MTR Corporation Ltd

Commission of Inquiry into the Construction Works at and near Hung Hom Station Extension under the Shatin to Central Link Project

Extended Inquiry
Structural Engineering Expert Report

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1 Introduction

1.1 In May 2018 allegations were made in the media regarding potential defects in the rebar fixing works and deviations from the design in the Hung Hom Station Extension ('HUH') in Contract 1112 ('Project') of the Shatin to Central Link.

1.2 In July 2018 a Commission of Inquiry ('CoI') was appointed by the Chief Executive of the Hong Kong Government ('Government') to inquire into the facts and circumstances surrounding the diaphragm wall and platform slab construction works in the HUH and, in particular, the steel reinforcement fixing works, which raised concerns about public safety.

1.3 Subsequently, the scope of the CoI was extended by the Chief Executive in February 2019 to inquire into the facts and circumstances surrounding the construction works in other areas of the Project, namely the North Approach Tunnels ('NAT'), the South Approach Tunnels ('SAT') and the Hung Hom Stabling Sidings ('HHS') which also raised concerns about public safety or the quality of the completed works[1].

1.4 In light of the concerns raised on the completed works in the NAT, SAT and HHS, MTR Corporation Ltd ('MTRCL') proposed on 15 May 2019 a verification study of the as-constructed conditions of the NAT, SAT and HHS ('Verification Proposal')[2]. The Verification Proposal was accepted on the same day by Government[3].

1.5 The Verification Proposal consisted of two parts:-

(a) Part 1 – Consolidation and verification of available construction records (Part 1a) and review and ascertainment of the as-constructed conditions of the structures (Part 1b); and

(b) Part 2 – Structural review.

1.6 The findings of the investigation under the Verification Proposal are stated in MTRCL's Final Verification Study Report on As-Constructed Conditions of the North Approach Tunnels, South Approach Tunnels & Hung Hom Stabling Sidings dated 18 July 2019 ('Verification Report')[4]. In assessing the spare structural capacity at the critical coupler locations in the NAT, SAT and HHS, MTRCL adopted a strength reduction factor of 35% and it stated that such a reduction factor was comparable to the strength reduction factor applied in the Holistic Report

[1] See [AA1/1]
[2] See [BB8/5125-5145]
[3] See [BB8/5146]
[4] See [BB16/9952-10000]

(which is another report relating to the as-constructed conditions of the HUH extension in respect of the NSL platform slab in the station box).

2 Instructions

2.1 I have been given and read the CoI's Directions on structural engineering expert evidence contained in the following emails from Lo & Lo:

(a) Email dated 29 August 2019[5];

(b) Email dated 20 September 2019[6];

(c) Email dated 12 October 2019[7]; and

(d) Email dated 25 November 2019[8].

2.2 I have also received a letter of instruction from my instructing solicitors, Mayer Brown, dated 5 December 2019, which confirms the instructions I had previously received concerning the preparation of this Report.

2.3 This Report responds to the redacted version of the Structural Engineering Expert Report produced by Mr. Nick Southward, Leighton's structural engineering expert, dated 18 October 2019 ('Southward's CoI 2 Report')[9].

2.4 I have prepared this Responsive Report in accordance with the CoI's Directions, in particular the following[10]:

"(a) the SE experts should focus on whether the as-constructed works are safe and fit for purpose from a structural engineering perspective; and only if they are considered not safe or fit for purpose that such experts should then provide their opinion on whether the suitable measures (as agreed in the Holistic Report or Verification Report, or subsequently) are necessary for safety from a structural engineering perspective; and

(b) the SE experts shall not be required to look into the question of whether the suitable measures (as agreed in the Holistic Report or Verification Report, or subsequently) are required for statutory or code compliance."

2.5 In order to provide context for my responses and to assist the CoI as much as possible in its consideration of those matters falling within its Extended Terms of Reference, it is necessary and appropriate for me to include what I consider to be the Guiding Principles in terms of considering and addressing problems similar to those which are presented by the NAT, SAT and HHS.

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[5] See [AA1/277-278]
[6] See [AA1/347-349]
[7] See [AA2/472-473]
[8] See [AA2/895-896]
[9] See [ER1/item 10.1]
[10] See [AA2/472-473]

3 Guiding Principles of the Assessment

3.1 In considering safety it must be recognised that there is a large difference between the levels of risk to be considered during the design and construction stages of any project and the post-construction stage. Taking an extreme example, the cost and programme risks reduce substantially as the project nears completion from a peak at the inception of the project to effectively zero at its completion. The same risk profile in my opinion applies to considerations of structural integrity and safety of the structure.

3.2 In the inception and design stages of a project, much is unknown as to the actual future construction loadings and sequence, material strengths and geometric accuracy. For this reason, international codes and standards contain partial safety factors. These factors include for the extremes of the variations in the applied loads and "ignorance" factors – "ignorance" factors are intended to reflect the level of uncertainties in the assumptions made in the design and the sophistication of the analysis methods to be adopted, to mitigate these unknowns; for example in BS8110:1985 these partial safety factors were described and defined. BS8110 was the code on which the HKCoP: 2004 Structural Use of Concrete ('HKCoP') is based.

3.3 In my opinion, the logical consequence of the substantial reduction in risk between inception and post-construction of a project is that the basis of assessment of the structure should recognise and take account of the fact that many of the safeguards and conservative assumptions included in the original design and construction no longer apply and should be relaxed. The reality of the situation is that the level of "ignorance" has greatly reduced and, hence, so should the partial safety and "ignorance" factors.

3.4 In stark terms, my opinion is that it is inappropriate to apply the same loading and material strength assumptions used at the inception of a project to its surveyed and analysed post-construction condition.

Fitness for Purpose

3.5 In this Responsive Report, I give my opinions in accordance with the CoI's Direction that "the SE experts should focus on whether the as-constructed works are safe and fit for purpose from a structural engineering perspective"[11]. In assessing whether the structures are "safe and fit for purpose", in my opinion the important aspect to be satisfied is whether the as-constructed structures are capable of being used and function as railway tunnels or stabling sidings safely and without any physical restrictions on their operations and as anticipated by MTRCL. In that regard, the structures should be durable, safe, have sufficient strength, and not

[11] See [AA2/472-473]

deflect or vibrate beyond those limits expected for railway tunnels or stabling sidings and provide adequate dimensional accuracy to enable the tunnels or sidings to operate as intended.

3.6 So far as I am concerned, it is very important to emphasise that "fitness for purpose" should not be confused with "Compliance". To be satisfied, "Compliance" requires the as-constructed works to be completed strictly in accordance with the contract specifications and requirements, irrespective of whether the specified requirement is necessary in terms of "fitness for purpose".

3.7 A crude example of the difference between these concepts would be if the specification required 10 rebars to be provided in a particular element of the structure to satisfy a "one-size-fits-all" standard detail, whereas upon scrutiny of the particular detail in the context of the as-constructed structure it can be shown that only 5 rebars are required to satisfy the operational performance requirements of the station; the former is a "Compliance" requirement and the latter would be a perfectly adequate construction solution meeting the "fitness for purpose" test.

3.8 A further example would be a situation in which a pile has been installed outside of the tolerances required by the contract or the relevant code, with the consequence that it fails the "Compliance" requirement. Notwithstanding, in many instances the pile would be acceptable on a "fitness for purpose" basis in the light of a review of the actual circumstances of the pile's location in terms of its loading and the soil conditions in which it was installed.

Compliance

3.9 In various parts of Southward's CoI 2 Report, he opines that the as-constructed works are "code-compliant". Compliance can have many definitions, but for the purposes of this Responsive Report it has been taken to be the strict application of the HKCoP[12] and those requirements specified in the BD acceptance letters[13]. Compliance with other codes of practices on site supervision and the Contract Conditions is not considered to be part of this structural engineering assessment of safety, so I do not address such matters. For the reasons stated below, I disagree with Mr. Southward that the as-constructed works are compliant with the HKCoP and the other requirements specified in the BD acceptance letters.

Codes of Practice and Safety Levels

3.10 Codes of Practice are by their very nature conservative documents. They have to be robust enough to cover a very wide range of applications – they are in a crude sense prepared on the basis of "one-size-fits-all". They are not a design manual. In fact, they are generally regarded as guidelines, and the foreword to the HKCoP

[12] See [H8/2818-3015]
[13] See [H9/3871-4053]

clearly states this to be the case. I recognise, however, that there are situations where they become mandatory as, for example, where they form part of a contract or the basis of a particular approval, but this does not alter the fact that they are conservative documents.

3.11 In many respects, in my opinion, some of the conservative provisions built into the HKCoP as well as into the initial design basis, do not apply to the post-construction reality of the tunnels and siding structures because, for example:

(a) they are completed structures which have been subjected to post-construction surveys and forensic analysis; and

(b) many of the partial safety factors which are built into the HKCoP, should no longer apply to their fullest extent in a structural re-assessment context of a completed structure.

3.12 For these reasons, when considering the structural integrity and safety of the tunnel and siding structures it is excessively conservative to continue to apply the full provisions of the HKCoP. For a post-construction assessment, it is in my opinion both logical and correct that the context of the individual clauses of the HKCoP are reviewed against the current technical knowledge which is available for consideration.

Engineering Assessment of Complex Problems

3.13 Engineering assessments, particularly of complex multi-faceted projects, are not purely mathematical exercises; in fact, they involve a rigorous first principle review of the information available, seek additional data in areas which appear to be inadequately explained, and finally make a judgement.

3.14 In the case of the tunnel and siding structures my approach has been:

(a) to review the data that has been produced through the various stages of the investigation under the Holistic and Verification Proposals[14];

(b) to consider the reports served upon and the expert evidence given to the CoI;

(c) to make limited studies subsequent to the publication of the Verification Report in areas where I do not agree with the conclusions being drawn, for example, on the use of a 35% strength reduction factor at coupler locations in the NAT, SAT and HHS.

[14] See [OU5/3229-3350] and [BB16/9552-10000]

4 Structural Engineering Expert Report by Mr. Southward dated 18 October 2019

4.1 The following sections of this Responsive Report are a response to Mr Southward's CoI 2 Report.

4.2 This Report has been structured around Mr. Southward's response to a number of specified questions as set out in Section 2 of his CoI 2 Report relating to:

(a) Coupler connections/coupler engagement; and

(b) Shear link reinforcement and partial utilisation of shear.

5 Coupler Connections / Coupler Engagement

Question - Issues 1 and 2

5.1 With reference to Sections 4.5.1 and 4.5.2 of the Verification Report[15], what is the spare structural capacity of the as-built works and should a strength reduction factor be applied at any locations where couplers were used in the NAT, SAT and HHS? If so, what strength reduction factor should be applied at each of these locations?

Response: The NAT and SAT structures

5.2 In relation to the NAT and SAT structures, paragraph 4.5.1 of the Verification Report[16] concludes that the spare structural capacity at critical coupler locations is greater than the assumed strength reduction factor of 35%. Similarly, in paragraph 4.1 of Southward's CoI 2 Report, he does not raise any concerns over the NAT and SAT structures. Likewise, I have no concerns that the NAT and SAT structures are neither unsafe nor unfit for purpose.

Response: The HHS structures

5.3 Paragraph 4.5.2 of the Verification Report[17] states that the spare structural capacity at critical coupler locations in the HHS trough wall kickers near movement joints with a total length of about 150m is less than the assumed strength reduction factor of 35%.

5.4 Paragraph 4.2.6 of the Verification Report[18] justifies the 35% reduction factor on the basis that it was required to address the lack of full site records. However, in my opinion the strength reduction factor of 35% was applied entirely from a "Compliance" perspective and was not derived from any engineering considerations, and hence that there is no engineering justification for the application of such a strength reduction factor to the HHS.

5.5 Based on the assessment carried out by MTRCL's designer for the HHS structures, AECOM, if the reduction factor of 35% is not applied, the utilisation rates of the HHS structures are below 100%[19] and, in my opinion, the structures are safe and fit for purpose.

5.6 Such a strength reduction factor maybe a reasonable reflection of risk for the NAT[20] and SAT[21] which are massive underground structures similar in complexity and scale to the HUH station box. However, for the HHS construction, in my

[15] See [BB16/9978]
[16] See [BB16/9978]
[17] See [BB16/9978]
[18] See [BB16/9976]
[19] See [BB17/10105 – 10107]
[20] See [AA1/127]
[21] See [AA1/126]

opinion, such a reduction factor is excessive from a structural safety perspective for the reasons I will explain below.

Geometry and Detailing

5.7 By comparison with the HUH station box and the NAT and SAT, the HHS[22] is of a lesser scale in terms of its sophistication and complexity and is an operational facility which is inaccessible to the public. This latter point is of fundamental importance in establishing the level of safety risk that should be ascribed to the design of the structure.

5.8 The construction is of a simple nature compared to the HUH station box with conventional construction detailing constructed in a relatively benign environment with few hazards and impediments to achieving a good quality of construction, particularly when compared to the conditions under which the HUH station box and the NAT and SAT were constructed.

5.9 Of special note, and directly relevant to the question posed, compared to the EWL and NSL constructions in the HUH station box, there should be greater confidence in the quality of workmanship of the coupler connections, for the following reasons:

(a) The rebar detailing is uncongested and very visible;

(b) The connection is vertical, unlike in the NSL and EWL, which is easier to install and has the advantage that an unconnected bar would literally fall over;

(c) The rebar diameters are small and easily handled by the operatives; and

(d) The detail is very visible at all stages of construction up to the casting of the concrete, unlike the EWL and NSL with their many layers of rebar and very deep thickness of construction.

Analysis

5.10 The approaches used by both the MTRCL designer, AECOM, and by Mr. Southward are based on variations of simple cantilever structures. AECOM analysed a conventional unrestrained wall using elastic analysis whereas Mr Southward used a yield line analysis.

5.11 The AECOM approach, although simple, gives a conservative result.

5.12 I agree that Mr. Southward's yield line analysis is an acceptable analytical approach but it has to be applied with care, because it is an upper bound method, in that the only appropriate yield line pattern is the one which generates the lowest value. In

[22] See [AA1/130-131]

addition, the pattern is also influenced by the distribution of rebar in the wall both vertically and horizontally. So, selection of the pattern is critical, and is the prime reason that such yield line analyses are normally only used where the pattern can be predicted with confidence. Superficially, the pattern selected by Mr. Southward is plausible, but the rebar distribution is more complex than he has assumed and hence I believe a more rigorous analysis would give a slightly lower but comparable capacity.

5.13 Whether the approving authorities would accept Mr. Southward's yield line analysis[23] as 'part and parcel' of the process of obtaining the ultimate approval of the use of the works is a matter of compliance, but in terms of being a basis for establishing safety, I consider it to be an acceptable approach.

5.14 In any event, whilst I accept that the yield line analysis is an acceptable approach, in my opinion both AECOM's and Mr. Southward's mathematical models are unnecessarily conservative, because neither has recognised or taken account of the existence of the substantial soil backfill behind the trough walls and the concrete slab between the trough walls. If account were taken of these features the applied loading would be shared between the impacted wall, the soil mass and the adjacent trough wall through the action of the soil mass and the concrete slab. Such an analysis would show a marked reduction in the force to be resisted by the impacted wall.

5.15 There are also other factors that would need to be taken into account in a more rigorous assessment, for example the dynamic nature of the loading and the particular level of risk that should be applied to such an impact event, but in my opinion the factors discussed above are more than sufficient to demonstrate that the structure is safe and fit for purpose.

Question - Issue 3

5.16 What are your comments on the "Updated Design Assumptions Adopted for Structural Review of HHS" in Appendix B3 of the Verification Report[24]?

Response:

5.17 The Updated Design Assumptions in Appendix B3 of the Verification Report do not apply to the HHS trough walls and therefore have no relevance to the safety or otherwise of the HHS trough walls.

[23] See sections 4.7.3-4.7.6 of Mr. Southward's CoI 2 Report.
[24] See [BB16/9994-9995]

6 Shear link reinforcement and partial utilisation of shear

Question

6.1 With reference to Sections 4.5.3 and 4.5.4 of the Verification Report[25], should a strength reduction factor be applied at any locations in the NAT, SAT and HHS as a result of the shear links? If so, what strength reduction factor should be applied at each of these locations?

Response:

6.2 In Section 5 of his report, Mr Southward deals with the alleged deficiency in shear links in certain areas of the SAT box structure. This is the only area of the NAT, SAT and HHS structures that any apparent deficiency has been identified.

6.3 In Section 5.2, Mr Southward challenges the basis on which the shear link reinforcement has been discarded. I agree and support the points he makes.

6.4 He then goes on to demonstrate that in considering the loadings on the NSL slab it is fundamentally important to recognise the three dimensional nature of the structure and the way in which the load is shared between the structural elements – a simple two dimensional model of the NSL slab will significantly overestimate the shear loading on the slab. I agree with his observation; the failure to recognise the importance of three dimensional behaviour is unfortunately not an usual event and leads to unnecessary concerns about the strength of structures.

6.5 I have no doubt that by using a three dimensional model of the SAT structure, it could be shown that there is no requirement for shear link reinforcement in the NSL slab, taking account of the comprehensive load sharing of the structural system in such a limited area and the actual strength of the concrete used in the construction.

6.6 In conclusion, it is my firm opinion that the SAT structure is fit for purpose and safe with regard to shear strength and there are a number of separate and distinct ways in which it can be demonstrated, including the following:

(a) It can be shown that the slab does not require shear links by considering the structure as a three dimensional structure and by taking account of the actual strength of the concrete used in the works;

(b) The for-construction drawings show a substantial over-provision of shear link reinforcement throughout the structure; and

(c) The actual strength of the concrete as shown by the concrete cube tests, and hence its shear strength, is greater than the design value and in my opinion

[25] See [BB16/9978]

should be used in any post-construction reviews of the safety of the structure.

7 Rebar Testing

7.1 Section 5.4 of Southward's CoI 2 Report contains his evidence concerning the lack of HOKLAS testing of approximately 7% of the rebar used in the Project. In this context I note that it is his understanding that all rebar used in the Project passed the manufacturers' testing procedures.

7.2 Notwithstanding, since it can be demonstrated on a fitness for purpose basis that the structure does not require shear link reinforcement, any consideration of using a reduced steel strength, even assuming that all or some of the untested steel did not pass the HOKLAS test, does not arise.

8 Conclusions

HHS Trough Walls

8.1 My opinion is that the structure is fit for purpose and safe, in that:

(a) The strength reduction factor applied to compensate for the lack of construction records and concern over the workmanship of the coupler connections installation has no technical justification; and

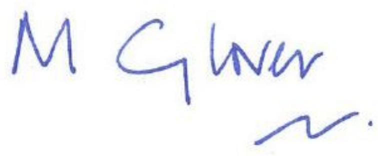
(b) A more considered approach involving a review of the construction risks of the structure, the operational nature of the facility, the consequences of failure and a more appropriate analysis model, would significantly reduce the design forces.

SAT Shear Links

8.2 I concur with Mr Southward's conclusion that the SAT is safe and fit for purpose.

9 Declaration

I declare that the contents of this Report are correct to the best of my knowledge, information and belief.



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6 December 2019