore, that both MTRCL and Leighton were responsible for serious deficiencies in their management and supervision systems*".

603. Instilling a good discipline of conformance with the design and works specifications in the construction works is vital to safeguarding the quality of the works. This does not mean that on-site changes, for instance in the design to cater for the site conditions or other warranted

[225] As noted in *paragraph 583 in* this Section, MTRCL has appointed an external consultant to carry out a full review and an update of the PIMS. Mr Rowsell has also given his views on the areas for improvement in the PIMS in his two expert reports to the Commission.

causes, should be discouraged. Instead, such justifiable changes should be facilitated. However, the changes should be properly checked, accepted and recorded, in accordance with the established requirements.

604. Likewise, the site supervision and control requirements should be rigorously observed on site. These requirements should not be lightly compromised, be it for any such pressing reasons as saving time or cost. Should it be necessary and found to be acceptable for valid reasons, the changes should be endorsed at a suitable level of authority, as well as clearly documented for maintaining transparency and traceability.

605. In view of the serious and extensive nature of the problem, it is recommended that MTRCL should review and implement measures for instilling a culture of good discipline in conformance with the design, works specifications, and site supervision and control requirements during construction.

606. It is also recommended that MTRCL should look into any additional or enhanced provisions in its project delivery processes, to ascertain that the discipline is maintained on site, both by the contractors and by MTRCL's site supervisory personnel. Consideration should be given to soliciting feedback from the involved parties about the difficulties or obstacles that might have hindered the compliance, so that the measures and provisions to be put in place are focused and pragmatic in addressing the needs given the specific nature and circumstances of MTRCL's railway projects.

Keeping Contemporaneous and Traceable Site Records

The concern

607. The keeping of contemporaneous and traceable site records is one of the most important subjects in the Hung Hom Site incident. The EA Team has summarized its observations about the relevant irregularities in ***Section 3*** of this report.

608. As the Commission has described, the RISC forms are of "*particular importance because they constituted primary evidence of works inspected (at hold point inspections) and certified as being correctly done*." [226] Conversely, the lack of RISC forms (and any other documentation of similar nature such as QSP and SSP) will cast doubt on the quality of supervision and the works. Apart from quality consideration, it also brings significant consequences from the statutory and contractual perspectives.

609. In this connection, the Commission noted that:

> *"As indicated earlier in this report, in the case of large parts of NAT, SAT and HHS, an unstructured approach to the use of RISC forms was allowed to come into being. Some Leighton site engineers, instead of initiating the RISC process, would instead notify MTRCL by telephone or by WhatsApp that particular works were ready for inspection and would accompany this notification with an undertaking to supply formal paperwork later. Evidence was put before the Commission that MTRCL personnel acquiesced in this modified arrangement, apparently in order to be co-operative and to avoid delaying the works. Regrettably, however, a material number of RISC forms were not subsequently submitted. The percentage of missing RISC forms was calculated in the Verification Report: the percentages are alarming."*[227]

610. The undesirable consequences were highlighted by the Commission:

> *"The fact that the RISC form process became so unstructured introduced a real element of risk. By way of illustration, hold point inspections could be missed if, in the absence of a properly completed RISC form, one inspector was under the*

[226] See paragraph 568 of the Final Report

[227] See paragraph 618 of the Final Report

impression that another inspector had already carried out the inspection. It does not require particular imagination to appreciate that the system, in its unstructured form, was open to abuse. The Commission accepts that there was other secondary evidence; for example, diary entries showing the concrete had been poured on a particular date. But such entries cannot be taken as definitive evidence that the necessary hold point inspections themselves were carried out and, importantly, that the inspections had found the works to be satisfactory."[228]

611. Furthermore, the Commission noted that the role of the middle management of MTRCL and its contractor in the case, as follows:

"As to how the RISC form process was allowed to become so unstructured, the Commission heard evidence that middle management within both MTRCL and Leighton were aware of the problem of the missing forms but seemingly did little to rectify the problem."[229]

612. The failure to maintain and update as-built drawings is another type of problem under the same category. Mr Rowsell has commented on this in his expert report:

"Based on my experience, it is normal practice to require the drawings to be updated during the course of construction to reflect the as-built details and any revisions made to the original design. Not maintaining and updating the drawings would carry a high risk that changes may not be incorporated into the final as-built drawings. The question here is whether the Contractor has been carrying out the as-built surveys and recording the details on the drawings, and if not, what steps has the Engineer taken to rectify the position? The evidence appears to indicate that, whilst the final as-built

[228] See paragraph 622 of the Final Report

[229] See paragraph 619 of the Final Report

documents are not yet required, the Contractor has not been able to make available the preliminary as-built drawings based on the regular survey and updating requirements which should have been produced in accordance with the General Specification during the course of the contract."[230]

613. Indeed, most of the construction irregularities discussed in ***Section 3*** of this report can be linked to the failure in keeping timely and traceable site records. Throughout the Holistic Assessment and Verification Study, one of the main difficulties encountered was to establish what were actually constructed in the built structures, aside the quality of the construction. This is a vivid illustration of the deficiencies in proper record-keeping and the adverse consequences in the Hung Hom Site.

614. As described in ***Section 8***, health-checking audits were conducted by MTRCL's HyD's and consultants in assessing whether the other SCL station sites might suffer from similar irregularities as the Hung Hom Site. While the consultants did not identify any major construction irregularities with significant structural safety implications, notable deficiencies in site record-keeping was found in most of the audited sites. These included missing, inconsistent and late preparation of RISC forms[231], non-compliance with the PIMS requirement for MTRCL to set up an independent RISC form register[232], and incomplete SSP inspection records.[233] This indicates that the flaw in compiling and maintaining contemporaneous and traceable site records was not confined to the Hung Hom Site, but was commonplace in the other sites of the SCL Project.

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[230] See paragraph 49 of Mr Rowsell's expert report dated 20 December 2018

[231] See *paragraphs 445 to 451* in ***Section 8***

[232] See *paragraphs 452 to 454* in ***Section 8***

[233] See *paragraphs 459 and 460* in ***Section 8***

Ramifications

615. The type, location and time of the construction works and the site supervision carried out are documented in site records. The records serve to maintain a traceable account of what have been built on site, who performed the required inspection and the findings of the inspection on the acceptability of the works.

616. In the case of a hold point, the inspection must be completed and the works conditions found to be satisfactory, before the next phase of the works is allowed to proceed. As regards the RISC form documentation in the hold point inspection process, the various undesirable scenarios that may arise from deficient record-keeping are highlighted in *paragraphs 135* to *144* in ***Section 3***.

617. Availability of proper site records does not guarantee that the works have been duly carried out. However, it would at least show the identity of the responsible personnel who performed the inspection, and whether the works have been timely inspected and found to be satisfactory. It is an established requirement that the site records should be properly prepared and maintained. Requirements for producing, signing and keeping site records are set out in the PIMS [234] and in the contract documents.

618. Where the required site records are missing, it casts doubt on whether the works have been duly executed and inspected. While this does not necessarily imply that the works are deficient, it fails to give the required assurance. Despite the possible availability of such other records as entries in the site diary and photographs on the works, it remains uncertain as to whether the works were carried out as designed and to the required quality. It is also impossible to trace who was responsible for overseeing that the works were properly carried out.

[234] For example, see *Sections 5.8* and *6* of PIMS/PN/11-4/A5 – Monitoring of Site Works.

619. Similar concerns exist in case of inspection records prepared with a considerable delay with respect to the time of construction or inspection. Given the time gap, there is a question about whether the information recorded is accurate and reliable. Particularly for hold point inspections, where the records are retrospective, the doubt remains as to whether the site supervision and control requirements for the relevant hold point had been duly implemented.

620. In this respect, the EA Team shared the views given by Mr Rowsell to the Commission:

> *"The need for records to be completed retrospectively, and for incidents to be recalled from memory, indicates to me that the importance of producing and retaining records by all those involved in the MTRCL and the Contractor's teams was not fully embedded in the inspection teams. The importance of records is often only recognised when something goes wrong. Professionalism in the application of robust processes is required to maintain comprehensive records despite the time pressures and the natural optimism that nothing will go wrong."*[235]

621. Hence, deficient record-keeping is not a minor flaw in project management. It would acutely undermine the effectiveness of the site supervision and control system in assuring the quality of the works and for tracing the accountability of the supervisory personnel who is to give this assurance. Where there is subsequently a doubt about whether the works are in compliance with the design or works specifications, it is difficult to ascertain from the deficient records what were actually built on site, whether the works were inspected as required, and who was responsible for the inspection. Furthermore, there is a risk that construction irregularities may remain unnoticed and without deterrence, despite the availability of the works specifications and control requirements on paper and presence of supervisory personnel on site.

[235] See paragraph 85 of Mr Rowsell's expert report dated 20 December 2018

622. As raised in *paragraph 463* in ***Section 8***, the change from paper RISC form to digital form (i.e. iSuper) may not be a panacea for all the problems in proper site record-keeping unless the underlying reasons for the problems have been identified and tackled. While the use of a digital system is supported, the EA Team would caution against possible complacency about the apparent success to date in boosting the availability of the RISC records from the use of the digital system.

623. Firstly, it should be recognized that the problem is not confined to RISC forms, but also other types of site records such as timely documentation of design changes, compilation of as-constructed records and preparation of QSP and SSP inspection records.

624. Secondly, there are indications that the problem might have stemmed, at least partly, from the design of the workflow and hold points. For example, lumping the inspection of the top mat and bottom mat of the EWL slab as one single hold point could have added to the risk of ineffective inspections due to access difficulty. It might also hinder timely completion of the RISC forms after inspection, should the top mat and bottom mat be inspected at different time or even by different inspectors.

625. Furthermore, the deviation from the requirement set out in the PIMS for MTRCL to set up an independent RISC form register is also a cause for concern. This and other issues in site supervision and control need to be addressed in totality, and it would be overly optimistic that they could be fixed by merely replacing the paper system with a digital one.

626. A number of recommendations on the subject matter have been put forward by the Commission and, in particular, in the two expert reports of Mr Rowsell. The EA Team would like to add that, apart from those probable causes identified by the Commission such as miscommunication between MTRCL and Leighton, pressure of work or difficulties in completing the paper RISC forms, MTRCL should probe into the core reasons for failure to maintain contemporaneous construction records. This will be further discussed in *paragraphs 650* to *669* below.

627. Specifically concerning the keeping of contemporaneous and traceable site records, it is recommended that MTRCL should review the nature and causes of the irregularities observed in the SCL Project, with a view to identifying improvement measures to avoid replication of similar problems in future. Account should be taken of the possible widespread presence of the deficiencies in different station sites in the SCL Project, and not to overly rely on the digital system as a panacea for the deficiencies.

628. In view of the importance of proper site record-keeping, it is also recommended that enhanced provisions should be made by MTRCL and HyD in future railway projects for auditing the availability, timeliness and completeness of the site records, particularly those which are pivotal in site supervision and control and in the assurance of the quality of the construction works.

Conducting Effective Audits

The concern

629. Both MTRCL and HyD have their own provisions for auditing the SCL Project.

630. On the part of MTRCL, the requirements and objectives of MTRCL's audits are stated in the PIMS Manual as follows:

> *"Audits of the Projects Division PIMS, suppliers, consultants and contractors are conducted at planned intervals in accordance with documented Procedures and Practice Notes to verify conformity to established requirements and effectiveness of the management systems. The management responsible for the area being audited ensures that actions are taken within an agreed timeframe to rectify the deficiencies found. The actions taken are verified and verification results are reported."*[236]

[236] See Section 7.4 of PIMS/MAN/003/A4

631. Three types of audits were regularly carried out on the SCL Project:

(a) *Internal Quality Audit ("IQA")*[237] – This is an internal audit carried out by the Quality Assurance team[238] of MTRCL's Projects Division to verify conformity and effectiveness of the implementation of the PIMS in project delivery by the project teams. The findings are reported to the senior management of MTRCL. The IQAs of November 2014, August 2018 and November 2019 covered the Hung Hom Site (Contract 1112).

(b) *Self Quality Audit ("SQA")*[239] – This is also an internal quality audit within the Projects Division, for different teams from different contracts to cross-audit one another. SQA was introduced in 2013 for enhancing the compliance with the PIMS. It used to be conducted at quarterly intervals until January 2018 when it was changed to half-yearly intervals. SQA was conducted on Contract 1112 in June 2016 and March 2018.

(c) *External Quality Audit ("EQA")* – This is conducted by the Quality Assurance team on MTRCL's contractors and consultants, i.e. a second-party audit by MTRCL. EQA was carried out on the contractor of Contract 1112 in November 2016, December 2017 and March 2020.

632. Despite the audit provisions in place by MTRCL, based on the information provided by MTRCL to the EA Team, the irregularities in the construction works and in the site supervision and control in the Hung Hom Site, were not revealed in the audits. Some of the irregularities involved non-conformances with the PIMS (e.g. RISC form documentation) and

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237 This is known as Internal Quality and Environmental Audit (IQEA) since 2018.

238 The Quality Assurance team is independent of the project delivery, and is led by the Project Quality Manager (PQM) of the Project Division.

239 SQA was introduced in 2013 as a measure to enhance MTRCL's project management system. See PIMS/PN/01-4/A2.

with other established requirements (e.g. those specified in the accepted drawings), and were also present in other SCL station sites apart from the Hung Hom Site. These non-conformances were not identified by the audits.

633. Indeed, without the Holistic Assessment and Verification Study and the Inquiries, the host of irregularities and non-conformances would not have been known. As multiple audits of different types were carried out but all failed to raise any alarm, this casts doubt about the effectiveness of MTRCL's audits in meeting its intended objectives.

634. On the part of HyD, its audits on the SCL Project were carried out by the M&V consultant (PYPUN) based on the "check the checker" approach on MTRCL's compliance with its obligations under the Entrustment Agreements. Unfortunately, PYPUN's audits had also not helped identify the irregularities and non-conformances.

635. As revealed in the Inquiry, PYPUN considered that the scope of its services focused on cost, programme and public safety, and did not include works quality. However, the Commission noted that "[*I]t was PYPUN's position that it was never under a duty to audit RISC forms: they did not fall under the headings of 'cost, programme and public safety'. The Government disagrees. It was the Government position that assessment of quality was integral to PYPUN's monitoring responsibilities.*"[240]

636. Notwithstanding the dispute, it was an admitted fact in the Inquiry that PYPUN had not carried out any audits for the purpose of checking the quality of permanent works.

637. While the limited scope of PYPUN's audits would have hampered their effectiveness in picking up the irregularities and non-conformances, the failure of the audits in identifying the non-compliance with the requirement for suspension of works upon the exceedance of the *Alarm Level* in TKW and EXC was of particular concern to the EA Team. In the case, PYPUN's audits did cover the matter, which fell within PYPUN's

[240] See paragraph 469 of the Final Report

scope of service relating to public safety. However, the audits were not only ineffective in identifying the non-compliance, but might also have given a misleading assurance in this respect. The relevant details are given in *paragraphs 565* to *569* in ***Section 9***.

Ramifications

638. Regarding MTRCL's audits, some issues deserve further consideration.

639. First of all, the pivotal role of the audits in project management should be recognized. The audits serve the important purpose of verifying whether the delivery and management of the project meet the established requirements and good practice set out in the PIMS. The audit findings, in particular concerning any non-conformances and deficiencies observed, should be construed as an alert for corrective and improvement actions by MTRCL. As the audit findings are reported to the senior management of MTRCL, they also provide important feedback to the senior management about whether the project is on the right track and any need for high-level attention or intervention.

640. In the case of the SCL Project, the alarm bell which should have rung have not served its function. Otherwise, the anomalies could have been detected in the early stage during construction, offering an opportunity for timely control and rectification of the problem. In this regard, even though the deficiencies in the audits may not be a direct cause of the irregularities, all parties should seriously review the lessons learnt and take improvement actions to ensure the effectiveness of the audits in future projects. The same applies to HyD's audits.

641. It would be useful to look into why MTRCL's audits have not been as effective as they should, which may attribute to different factors.

642. Taking MTRCL's audits on Contract 1112 (the Hung Hom Site) as an example, the EA Team noted some possible areas for improvement from the available information. These are briefly explained as follows:

(a) *Frequency of audit* – MTRCL advised that over an eight-year period from 2012 to 2019, an average of 17.5 contracts or departments [241] per year were subject to IQA. These contracts were not confined to those of the SCL Project. Given the large number of projects with numerous active contracts and departments managed by the Projects Division in the period, the audit frequency for an individual contract is apparently rather low. Specifically for Contract 1112, there was a significant interval of 46 months between the first (in November 2014) and second (in August 2018) IQA, during which the Hung Hom Site was under active construction. This illustrates the insufficient frequency of IQA for a large-scale and complex railway project like the SCL Project.

(b) *Scope of audit* – Given the wide range of procedures and requirements of the PIMS, the scope selected for an individual audit is rather limited. For example, Contract 1112 was subject to only two EQA during its active construction period, i.e. in November 2016 and December 2017. The scope of its 2016 EQA covered "*the construction of new stabling siding at the former Hung Hom Freight Yard, installation of acoustic panels and modification works in the existing HUH station*.", whereas that in 2017 was "*completion of ABWF [Architectural Builder's Work and Finishes] works in the new HUH station, preparation for FSD inspection and as-built drawing submission*." It can be seen that the scope of the two EQAs was narrow and restrictive, amid the wide range of construction activities in the Hung Hom Site.

(c) *Sample size in audit* – The sparse number of samples being checked on an audited item, based on which generic conclusion was drawn in the audit, is another possible limitation of the audit. For example, in the SQA on Contract 1112 in June 2016, the submission and handling of RISC forms

[241] Apart from active construction projects, departments within the Projects Division, such as Operations Projects Department, Project Engineering Department and Projects Management Office, are also subject to IQA. These departments are sometimes audited twice in a year.

was an item to be audited among a total of 21 items shown in the audit checklist. According to the SQA report, the auditor had checked only one RISC form about the kicker formwork alignment and level of track slab (RISC Form No. 1112-SUR-006795), to conclude that the PIMS requirements on this was in compliance. While this conclusion might be correct so far as this particular RISC form was concerned, this form was far from representative. Indeed, as it turned out from the Inquiry, a substantial number of the required RISC forms in the Hung Hom Site were not found, incomplete or incorrect. Had a more representative sample size, in terms of both the number of RISC form and the type of hold point, been audited, the irregularities that came before the Commission might have been identified in the audit.

(d) *Duration of audit* – The time spent by the auditors for each project or contract in an IQA is relatively limited. For example, in the IQA of Contract 1112 on 4 November 2014, the auditor had only spent 3 hours on the task. Similar for the audit frequency, there are resource considerations in the time consumed by the auditors in the audit. Given the limited time available and the breadth of subjects to be covered, the constraint on the thoroughness and depth of the audit is conceivable.

(e) *Auditors* – The IQA and SQA auditors were, in general, of a lower rank than those of the auditees. This might saddle the auditors with pressure if they are to make adverse observations and conclusions on the auditees, who are at a higher position in the hierarchy. As for EQA, e.g. that on Contract 1112 in November 2016, it was noted from the audit report that the lone auditor who was a Quality Assurance Engineer II of MTRCL had to face a sizeable team of auditees led by the Project Director of the contractor. Again, in the view of the EA Team, this arrangement might result in undesirable pressure on the auditor.

643. From EA Team's review of selected audit reports on Contract 1112, questionable issues in the audit findings were also noted. For example, in the 2014 IQA report, one of the key findings stated that "*SIOWs maintained a register of work inspection/survey check (RISC) forms for the necessary follow-up of minor defects or re-inspections*". This is inconsistent with the irregularity which was revealed from the health-checking assessment about non-conformance in many SCL stations with the PIMS requirements for MTRCL to set up its independent RISC form register (see *paragraph 454* in ***Section 8***).

644. Also, in the same report, it was indicated in the "*Summary*" Section that "*the audit result is 'Acceptable'* ". One may doubt if this overall conclusion on the audit results for the whole report (covering a dozen or so different projects and departments[242]) may be halo effect of certain positive findings encountered by the auditors but not necessarily representative of the actual situation in the projects audited.

645. Furthermore, it was observed from the audit checklists and reports that the audits were apparently focusing on whether the relevant procedures were followed in project delivery and management, with scant scrutiny of the quality and effectiveness aspects. Audits of this kind have a fundamental limitation, in that although they may help examine whether an action under the procedure has been taken, they could not differentiate whether the action had achieved its intended purposes. In comparison, the audits which were specifically conducted for the health-checking assessment of the other SCL stations (see ***Section 8***) are more useful in providing diagnostic insights into not only the availability but also the effectiveness of the required actions taken. There is scope for MTRCL and HyD to explore whether their prevailing audits may be enhanced along this line.

[242] In the IQA report for 2014, there were a total of 14 projects under three different railway lines (i.e. the SCL, SIL(E) and KTE), in which Contract 1112 was but one of the 14 projects audited.

646. The culture of an organization and stance of the senior management have a profound influence on the effectiveness of the audits. An organization which takes audits as an opportunity for improvement instead of fault-finding would stand a much better chance of achieving the intended objectives of the audits. Where the senior management is receptive to discovery and learning lessons from deficiencies, this would encourage honest feedback from the audits. It is advisable for the senior management to take this into consideration in improving the effectiveness of the audits.

647. Regarding the audits conducted by PYPUN for HyD in the SCL Project, the limited scope of the audits are described in *paragraphs 634* to *637* above. In this connection, the observations made by the Commission in its Final Report on this, regarding the audit of RISC forms in particular, are enlightening:

> *"It was PYPUN's position that it was never under a duty to audit RISC forms: they did not fall under the headings of 'cost, programme and public safety'. The Government disagrees. It was the Government position that assessment of quality was integral to PYPUN's monitoring responsibilities."*[243]

> *"It is not for the Commission to determine disputed contractual obligations. However, the Commission does observe that if there had been an audit of RISC forms that would have better ensured compliance with the RISC form procedures and may well have avoided the difficulties encountered in this inquiry."*[244]

648. In the light of the above, it is recommended that both MTRCL and HyD should review their audit systems and provisions to enhance the effectiveness of the audits on future railway projects, with account taken of the lessons learnt from the SCL Project. These may involve improvements to the scope, frequency and approach of the audit,

[243] See paragraph 469 of the Final Report

[244] See paragraph 470 of the Final Report

deployment of suitable personnel and resources, and unswerving support from the senior management.

649. It is also recommended that HyD should clarify, and expand if necessary, the scope of service of the M&V consultant in its future railway projects undertaken by MTRCL, so that the "check the checker" approach would embrace audits on the quality of project delivery and effectiveness in project management. In line with the "check the checker" approach, consideration should also be given to verifying the adequacy and performance of MTRCL's audit system implemented in the projects.

Probing into the Underlying Causes

The concern

650. In the Hung Hom Site, the initial concern about the site works arose from the allegation of unauthorized cutting of the threaded ends of rebars. As further information became available from the investigation, including the Holistic Assessment and Verification Study, diverse types of other major irregularities were unfolded. The Commission's Inquiry has yielded important findings and conclusions in many core issues pertinent to its remit. Participation in the review of the SCL Project in the last two years has enabled the EA Team to examine the available information and make observations. This covers the Hong Hom Site, as well as other SCL station sites in some respects.

651. In a major construction site, it is inevitable that some minor workmanship defects, such as localized honeycombing and isolated areas of insufficient concrete cover, would be present in the construction works. Normally, these are identified and readily rectifiable on site. However, in the Hung Hom Site, the irregularities were found to be much more serious and extensive, and were not confined to workmanship defects. By nature, these major irregularities fall broadly into the following four categories:

(a) *construction irregularities*, i.e. construction works which did not comply with the design or works specifications (e.g. defective coupler connections and missing shear links);

(b) *lax site supervision and control*, which did not conform to the requirements for supervision, inspection and verification of works (e.g. hold point and SSP processes not properly implemented);

(c) *lack of contemporary and traceable site records* (e.g. missing RISC forms and incomplete or inaccurate as-constructed records); and

(d) *other major deviations from the project management requirements or established good practice* (e.g. non-conformance with the NWDSM's requirements for seismic design, and non-conformance with the requirements specified in the agreed monitoring and control plan for suspension of works upon exceedance of the *Alarm Level*).

652. The categories of irregularities denoted in Items (c) and (d) above are not confined to the Hung Hom Site, but are also found in other SCL station sites.

653. Furthermore, the existence and continual occurrence of the major irregularities have remained unnoticed for a prolonged time during construction, despite the site supervision and control provisions and the regular audits by MTRCL and HyD. This is also a cause for concern. Arguably, without the initial allegation of cutting of the threaded rebars, the investigation carried out in the Holistic Assessment and Verification Study, and the Inquiry by the Commission, the manifold and extensive nature of the irregularities would not have come to light.

654. Identifying the irregularities is one thing, recognizing their causes is another matter. In this connection, it is noteworthy that there are different "levels" of causes. For construction irregularities as an example,

one may rightly ascribe the direct cause to poor workmanship. If a further question is asked about why the workmanship is poor, then it may be due to a deeper "level" of contributory causes, such as inadequate training, lack of supervision, poor working environment, tight construction schedule, breakdown of communication, etc. Yet, one may further ponder as to whether the irregularities and causal factors could have sprung from some underlying causes which are intrinsic and root to the anomalies.

655. The investigation completed to date has served to gauge the extent of the irregularities, which enabled an objective assessment of the structural integrity and the required remedial works for compliance with the applicable codes. It has also provided insights into the probable causes of the irregularities and areas for improvement.

656. Notwithstanding this, the EA Team is both conscious of, and concerned about, the possibility that the underlying causes might not have been fully unveiled.

657. The nature and extent of the irregularities at the Hung Hom Site are uncommon among major civil engineering projects in Hong Kong. MTRCL is well recognized for its long-standing reputation for railway and underground construction works. There could have been some underlying reasons for the occurrence of the problems in the Hung Hom Site, and not in other major civil engineering projects in Hong Kong. These could also have rendered the problems to surface now in the SCL Project, and not in the other railway projects previously undertaken by MTRCL.

Ramifications

658. In this report, recommendations on the improvement measures are put forward by the EA Team in the light of the lessons learnt from its review of the SCL Project. These would add to the list of recommendations that have already been made in the Inquiry and by other parties, such as MTRCL's external management consultant. It is expected that the implementation of the recommendations will lead to enhancement in the management and delivery of future railway projects.

659. Despite this, in EA Team's view, it is useful to probe further into whether there are underlying causes yet remain undiagnosed to date. Pinpointing these will yield diagnostic insights into the inherent factors, which if duly addressed, would be pivotal in bringing about the required improvement and avoiding recurrence of similar problems in future. It will also shed light on where priority or focused attention should be given, among the large number of follow-up actions arising from the lessons learnt and recommendations which have already been identified. On the contrary, losing sight of these causes may undermine the effectiveness of the improvement measures in achieving the intended purpose.

660. Yet, what are the probable underlying causes? Some might suggest that the unprecedented surge in the volume of active railway projects undertaken by MTRCL over the years is relevant. Others might wonder that the tight project programme and immense pressure to meet the project delivery milestones could expose the project to the risk of compromising quality for works progress. One might also speculate about other possibilities, such as shortage of competent personnel, lack of checks and balances, overreliance of the "check the checker approach", or even criminal elements.

661. In the Inquiry, the Commission has taken note of factors which might have underlain some of the irregularities. For instance, regarding the extensive and prolonged failure to comply with the RISC form process in the Hung Hom Site, the Commission stated that:

> *"In an apparent effort to be collaborative and not to delay the works, MTRCL personnel would then carry out inspections on the understanding that RISC forms would follow in due course. In many cases, as the evidence has shown, those RISC forms were never submitted."*[245], and

[245] See paragraph 463 of the Final Report

> *"The Commission is further satisfied that the reason such a high percentage of RISC forms were never completed was that a form of contempt for the process was allowed to develop. The cause for that was poor management".*[246]

662. In this connection, the Commission noted that PYPUN (i.e. HyD's M&V consultant) did not audit RISC forms, although there were different views between PYPUN and the Government about whether this should fall into PYPUN's monitoring responsibilities.[247] The Commission opined that:

> *"It is not for the Commission to determine disputed contractual obligations. However, the Commission does observe that if there had been an audit of RISC forms that would have better ensured compliance with the RISC form procedures and may well have avoided the difficulties encountered in this inquiry."*[248]

663. These observations by the Commission allude to some possible reasons for the sustained irregularities in the RISC form process, e.g. avoidance of delay to the works and poor management on the part of MTRCL, and lack of awareness of the problem (not included in PYPUN's audits) on the part of HyD. Undoubtedly, these warrant attention, notwithstanding that there may also be other reasons which should be addressed.

664. In EA Team's opinion, two notable implications are illustrated in this example.

665. Firstly, there is a wealth of useful information and observations from the Inquiry by the Commission, which may help the diagnosis of the underlying causes. Secondly, these causes may be organization-specific, i.e. those on MTRCL's side may be different from those of HyD.

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[246] See paragraph 467 of the Final Report

[247] See paragraph 469 of the Final Report

[248] See paragraph 470 of the Final Report

666. Hence, it is pertinent to take due consideration of the Commission's findings in diagnosing the underlying causes. Also, it is vital for each of the key parties to look into its own underlying causes. In the process, account should be taken of the possibility that the individual parties may have further information on and awareness of its own circumstances, which would augment the available observations to facilitate the diagnosis.

667. The EA Team is neither provided with the investigative power nor resources for diagnosing the underlying causes. Also, the EA Team does not have unrestricted access to all the information held by the individual parties. The EA Team considers that the key parties involved in the saga of the irregularities are in a better position to deal with this issue, given their first-hand knowledge of the case, direct access to the relevant records and personnel, and continual awareness of their own circumstances.

668. In view of the above, it is recommended that the relevant key parties, viz. MTRCL and HyD in particular, should conduct a candid review for probing into the underlying causes of the irregularities.[249] This would provide insights into the need and priority for follow-up actions that cater for the circumstances and needs of the respective parties, among the large number of improvement measures to pursue. While MTRCL and HyD may separately conduct its own review, it is advisable for them to interact, share the findings with and solicit feedback from each other in the process.

669. High-level support is vital to the success of the review. It is recommended that the senior management of the respective parties should give its firm commitment and attention to the review and implementation of the required follow-up actions.

[249] The categories of irregularities listed in *paragraph 651* of this section may be a useful classification for use in the review.

Section 11 Relevance to Other Works Projects

670. The EA Team is tasked to look into the irregularities in the Hung Hom Site and other related matters pertinent to the works of the SCL Project. Therefore, all issues addressed in this report are focused on the SCL Project, and where appropriate, with implications for the future railway projects undertaken by MTRCL and HyD.

671. The EA Team opines that certain observations made and lessons learnt in this case may have relevance to other non-railway projects in Hong Kong. For example, those concerning site supervision and control should not be prerogative of MTRCL and HyD. They are worthy of attention by all parties in project management and delivery, both in the private and public sectors.

672. The EA Team believes that the lessons learnt in this case do offer an opportunity for the construction industry as a whole to seek for improvement. Specifically, given the similarity of the SCL Project to other major public works projects in terms of their scale and complexity, it is advisable for the relevant Works departments to maintain awareness of the lessons learnt from the SCL Project and review any necessary improvement to be made in their project management and delivery.

Section 12 Summary of Recommendations

673. This Section is a summary of the recommendations put forward by the EA Team in this report. For easy reference, the recommendations are grouped according to the subject areas being addressed.

Paragraph	Recommendation
Quality Assurance for the Hung Hom Site	
97 103	**MTRCL** has to submit a detailed proposal on water seepage prevention measures with continuous monitoring for the water seepage condition. The proposal should also serve to address the corrosion problem for the couplers in the platform slabs of the HUH Extension structure.
249 277 284	To cater for the restrictions and precautionary arrangements in the *Updated Design*, **MTRCL** should make suitable provisions in the relevant management plans and monitoring schemes. These may include, among other provisions, standard instrumentation and monitoring measures (e.g. continuous groundwater monitoring using pneumatic piezometers). **MTRCL** should identify and draw up a list of potential concerns about the long-term performance and durability of the built structures in the Hung Hom Site for agreement by the Government, so that suitable provisions are made in the long-term monitoring to address the concerns.

Paragraph	Recommendation
258	For the Hung Hom Site, detailed proposals in dealing with water seepage, corrosion, long-term monitoring, and additional undertaking of quality assurance from MTRCL are yet to be finalized. **MTRCL and HyD** should speed up the required follow-up actions.
282	**HyD** should carry out further analysis on the structural integrity and long-term durability of the connection between the EWL slab and the east D-wall, in consultation with the experts. In case of unresolved concerns, it may be prudent to include suitable provisions in the long-term monitoring for addressing the concerns.
287	**HyD** should seek advice from its independent structural experts in compiling the list of potential concerns and in deliberating suitable provisions for addressing these concerns in the long-term monitoring.
290	**HyD** should enlist independent and experienced professionals in vetting the long-term monitoring reports submitted by MTRCL and in reviewing the required follow-up actions.
291	**MTRCL** has undertaken to explore options for providing the Government with additional undertaking of quality assurance for the built structures in the Hung Hom Site. The scope and details of the additional quality assurance provisions may be related to, and thereby should be deliberated in connection with, the arrangement for the long-term monitoring.
294	**MTRCL and HyD** should finalize the programme and details of the long-term monitoring for implementation, with account taken of the relevant considerations given in *Section 5* of this report.

Paragraph	Recommendation
259 364 377	**HyD** should timely complete the checking of the design of the built structures in the Hung Hom Site in respect of compliance with the additional requirements of the NWDSM. **HyD** should document the approach for and the findings of its checking to demonstrate its accountability with transparency on not only the due completion of the checking but also on how it has been conducted to meet the intended objective. As part of its design check for compliance with the additional requirements of the NWDSM, **HyD** should ensure that the seismic design requirements for the structures in the Hung Hom Site are complied with.
	Quality Assurance for Other SCL Stations
378	**HyD** should take stock of whether the approach and procedures specified in the NWDSM for seismic design were followed in the design of the other SCL stations. **HyD** should speed up the stock-taking to ascertain whether any further follow-up actions are required.
471	**MTRCL** should take due account of the concern about the deficiencies in site records and their possible implications in devising the future maintenance plans and monitoring schemes for these SCL stations [HIK, DIH, KAT, SUW, TKW and EXC].
472	**MTRCL** should explore options for providing the Government with additional undertaking of quality assurance in respect of the built structures of these SCL stations.

Paragraph	Recommendation
Design-Related Issues	
325	**MTRCL** should review and improve its prevailing design practice and checking provisions, so as to avoid overly conservative design and ensure proper detailing following the good practice given in the design codes.
365	For Government-funded railway projects undertaken by MTRCL in future, **HyD** should ensure that compliance with all the applicable codes, rather than confining only to the regulatory requirements, is covered in Government's checking.
369	In the interest of streamlining procedures and providing one-stop service as far as practicable, **HyD** should explore the possibility of having the compliance checking against the regulatory requirements and the NWDSM carried out under one roof in future.
379	**HyD, BD and MTRCL** should review the need and formulate training and development plans for enhancing their professional competence in dealing with seismic design.
381	**MTRCL** should consider engaging an ICE to deal with the checking of seismic design, as the need arises as in case of insufficient in-house resources or expertise.
384	There is scope for **HyD** to examine whether its future railway projects undertaken by MTRCL should follow the requirement of the SDM for an independent design check of complex structures by an ICE. **HyD** should look into the need and possible arrangement for this in the delivery of its future railway projects.

Paragraph	Recommendation
395	**MTRCL and HyD** should be vigilant of the judicious use of coupler connections, particularly in avoiding their inadvertent use and in implementing effective site supervision and control to ensure that the required specifications and workmanship quality are met.
405	**MTRCL and HyD** should review the adequacy of their prevailing practice in addressing the buildability aspects of the design and construction, with a view to enhancing the identification and resolution of major buildability issues in their future railway projects.
Settlement Issues	
538	In formulating similar monitoring and control plans in future, **MTRCL** should set a realistic *Alarm Level* (i.e. the threshold for suspension of works) which tallies with the predicted ground response, subject to proper justification of the acceptability of this limit.
544	**MTRCL** should rigorously observe the requirements for implementation of the response actions specified in the accepted monitoring and control plans, including suspension of the relevant construction activities upon exceedance of the *Alarm Level*. **MTRCL** should also enhance their project management practice to avoid recurrence of similar non-conformances.
547	**MTRCL** should timely revise the AAA Levels with justifications for acceptance, particularly upon the exceedance of the *Alarm Level*, to ensure that the relevant works which are yet to be carried out are subject to the control of a suitable and applicable AAA mechanism. After exceedance of the *Alarm Level*, resumption of works should not be allowed without an applicable and accepted AAA mechanism being in place

Paragraph	Recommendation
551	In addition to safety consideration, damage inspection and assessment should be thoroughly carried out by **MTRCL** after the exceedance of the *Alarm Level*, to provide a basis for establishing the need for any mitigation or other follow-up actions and ascertaining the acceptability of resumption of works.
552	In assessing the acceptability of the AAA Levels, due consideration should be given by **MTRCL and relevant Government departments** to containing damage to properties, apart from avoidance of structural failure.
554	**The relevant Government departments** should adopt a proactive and firm approach to ensure that the response actions specified in the accepted monitoring and control plan are duly taken by MTRCL. This applies in particular to suspension of works in the event of exceedance of the *Alarm Level* and revision of the AAA levels with justifications for acceptance before resumption of works.
557	**The Government** should look into means of enhancing the coordination in dealing with facilities affected by more than one project, to ensure that the combined effects are duly accounted for in the monitoring and control plans of the future railway projects. This applies to both the formulation and implementation of the monitoring and control plans.
563	In formulating and implementing monitoring and control plans for future railway projects, **MTRCL and the relevant Government departments** should take due account of the possible delay in the response of ground and building settlements induced by tunneling works.

Paragraph	Recommendation
574	**MTRCL, HyD and BD** should refine the *Enhanced Mechanism* to incorporate the areas for improvement identified from the settlement audit and other experience gained, for implementation in future railway projects.
575	**MTRCL and the relevant Government departments** should maintain a close dialogue with the industry in pursuing improvement to the monitoring and control system and soliciting their feedback.
Project Management Issues	
353	It would be prudent for the established good practice for avoidance of conflict of interest in public works projects to be also adopted in Government-funded projects undertaken by MTRCL. **HyD** should look into this in future railway projects.
354	**MTRCL** should consider adopting similar requirements for avoidance of conflict of interest in its own projects. It is advisable for **MTRCL** to take concrete actions in more explicitly debarring its consultants from working for the contractor under the same contract, unless in circumstances that are truly exceptional due to other overriding considerations.
424	There is scope for improvement by **MTRCL** in ensuring that the objective given in the PIMS on cost-effective design are achieved in project delivery. **MTRCL** should review its relevant practices and provisions with a view to seeking improvement.

Paragraph	Recommendation
425	**HyD** should strengthen its management of future Government-funded railway projects undertaken by MTRCL, so that these projects are at least on a par with Government's public works projects in the quest for improvement in cost management. Consideration may also be given by **HyD** to inclusion of the cost-effective aspects in Government's design vetting and in the audits by the M&V consultant.
605	In view of the serious and extensive nature of the problem of maintaining discipline in compliance with design and works requirements, **MTRCL** should review and implement measures for instilling a culture of good discipline in conformance with the design, works specifications, and site supervision and control requirements during construction.
606	**MTRCL** should look into any additional or enhanced provisions in its project delivery processes, to ascertain that the discipline is maintained on site, both by the contractors and by MTRCL's site supervisory personnel. Consideration should be given to soliciting feedback from the involved parties about the difficulties or obstacles that might have hindered the compliance, so that the measures and provisions to be put in place are focused and pragmatic in addressing the needs given the specific nature and circumstances of MTRCL's railway projects.

Paragraph	Recommendation
627	Concerning the keeping of contemporaneous and traceable site records, **MTRCL** should review the nature and causes of the irregularities observed in the SCL Project, with a view to identifying improvement measures to avoid replication of similar problems in future. Account should be taken of the possible widespread presence of the deficiencies in different station sites in the SCL Project, and not to overly rely on the digital system as a panacea for the deficiencies.
628	**MTRCL and HyD** should make enhanced provisions in future railway projects for auditing the availability, timeliness and completeness of the site records, particularly those which are pivotal in site supervision and control and in the assurance of the quality of the construction works.
648	**MTRCL and HyD** should review their audit systems and provisions to enhance the effectiveness of the audits on future railway projects, with account taken of the lessons learnt from the SCL Project. These may involve improvements to the scope, frequency and approach of the audit, deployment of suitable personnel and resources, and unswerving support from the senior management.
649	**HyD** should clarify, and expand if necessary, the scope of service of the M&V consultant in its future railway projects undertaken by MTRCL, so that the "check the checker" approach would embrace audits on the quality of project delivery and effectiveness in project management. In line with the "check the checker"

Paragraph	Recommendation
	approach, consideration should also be given to verifying the adequacy and performance of MTRCL's audit system implemented in the projects.
668 669	**The relevant key parties, viz. MTRCL and HyD in particular**, should conduct a candid review for probing into the underlying causes of the irregularities. While MTRCL and HyD may separately conduct its own review, it is advisable for them to interact, share the findings with and solicit feedback from each other in the process. The senior management of the relevant key parties should give its firm commitment and attention to the review and implementation of the required follow-up actions.
Relevance to Other Works Projects	
671 672	Some of the observations made and lessons learnt in this case may have relevance to other non-railway projects in Hong Kong. They are worthy of attention of all parties in the construction industry, both in the private and public sectors. It is advisable for **the relevant Works departments** to maintain awareness of the lessons learnt from the SCL Project and review any necessary improvement to be made in their project management and delivery.

674. The EA Team appreciates the co-operation and assistance rendered by MTRCL, the relevant Government departments and other involved parties in the past two years, which led to the completion of this report.

675. The remarks made in the report are not meant to be fault-finding. Rather, all the observations and recommendations are intended primarily for bringing continual improvement to railway projects in specific and the construction industry in Hong Kong at large.

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