Professor YIN Guosheng
Head of Department, Department of Statistics & Actuarial Science
The University of Hong Kong

Specialist Field[1]: Statistical Learning for Big Data; Bayesian Computation and Analysis; Survival Analysis; Clinical Trials Methods; Adaptive Design; Data Mining; Machine Learning; Deep Learning; AI

Instructions

I have been instructed to provide my opinion in respect of the following issues:-

1. The appropriateness of using binomial analysis as suggested by MTRCL in investigating the defective rate of coupler connections at Hung Hom Station Extension ("HUH").

2. The rationale and considerations in relation to the random sampling of coupler connections at East West Line ("EWL") and North South Line ("NSL") slabs for the Stage 2 opening-up investigation under the Holistic Proposal.

3. The statistical analysis of the results of the enhanced Phased Array Ultrasonic Test ("PAUT") obtained from the opening-up investigation for deriving the coupler defective rates for EWL and NSL slabs.

4. The statistical analysis to derive a combined defective rate to account for the condition on both sides of coupler connections at those locations where the EWL slab was connected to the diaphragm wall ("D-wall") via capping beam.

5. Application of the defective rate in HUH to the adjacent North Approach Tunnels ("NAT"), South Approach Tunnels ("SAT") and Hung Hom Stabling Sidings ("HHS").

6. The list of issues raised by Leighton in relation to testing of steel reinforcement bars ("rebar") under the Extended Inquiry [AA1/240].

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[1] A copy of my CV is attached as Appendix A.

Declaration

I declare that:-

(a) I have read the code of conduct set out in Appendix D of the Rules of the High Court (Cap. 4A) and agree to be bound by it;

(b) I understand my duty to the Commission; and

(c) I have complied with and will continue to comply with that duty.

Professor YIN Guosheng
Date: 16 September 2019

Opinion

1. Appropriateness of using binomial analysis as suggested by MTRCL in investigating the defective rate of coupler connections at HUH

1.1 Background

1.1.1 The Shatin to Central Link ("SCL") is a railway project of Hong Kong under construction, which involves construction of new stations and the extension of existing stations (including the HUH). The Government entrusts to the MTR Corporation Limited ("MTRCL") the design, construction, procurement of services and equipment, testing, commissioning and all other matters associated with the bringing into service of the SCL. The construction work for HUH is being carried out under Contract No. 1112. The Contractor of Contract No. 1112 is Leighton Contractors (Asia) Limited ("Leighton").

1.1.2 At the HUH, two new platforms were constructed in the form of two reinforced concrete slabs supported by D-walls. The reinforcement connections between the platform slabs and the D-walls were formed by screwing rebars of the platform slabs into couplers embedded in the D-walls.

1.1.3 In May 2018, there were media reports that there had been unauthorized cutting of threaded ends of rebars during the construction of the above-mentioned platform slabs. Such allegation, if true, casts doubt on the quality of workmanship on whether the rebars are properly connected to the couplers embedded in the D-walls.

1.1.4 MTRCL had then been following up by reviewing the available photographic and other site records of the construction works of the platform slabs. MTRCL appointed independent expert consultants for a holistic study which was intended to verify the as-constructed condition of the HUH of the SCL Project.

1.1.5 After several rounds of discussion between the Government and MTRCL, MTRCL submitted to the Government on 4 December 2018 a Holistic Proposal for Verification & Assurance of As-constructed Conditions and Workmanship Quality of the HUH (EWL Platform Slab, NSL Platform Slab and the Connecting Diaphragm Walls) ("Holistic

Proposal"). The Holistic Proposal is a staged approach exercise consisting of Stage 1 (desktop exercise), Stage 2 (physical investigation) and Stage 3 (structural assessment).

1.1.6 In particular, the Holistic Proposal includes sampling method for verification of workmanship of coupler connections. Considering the specialized nature of the sampling design and the need to ensure that findings would be statistically meaningful, I and my two colleagues of the Department of Statistical and Actuarial Science HKU ("HKU Statistics Team") were engaged by the Government to provide independent statistical advice and expert opinions on MTRCL's Holistic Proposal in respect of its adequacy and any deficiencies in the sampling approach, methodology and associated statistical analysis throughout the process of sampling and subsequent analysis.

1.2 <u>Proposal to use binomial analysis</u>

1.2.1 The proposal to use binomial analysis was initiated by MTRCL in November 2018 in a draft Holistic Proposal for the purpose of assessing the workmanship in the coupler connections and rebar fixing in light of the allegations raised. It was suggested the extent of opening up should be based on statistical theory. A sample size of not less than 84 randomly selected coupler connections will give a meaningful result with 95% confidence level using binomial statistics. The coupler/rebar connection process was assumed to be similar at the EWL slab and NSL slab and the occurrence of defective coupler connections was considered as random in general. Therefore, the test results of coupler connections at one location can be treated as independent representative results for statistical analysis. I was given to understand that the construction method and design details of the EWL and NSL slabs are different. The EWL and NSL slabs are therefore treated as two populations.

1.2.2 I was asked by the Government to comment on the methodology proposed by MTRCL and to verify the accuracy of the sample size calculation provided.

1.3 <u>The underlying assumptions for the binomial distribution and appropriateness of binomial analysis</u>

1.3.1 In the first phase, I considered whether binomial analysis was an appropriate method by going through whether the underlying assumptions were satisfied.

1.3.2 As its name would suggest, a binomial distribution means each trial will lead to two possible outcomes, say either pass or fail. Suppose a random sample size of $\boldsymbol{n}$ coupler connections is drawn for assessment. Each selected coupler connection can have two possible outcomes only, either pass or fail in terms of the quality of the workmanship, and the coupler connection of a failed quality of workmanship is considered defective. The whole exercise focuses in the estimation of $\boldsymbol{p}$, i.e. the proportion of defective coupler connections in the population.

1.3.3 The binomial distribution is frequently used to model the number of "failures" or "successes" in a random sample of size $\boldsymbol{n}$ in clinical trials and statistical quality control. The binomial analysis is only appropriate if the following assumptions are satisfied:-

(i) The experiment consists of $\boldsymbol{n}$ identical trials;

(ii) Each trial results in one of the two possible outcomes, either "Defective" or "Non-defective";

(iii) The probability of selecting a defective coupler connection in each trial equals to $\boldsymbol{p}$ and remains the same;

(iv) The trials are independent.

1.3.4 The random variable of interest is the number of defective coupler connections observed in the $\boldsymbol{n}$ trials. The appropriateness of the four assumptions listed above was discussed in consultation with the Government's project team.

1.3.5 First, assumption (i) is satisfied naturally as the opening-up exercise to expose the coupler connections for each of the $\boldsymbol{n}$ selected locations is identical, regardless of the location of the subject coupler connection. Second, as we only considered the quality of the workmanship on each coupler connection to be either satisfactory (i.e. complying with the supplier specification) or not satisfactory (i.e. failing to comply with the supplier specification), assumption (ii) is also satisfied by the nature of the opening up exercise. Furthermore, the coupler connections in question were carried out by the same contractor, under similar site condition and the quality of workmanship is considered to be generally consistent with respect to the locations of the coupler connections. In other words, the defective coupler connections are random events which are distributed randomly, and the probability of selecting a defective coupler connection can be regarded as constant. Moreover, the outcome of a coupler connection will have no effect on the outcomes of other coupler connections; hence assumptions (iii) and (iv) are also satisfied. As such, binomial analysis is considered a reasonable and suitable approach for the purpose.

1.4 Adequacy of sample size

1.4.1 With the assumptions satisfied, I now discuss the adequacy of the sample size suggested by MTRCL. A general practice is to use a confidence level of 95% throughout the sample size calculation exercise. I calculated, p_U, the upper bound of the 95% (1-sided) confidence interval for the proportion of defective coupler connections in the population using the exact binomial probability formula:

$$\sum_{k=0}^{y} \binom{n}{k} [p_U]^k \, [1 - p_U]^{n-k} \leq (1 - 0.95)$$

where $\boldsymbol{n}$ is the sample size, $\boldsymbol{y}$ is the observed number of defective coupler connections in the sample. A higher accuracy is associated with a smaller margin of error ($|p_U - p|$) leading to a larger sample size required. In other words, a smaller sample size will yield a larger margin of error. For example, the estimated margin of error is estimated to be 5.8% when $\boldsymbol{n} = 50$ and $\boldsymbol{y} = 0$.

1.4.2 As suggested by MTRCL, a random sample of size $\boldsymbol{n} = 84$ yields an estimated margin of error of 3.5% when the number of defective coupler connections in the sample is zero ($\boldsymbol{y} = 0$). In other words, if none of the 84 exposed coupler connections are found to be improperly connected, no more than approximately 3.5% of coupler connections in the population could potentially be defective (in a worst case scenario with 95% confidence level). This estimated margin of error (i.e. the maximum failure rate) is considered to be reasonable and acceptable, with due consideration of cost and time implications.

1.4.3 The table below shows the maximum failure rate in the population based on the binomial statistical approach for a total number of samples of 84.

Total sample number = 84	
Total number of failures in the samples	Maximum failure rate in the population at 95% confidence level
0	3.5%
1	5.5%
2	7.3%
3	9.0%
4	10.6%
5	12.1%
10	19.4%
20	32.7%
30	45.2%

2. Rationale and considerations in relation to the random sampling of coupler connections

2.1 With the submission of the final Holistic Proposal by MTRCL on 4 December 2018, I was invited to conduct the random sampling exercise for the locations to be opened up. This section is to illustrate the methodology for the selection of coupler samples for the Purpose (ii) investigation, which is to verify the workmanship quality of the coupler connections between the D-wall panels and EWL / NSL slabs in Areas A, HKC, B, C1, C2 and C3. The methodology was designed and the random selection was conducted by the HKU Statistics Team led by myself.

2.2 <u>D-wall panels available for selecting sampling units at EWL and NSL slabs</u>

EWL slab

2.2.1 The EWL slab is connected to East D-wall and West D-wall of approximately 400 metres run from Gridlines 0 to 50, comprising a total of 234 D-wall panels. These D-wall panels to EWL slab connections can be divided into four groups, namely EWL East Wall Top connections, EWL East Wall Soffit connections, EWL West Wall Top connections and EWL West Wall Soffit connections. Rebars connecting D-wall panels and EWL slab in these four groups of connections include design with coupler connections or suspected to have coupler connections or with straight continuing rebars only.

2.2.2 Before conducting random selection of coupler connection samples for verification, the Government and MTRCL, after going through the relevant construction records, reached general consensus on the identification of D-wall panels with or suspected to have coupler connections among the 4 groups of connections. The number of D-wall panels identified to have coupler connections are summarized below:-

Group of connections at EWL slab	No. of D-wall panels with / suspected to have coupler connections
(A1) EWL East D-wall Top connection	27
(A2) EWL West D-wall Top connection	10
(A3) EWL East D-wall Soffit connection	88
(A4) EWL West D-wall Soffit connection	107
Total :	**232**

NSL slab

2.2.3 Similar to EWL slab, the NSL slab is connected to East D-wall and West D-wall but at a level lower than the EWL slab. The D-wall panels to NSL slab connections can also be divided into four groups, namely NSL East Wall Top connections, NSL East Wall Bottom connections, NSL West Wall Top connections and NSL West Wall Bottom connections. According to the details in the original working drawings (which as I understand have been complied with), rebars connecting D-wall panels and NSL slab are all connected by couplers.

2.2.4 The Government and MTRCL had gone through the relevant construction records before the random selection exercise of coupler samples at NSL slab for verification. MTRCL advised that certain locations of D-wall panels and NSL slab connections are physically inaccessible for verification of coupler connections based on the following reasons:

(i) the NSL slab is founded on soil which made the slab-to-D-wall bottom connections at NSL slab physically inaccessible from the underside of the NSL slab; and

(ii) the presence of mass concrete filling on top of the NSL slab has completely filled and covered up NSL D-wall Top connections at certain locations in Area A and Area B, which also made the slab-to-D-wall top connections at these panels physically inaccessible.

2.2.5 In view of the constraints mentioned in paragraph 2.2.4 above and as jointly agreed by the Government and MTRCL, the D-wall panels at which coupler connections are available for random sampling for Purpose (ii) investigation and the amount of these D-wall panels are summarized below:-

Group of connections at NSL slab	No. of D-wall panels with / suspected to have coupler connections
(B) NSL East and West D-wall Top connection	**189**

2.3 Methodology of two-phase cluster sampling scheme

2.3.1 The aim of the random selection of coupler connection samples (conducted independently by the HKU Statistics Team) was to select from the overall population of coupler connections in the D-wall to EWL and NSL slabs connections the locations at which the coupler connection samples are to be opened up for verification of workmanship.

2.3.2 A two-phase cluster sampling scheme was adopted in the selection of sampling units, each opening-up site (or sampling unit) yielding three coupler connections. Phase 1 sampling selection was to determine the locations of sampling units on plan, while Phase 2 sampling selection was to determine the layer of coupler connections to be exposed for workmanship verification at locations selected in Phase 1. The methodology of the sampling selection is discussed in detail in the following paragraphs.

Phase 1 sampling selection

2.3.3 As described above, the Government and MTRCL jointly identified 232 and 189 D-wall panel locations at EWL slab and NSL slab respectively, which are physically accessible for site verification, and thus available for Phase 1 sampling selection. Based on the prior decision made, 28 sampling units, each yielding 3 coupler connections, would be selected from each of EWL slab and NSL slab.

2.3.4 For EWL slab, the top connections available for sampling were significantly fewer than those at the soffits. It was considered more appropriate to select sampling units at each group of connections separately on a proportional basis to ensure the sampling units selected would be more proportionally distributed in the 4 groups of connections and that random samples from all 4 groups will be selected (to enhance representability of the samples). The number of sampling units to be selected from D-wall panels in each group of connections are tabulated below:-

Group of connections	No. of D-wall panels with / suspected to have coupler connections	No. of sampling units selected
(A1) EWL East D-wall Top connection	27	3
(A2) EWL West D-wall Top connection	10	1
(A3) EWL East D-wall Soffit connection	88	11
(A4) EWL West D-wall Soffit connection	107	13
Total	**232**	**28**

2.3.5 For NSL slab, the numbers of top connections available for sampling at East D-wall (92 panels) and West D-wall (97 panels) were roughly the same. Therefore, it was considered unnecessary to select sampling units from these two groups of connections on a proportional basis. These panels were pooled together for random selection of sampling units for NSL slab.

Group of connections	No. of D-wall panels with / suspected to have coupler connections	No. of sampling units selected
(B) NSL East and West D-wall Top connection	189	28
Total	**189**	**28**

2.3.6 In order to select D-wall panels on a random basis, a number with 5 decimal places was randomly generated from a uniform distribution ranging from 0 to 1 and assigned to each D-wall panel in the group. D-wall panels available for selection in each group were then sorted in a descending order based on the assigned random number, and the required number of D-wall panels were selected from the top of the list, i.e. with the largest random number, downwards. The D-wall panels listed after the required number of selected D-wall panels formed the "waiting list" and served as back-up replacement locations in case difficulties were encountered during opening up of the coupler connections at the originally selected D-wall panels. For instance, for EWL East D-wall Top connection where 3 sampling units were to be selected, the top 3 D-wall panels sorted out of 27 panels according to the values of the randomly generated numbers would be chosen as the panels to be opened up, and the 4th D-wall panel in the sorted list would replace any one of the top 3 originally selected D-wall panels if exposure of coupler connections was found to be not feasible. Likewise, the panel with the highest value out of 10 random numbers generated for EWL West D-wall Top connection was selected to be opened up, and the next panel would replace the originally selected panel if difficulties were encountered.

2.3.7 While the lengths of panels range from 2.8m to 7.2m and that the size of the opening up area was about 400mm width for yielding 3 coupler connections in the same layer, it was necessary to determine the exact location of the opening up area on plan at each of the D-wall panels selected as described above. To achieve this, another random number with 5 decimal places valued from 0 to 1 was generated from a uniform distribution for each of the selected D-wall panels and the random number would be multiplied by the corresponding D-wall panel length in order to determine the distance of a reference point from the southern end of the D-wall panel. The reference point will be used as the basis for locating the sampling unit on plan. **Figure 1** illustrates the determination of the reference point.

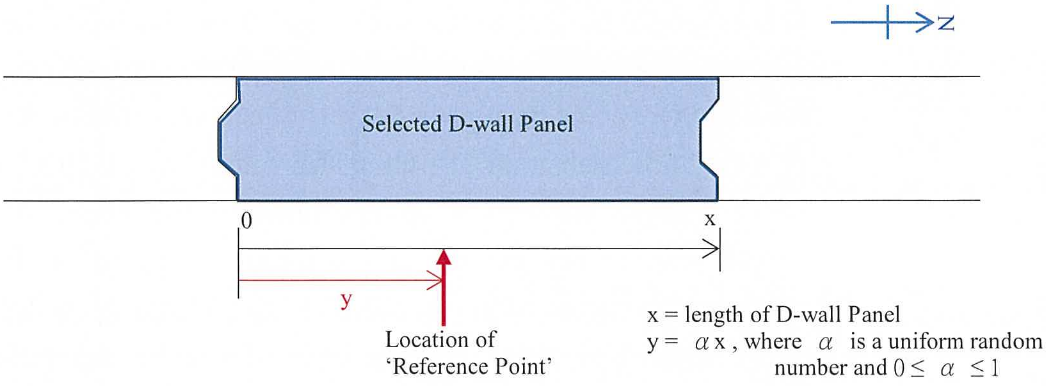


Figure 1 – Determine "Reference Point" for locating the sampling unit on plan

2.3.8 The exact location of a sampling unit, which should yield 3 coupler connections at the same layer, at each selected D-wall panel was determined based on the location of the reference point using the "best compliant" approach. The "best compliant" approach provided that once a reference point at the selected D-wall panel was determined, unless the reference point could not physically be accessible or opened up due to physical constraints, all reasonable efforts should be made to obtain the data at such selected location. If it was impossible to expose such coupler connections, the 3 coupler connections which were at the nearest location to the reference point would be chosen as the sampling unit instead. And if the nearest location with 3 coupler connections measured from the Phase 1 selected location were of equal distance on both sides, then the north side from the Phase 1 selected location would be chosen for opening up.

2.3.9 While the determination of reference point locations was carried out in advance, the exact location of each sampling unit was determined on site by Ground Penetration Radar (GPR).

2.3.10 To maintain the independence and impartiality of the random selection process, the generation of random numbers, the sorting of D-wall panels in numerical orders, and the calculations of reference point locations were under the full control of the HKU Statistics Team.

Phase 2 sampling selection

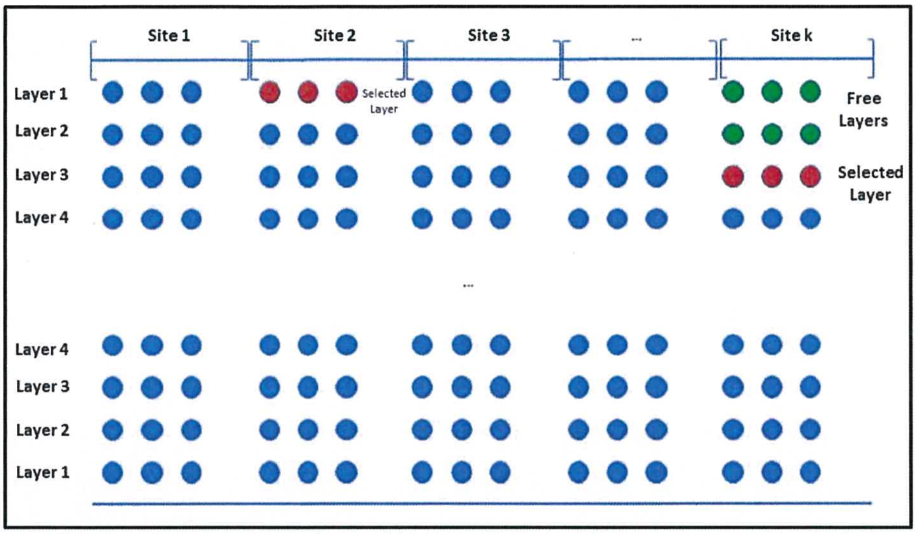
2.3.11 Phase 2 sampling selection was to determine the layer of coupler connections to be exposed for workmanship verification at the locations selected in Phase 1. According to the drawings and construction records, there could be at most 5 layers of coupler connections at the top or soffit of the slab at the D-wall to slab connections, which varies from panel to panel. In view of the uncertainty in the number of layers of coupler connections existing at the locations selected in Phase 1, a random permutation of the numbers "1" to "5" was generated for each panel selected in Phase 1. The layer of coupler connections to be exposed as the sampling unit was prioritized according to such permutation. The details are described in the following paragraphs.

2.3.12 For each panel selected in Phase 1 sampling selection, a numerical sequence consisting of numbers from "1" to "5" was randomly generated. The numerical sequence of each panel represented the order of priority of the layer of coupler connections to be exposed for that panel at the selected location. In parallel, MTRCL reviewed the approved drawings and as-constructed records and advised the maximum number of layers of coupler connection present in the selected locations.

2.3.13 At each selected location, the maximum number of layers of coupler connections advised by MTRCL was then mapped with the numerical sequence generated by the HKU Statistics Team. The first number in the numerical sequence that was smaller than or equal to the maximum number of layers of coupler connections at the selected location was chosen as the layer to be exposed. For example, if a numerical sequence of "4, 2, 5, 1, 3" was generated for a particular panel and that such panel was revealed to have at most 3 layers of coupler connections, then the sampling unit for that panel would be located in the 2nd layer of coupler connections counting from the outermost layer because the first number "4" was greater than the maximum number of layers of coupler connections and the subsequent number "2" was smaller than the number of actual layers of coupler connections, making such layer possible to be exposed.

2.3.14 The procedures described in paragraphs 2.3.12 and 2.3.13 were repeated for all panels selected in Phase 1 until the layers of coupler connections at which the sampling units at all the selected panels were determined.

2.3.15 It is expected that each layer will yield 3 coupler connections. If 3 couplers at Layer 3 are selected, the 6 coupler connections in Layers 1 and 2 will also be examined and included as extra samples (**Figure 2**).



Note: Couplers above the selected layer will be exposed and included as extra samples for verification of workmanship quality.

Figure 2 – An illustration of the proposed sampling scheme with Layer 1 of Site 2 and Layer 3 of Site k being selected

2.4 <u>Samples selection meetings</u>

2.4.1 Two meetings were held between the Government and MTRCL for the random selection of sampling units at EWL slab and NSL slab for Purpose (ii) investigation.

First samples selection meeting

2.4.2 The first meeting was held on 5 December 2018 at 11:00 am at Run Run Shaw Building, The University of Hong Kong. The aim of the first meeting was to conduct the Phase 1 sampling selection exercise for EWL slab.

2.4.3 The random selection was conducted by the HKU Statistics Team and witnessed by representatives of the Government and MTRCL.

2.4.4 The HKU Statistics Team briefed the meeting the random sampling arrangement described in section 2.3 above. The Government and MTRCL also agreed on the sampling population described in section 2.2 above. Further, the meeting discussed and agreed the "best compliant" approach described in section 2.3.8 above.

Second samples selection meeting

2.4.5 The second meeting was held on 10 December 2018 at 10:00 am at Run Run Shaw Building, The University of Hong Kong. The aim of the second meeting was to conduct the Phase 1 sampling selection for NSL slab, and the Phase 2 sampling selection for both EWL slab and NSL slab.

2.4.6 Again the random selection was conducted independently by the HKU Statistics Team and witnessed by representatives of the Government and MTRCL.

2.4.7 At the beginning of this second meeting, MTRCL's representative advised that after checking the locations of the sampling units at the EWL slab selected in the first sample selection meeting against the as-constructed records, the following difficulties were envisaged in exposing the coupler connections at certain selected locations. After discussion, the solutions as stated below were agreed among the parties.

Location selected in first meeting	Difficulty encountered	Agreed solution
EWL West D-wall Top – Panel WH35	Tie-beam was found at the selected reference point at offset 3.416m, and there was no rebar connecting D-wall and EWL slab at that offset location.	Apply "best compliant" approach to exposing the nearest coupler connections from the selected reference point.
EWL East D-wall Soffit – Panels EH27, EH29 and EH38	Mass concrete of at least 1 metre thick has been cast against the soffit of EWL slab at these three panels of East D-wall, which obstructs the exposure of coupler connections.	Replace these three locations with the first three panels on the "waiting list" produced at the first meeting under the Group (A3) - EWL East D-wall Soffit connection (i.e. EH107, EM90 and EH97)
EWL West D-wall Soffit – Panels WH30, WH36 and WH42	Mass concrete of at least 1 metre thick has been cast against the soffit of EWL slab at these three panels of West D-wall, which obstructs the exposure of coupler connections.	Replace these three locations with the first three panels on the "waiting list" produced at the first meeting under the Group (A4) - EWL West D-wall Soffit connection (i.e. WM78, WH68 and WM133)

2.4.8 After all the locations to be opened up and the respective layers of coupler connections to be exposed were selected, the random sampling results were validated at the meeting to ensure that all parties agreed with the sampling results.

3. Statistical analysis of the PAUT results obtained from the opening up investigation

3.1 Verification of defective rates

3.1.1 The opening up exercise took place from December 2018 to April 2019. Throughout the period, I noted that the opening up and PAUT results were published and regularly updated on the Highways Department's website.

3.1.2 After all the PAUT results became available, I was invited to verify the accuracy of the estimated defective rate calculated on the basis of the PAUT results provided by MTRCL.

3.1.3 The opening up exercises were carried out in the EWL and NSL slabs independently. The target sample size in each slab was at least 84 as suggested. MTRCL provided 90 valid PAUT results for EWL slab of which 25 were found to be defective, and 93 valid PAUT results for NSL slab of which 23 were found to be defective. I reviewed the opening up results, and found no strong statistical evidence of clustering in the sample.

3.1.4 Using the exact binomial formula as listed in paragraph 1.4.1 above with a 95% confident level, the upper bounds were estimated to be 36.6% and 33.2% for EWL and NSL slabs respectively.

3.1.5 I noted that MTRCL used the Clopper-Pearson method [OU6/9684 - 9685] to calculate the upper bounds of the defective rates for EWL and NSL slabs and also arrived at 36.6% and 33.2% respectively. I considered that the methods and calculations performed by MTRCL were appropriate and in order.

3.2 The issue of partial engagement of coupler connections

3.2.1 The current analysis of the quality of workmanship of coupler connections is based on binomial analysis. I have not received any instructions to review and comment on any proposals regarding partial engagement of coupler connections and the associated statistical analysis. As far as I understand, some tests on the partially engaged coupler connections were carried out by MTRCL. However, these test results failed to comply with all the engineering requirements and there was no proposal received by the Government regarding the use of any residual strength that partially engaged coupler connections may provide.

3.2.2 In the design stage of the Holistic Proposal, I verified the suggestion using a binomial analysis by MTRCL. I considered the binomial analysis appropriate because it uses the minimum number of assumptions. From the statistical perspective, the fewer assumptions one makes, the more desirable is the statistical analysis. More assumptions may introduce more uncertainty as some assumptions cannot be verified easily. If the assumptions made are not entirely true, the conclusion drawn from the statistical analysis may no longer be valid.

3.2.3 In the first part of the Inquiry, there were discussions regarding the residual strength of the partially engaged coupler connections. If coupler connections with insufficient engagement can be allowed and taken into account in the design, multinomial analysis may be relevant. However, to design a multinomial analysis procedure, one needs to classify a failed (i.e. partially engaged) coupler connection into several classes with different ranges of engagement lengths. One has to determine the number of classes, the range covered in each class, and the corresponding allowable residual strength of the coupler connections, if any, in each class. However, I am not aware of any reference standards which may facilitate or allow for such determination. Moreover, a testing plan needs to be developed to provide a reliable and representative estimate for the allowable residual strength, if any, in each class. For each class, there should be a sufficient number of samples so as to achieve a reasonably small margin of error with a high level of confidence. That means more classes would necessitate a much greater sample size as compared to the binomial analysis.

3.2.4 As mentioned above, there are many additional arbitrary decisions which would need to be made for a multinomial analysis - such as the number of classes, the range of engagement lengths of each class and so on.

Different combinations of these decisions will end up with different estimates. For example, consider the case with 3 classes, namely (A) pass, (B) partial pass, and (C) fail. Consider two designs with different ranges for classes (B) and (C) with the first design having 70% (A), 25% (B) and 5% (C) and the second design having 70% (A), 15% (B) and 15% (C). The estimates to be arrived at based on the two designs can be very different which would introduce room for manipulation of the data.

3.2.5 I consider the use of binomial analysis reasonable as it involves less arbitrary decisions in the design. It is also more practical due to the smaller sample size required and hence less cost and time implications. It is a more suitable approach for achieving the primary objective to assess whether the quality of coupler connections is in compliance with specification or not.

4. Statistical analysis to derive a combined defective rate to account for the condition on both sides of coupler connections at locations where EWL slab was connected to the D-wall via capping beam

4.1 The issue

4.1.1 I was given to understand that some of the randomly selected panels to be opened up are with a different configuration from the others in that there is a capping beam resting on top of the D-wall such that the coupler connection is located within the EWL slab instead of partly embedded in the D-wall. During the opening up exercise, some of the coupler connections on the side of the capping beam, in addition to the side of the platform slab, were exposed as well. As a result, the workmanship of coupler connections on the capping beam side also came to light.

4.1.2 Based on the information provided by MTRCL, out of the 11 exposed coupler connections on the capping beam side, 2 of them were found to be not in compliance with the manufacturer's specification, i.e. with more than two threads exposed. On the platform slab side of the same panels, 2 out of 7 coupler connections with valid PAUT results are found to be not in compliance with the manufacturer's specification. This finding has brought up a new situation on the acceptance criteria of the coupler connection. While a coupler connection could only perform as intended when the rebars on both sides of the coupler are properly screwed in, it is necessary to consider the workmanship of the coupler connection of both sides. Only in the situation where the connections on both sides are proper can a coupler connection be considered as satisfactory for this type of configuration. Failure in either side or both sides of the coupler connection will result in a defective coupler connection as a whole. It is therefore necessary to find a way to take into account the failure rates on both sides of the coupler connections for those EWL panels with capping beam. This situation arose due to some unexpected observations, and was not contemplated when designing the sampling plan. I was therefore requested to review the situation and make a suggestion on how the effect of defective coupler connections on both sides of a coupler could be reflected in a single defective rate, namely in statistical terms.

4.2 Derivation of a combined defective rate

4.2.1 As mentioned above, a satisfactory coupler connection is defined as one for which both sides of the connection satisfy the installation requirements. Failure in either side or both sides of the coupler connection will result in a defective coupler connection.

4.2.2 To assess the combined effect of the defective workmanship on both sides of a coupler connection, a two-step approach is used. Based on the information provided by MTRCL, the proportions of failed coupler connections on each sides could be calculated. Assuming that the quality of workmanship on the two sides of the coupler connection were independent, a combined defective rate taking into account the failed proportions of both sides of the coupler connection can be computed using simple probability theory described as follows.

4.2.3 Let p_B be the proportion of defective coupler connections for those panels with capping beam at EWL level. Assume that the quality of workmanship on the two sides are independent. Since the coupler connection is considered satisfactory if and only if the connection on both sides are satisfactory, therefore it is easy to see that

$$1 - p_B = (1 - p_{B1})(1 - p_{B2})$$

where p_{B1} and p_{B2} are the proportions of unsatisfactory connections on the platform slab side and capping beam side respectively. The proportion (i.e. the combined defective rate) can be estimated by

$$\hat{p}_B = 1 - (1 - \hat{p}_{B1})(1 - \hat{p}_{B2}).$$

According to the data provided by MTRCL, we have $\hat{p}_{B1} = \frac{2}{7}$ and $\hat{p}_{B2} = \frac{2}{11}$, therefore p_B is estimated to be

$$\hat{p}_B = 1 - \left(1 - \frac{2}{7}\right)\left(1 - \frac{2}{11}\right) \approx 0.4156 = 41.56\%\,.$$

4.2.4 The above combined defective rate only represents the defective rate at the opened up locations. To determine the defective rate applicable for all panels of similar configurations at 95% confidence level, a statistical inference is required.

4.2.5 Using the delta method and after some algebraic manipulation, the variance of $\hat{p}_B$ is given by

$$\mathrm{Var}(\hat{p}_B) = \{(1 - \hat{p}_{B1})(1 - \hat{p}_{B2})\}^2 \left[\frac{\hat{p}_{B1}}{7(1-\hat{p}_{B1})} + \frac{\hat{p}_{B2}}{11(1-\hat{p}_{B2})}\right] = 0.0264.$$

Using the normal approximation, the upper bound of a one-sided 95% confidence interval for p_B is given by

$$0.4156 + 1.645 \times \sqrt{0.0264} = 0.6829.$$

4.2.6 The above calculation represents construction of a one-sided 95% confidence interval with reference to the proportion of the number of opening up locations against the actual number of panels with the same configuration. And the upper bound value of the 95% confidence interval for the combined defective rate using the normal approximation was found to be 68.3%.

5. Application of the findings in HUH to the adjacent NAT, SAT and HHS

5.1 Apart from the Holistic Proposal, I understand that there are issues arising from the missing site records at the areas surrounding HUH, namely SAT, NAT and HHS. MTRCL has submitted a Verification Proposal to verify the as-constructed conditions, ascertain the structural integrity and ensure the quality assurance of the structures in these areas. I was given to understand that there were couplers installed in these areas, but there was no opening up exercise similar to that carried out at HUH to verify the quality of workmanship of these coupler connections. As such, it was considered that there was a need to make use of some auxiliary information for such purpose and the most relevant information would be what has been obtained from the opening up exercise and PAUT results for the coupler connections at HUH. I note that MTRCL proposed to use a strength reduction factor of 35%, which is comparable to the defective rate derived from the analysis of the opening up exercise and PAUT results at HUH. I consider that such decision of adopting the auxiliary information from nearby areas under the same contract is primarily an engineering or management decision and there is no statistical consideration involved. I was not consulted by the Government on such non-statistical decision.

6. Opinions on the issues raised by Leighton

6.1 <u>The issue</u>

6.1.1 I have been requested to provide my opinion with respect to the issues raised by Leighton regarding the rebar testing [AA1/240]. In giving my opinions, I should set out that the statistical issues in regard to rebar testing raised by Leighton were not exactly clear and I provide my opinions only based on the background information on how the concerns arising from the 7% untested rebars were addressed.

6.2 <u>Statistical assessment of the quality of the rebars based on the results of the tests conducted by the manufacturers and those conducted after delivery to the site</u>

6.2.1 Statistical assessment of the quality of the untested rebars based on the results of the tests conducted by the manufacturers at the mill and/or those conducted on other rebars after delivery to the site requires some assumptions, such as an assumption of homogeneous quality of rebars of different casts, delivered to the site in different batches or at different times, or produced by different manufacturers. In other words, to enable a valid statistical assessment to be made, the probability of any selected rebar to be defective within each and every batch of rebars delivered to the site needs to be (or has to be assumed to be) identical.

6.2.2 The validity of this homogeneity assumption cannot be established easily. Sampling and testing of each batch are critical as a gatekeeping procedure. For instance, in a PowerPoint presentation prepared by CARES (Certification Authority for Reinforcing Steels) [2] entitled *"CARES and the reinforced concrete industry: Providing confidence in reinforcing steels"*[3], it is observed that (a) *"[e]ach cast can vary in its make up and properties...CARES recognises that there may be some variability within the reinforcing steel"* (p 19); and (b) the usage of steel that is not subject to a centralized certification scheme may contain *"[s]ignificant variations" due to "poor process control during the steel making, casting or rolling processes resulting in significant variations in product's mechanical properties"* (p 33).

6.2.3 On the facts of the present case, the validity of the homogeneity assumption cannot be established easily when the rebars were from different manufacturers and were of different casts delivered to the site in different batches and at different times[4].

6.2.4 For these reasons, in my judgment, I do not think I can make the statistical assumption that all batches of rebars delivered to the site were "homogeneous". Without such an assumption being established, I am also not in a position to comment on the level of confidence which could be derived from the results of the tests conducted by the manufacturers and those conducted on some of the batches of rebars after delivery to the site.

6.2.5 Another required assumption is that the untested batches occurred at

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[2] Which, I have been told, is an reinforcing steel certification authority mentioned and endorsed by the Commission's own project management expert Mr Steve Rowsell at paragraph 101 of his report dated 23rd August 2019 [ER1/50].

[3] The PowerPoint presentation is at Appendix B and is available on the website of CARES (https://www.ukcares.com/presentations/reinforcing-steel).

[4] I am given to understand that the rebars used in Contract 1112 were from different manufacturers in different countries/areas, for example, Hong Kong, Mainland China, Russia and so forth, and were of different casts delivered to the site in different batches and at different times [see CC11/7252-7282 and the documents in item 332 in Bundle CC11].

random, which cannot be easily validated as well.

6.2.6 Without establishing the validity of these assumptions, no valid statistical conclusion can be made.

6.3 Comments on the statistical methods and analysis referred to in Section 4.3 of the Verification Report and the conclusions drawn

6.3.1 As explained in Section 4.3 of the Verification Report, in order to determine the effect of the 7% of untested rebars on the completed structures, the testing records of MTRCL's HOKLAS laboratory were used as a reference. Over the past 9 years, about 110,000 rebar samples were tested at MTRCL's laboratory and out of which 55 samples failed the test. These 55 samples are divided into two groups, i.e. samples with a bar diameter equal to or greater than 16 mm and samples with a bar diameter of less than 16 mm. For the former group, the worst case failure gives a tensile strength reduction of 4%, i.e. the measured tensile strength of the worst case is 4% less than the design tensile strength. For the latter group, the worst case failure gives a tensile strength of about 13% lower than the required design strength. In other words, these 4% and 13% strength reductions represent the worst case scenario of the 55 failed samples. They are the extreme failure cases by tests and were not derived from any statistical analysis. I note that these two strength reduction factors were used in the structural review, by *assuming* that the said reduction factors apply to all rebars used in NAT, SAT and HHS, in order to assess if the completed structures could accommodate such strength reduction.

6.3.2 This is a sensitivity analysis by plugging in the worst case scenario based on the information from past experience rather than a statistical analysis.

Guosheng Yin

Patrick S. C. Poon Endowed Professor
Department of Statistics and Actuarial Science
The University of Hong Kong
Pokfulam Road, Hong Kong
Tel: 852-3917-8313 Fax: 852-2858-9041 Email: gyin@hku.hk

EDUCATION

Ph.D. (2003)	Biostatistics, University of North Carolina at Chapel Hill, NC, USA
M.S. (2000)	Biostatistics, University of North Carolina at Chapel Hill, NC, USA
M.A. (1997)	Physics, Temple University, Philadelphia, PA, USA
B.S. (1995)	Physics, Jilin University, Changchun, China

POSITIONS

2018 – present	Patrick S. C. Poon Professor in Statistics and Actuarial Science, University of Hong Kong
2017 – present	Head of Department Department of Statistics and Actuarial Science University of Hong Kong, Hong Kong
2014 – present	Professor (with Tenure) Department of Statistics and Actuarial Science University of Hong Kong, Hong Kong
2009 – 2014	Associate Professor (Tenure-track) Department of Statistics and Actuarial Science University of Hong Kong, Hong Kong
2008 – 2009	Associate Professor (with Tenure) Department of Biostatistics University of Texas M. D. Anderson Cancer Center, Houston, TX, USA
2003 – 2008	Assistant Professor (Tenure-track) Department of Biostatistics University of Texas M. D. Anderson Cancer Center, Houston, TX, USA

RESEARCH INTERESTS

Clinical trial methodology and adaptive design
Data mining, machine learning, AI
Bayesian methods and inference
Survival analysis
Big data and high-dimensional data analysis

COMPUTER SKILLS

C/C++, Python, SAS, R, Matlab, WinBUGS, East, PASS, nQuery

PROFESSIONAL MEMBERSHIP

American Statistical Association (ASA)
Eastern North American Region of the Biometric Society (ENAR)
International Society for Bayesian Analysis (ISBA)
Institute of Mathematical Statistics (IMS)
International Chinese Statistical Association (ICSA)

HONORS & AWARDS

2013	Fellow of the American Statistical Association
2012	Elected Member of the International Statistical Institute
2009	James E. Grizzle Distinguished Alumni Award, Department of Biostatistics, University of North Carolina at Chapel Hill.

STUDENTS ADVISED

Over 30 M.S., M.Phil., Ph.D., Post-doctor fellows, and Research Assistants/Associates

PRESENTATIONS

Over 200 invited talks, presentations, or seminars in conferences and universities.

GRANTS

Multiple grants from Hong Kong Research Grants Council and National Cancer Institute.

EDITORIAL SERVICES

Associate Editor	*Statistical Analysis and Data Mining* (2018 – present)
Associate Editor	*Japanese Journal of Statistics and Data Science* (2018 – present)
Associate Editor	*Journal of the American Statistical Association* (2013 – present)
Associate Editor	*Contemporary Clinical Trials* (2012 – present)
Associate Editor	*Bayesian Analysis* (2009 – 2015)
Guest Editor	Special issue on Clinical Trials for Personalized Medicine in *Contemporary Clinical Trials* (2012)
Grant Reviewer	Hong Kong Research Grants Council Faculty Research Grant, Hong Kong Baptist University
Book Reviewer	John Wiley & Sons, CRC Press (Taylor & Francis Group), Springer

PUBLICATIONS

Book

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19. Gu, J. and **Yin, G.*** (2019). Fast algorithm for generalized multinomial models with ranking data. *ICML* 2019 (36th International Conference on Machine Learning).

20. Zhang, C. and **Yin, G.*** (2019). Fast and stable maximum likelihood estimation for incomplete multinomial model. *ICML* 2019 (36th International Conference on Machine Learning).

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Statistics in Top Medical Journals (corresponding author*)

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The purpose of this presentation is to identify the risks taken if CARES product certification is not specified and therefore that products manufactured by CARES Approved Firms are not used. Reinforcing bar is a globally traded product, with in excess of 180 producers around the world. The reinforcing steel purchased for a construction project could be from any one of the manufacturers around the world. Only 35 of these are CARES approved. This presentation identifies the differences between products manufactured by CARES Approved firms and those that are not.

Structural concrete is one of the most widely used construction materials throughout the world. It is commonly considered a durable and cost-effective composite material. The quality of the composite material will be dependent upon al of its constituents. A Structural Engineer needs to know that the strength properties of the steel consistently meet their expectations. The supply chain for reinforcing steel, i.e. it’s manufacture, processing and supply to a construction site is relatively short but complex. At each stage in the supply chain responsibility for the steel is transferred from one company to another. This may result in a loss of material identity and the use of material of dubious or unknown origin and hence unknown properties and performance.

Reinforcing Steel Properties

- **Bar/Coil (BS4449) Grade B500A, B and C.**

Variability:- Bar.

- 7/8 N/mm^2 on any 1 bar.

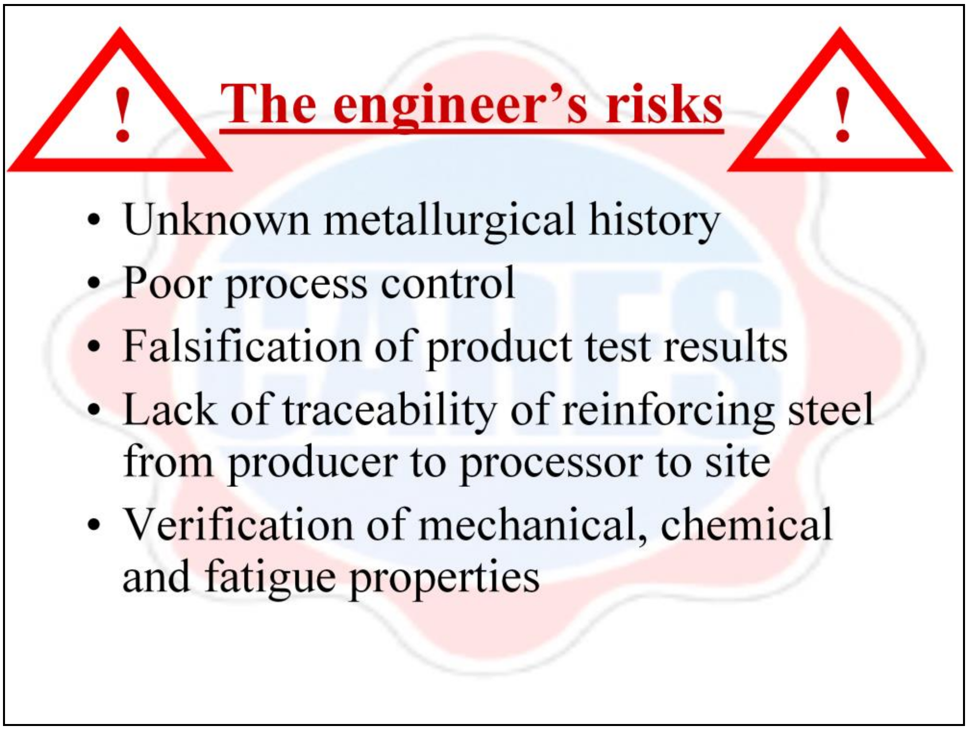
- 15/20 N/mm^2 on any 1 cast.

- 30/40 N/mm^2 on a population (LTQL)

(50/50 – Material and Testing)

(Accuracy of result depends on the property being tested.)

BAR, either in bar form or coil form, is manufactured from individual casts of steel. The size of these casts vary, but are notionally 100 tonnes. Each cast can vary in its make up and properties and as CARES and the relevant British Standards wish to ensure consistency pf product requirements, CARES looks very closely at both the processing of the steel and also its finished properties. CARES recognises that there may be some variability within the reinforcing steel, but wishes to see this variability reduced. This slide describes typical variability of a reinforcing bar, using the important property of Yield Strength as an example. It should be noted that past work has found that variability may result from both the steel and its testing, and therefore CARES takes this into account when performing its assessment.



The engineer’s risks or the potential problems of non-CARES approved reinforcement products.

Poor quality – made from re-rolled railway lines, high carbon poor weldability, unknown metallurgical history, stock bar on site unsuitable for bending

Significant variations – poor process control during the steel making, casting or rolling processes resulting in significant variations in product’s mechanical properties

Falsification – product test certificates from good material was supplied with material from an unknown producer

Lack of traceabilty – reinforcing steel purchased globally, traceability not considered important

Verification – extensive sampling and testing on site, long delays on site, problems with interpretation of results, more material in supply chain,