HIGHWAYS DEPARTMENT

GUIDANCE NOTES ON MAINTAINABILITY REQUIREMENTS FOR BRIDGE STRUCTURES WITH EXTERNAL PRESTRESSING SYSTEMS

NT Region

NT/GN/050
March 2023

Highways Department
NT/GN/050

Guidance Notes on Maintainability Requirements for Bridge Structures with External Prestressing Systems

Background

External prestressing technique has been widely adopted in Hong Kong for the construction of bridge structures. Over the past decades, external prestressing cables were commonly adopted for highway bridges over the Territories.

2. The Structures Design Manual for Highways and Railways ("SDM") provides some general guidance for the external prestressing design of bridge structures in Hong Kong. In order to enhance the guidance for external prestressing design, the Bridges and Structures Division ("B&S Division") of the Highways Department conducted a review on the SDM, and made two amendments to SDM in 2020 and 2021 respectively (see **Annex I**). In the first amendment (AMD. 1/2020), Section 5.6.3 (which provided guidance for the design of external prestressing) was amended with an aim to enhancing the design requirements for external prestressing and making them commensurate with international practices. The amendments incorporated in AMD. 1/2020 were related to general requirements for the inspection/removal/replacement of external tendons, grouting of the tendon ducts, and the provision of remote monitoring/warning systems for the detection of tendon/strand/wire breakage. In the second amendment (AMD. 1/2021), new requirements were proposed to Section 5.6.3 with a view to ensuring the quality of grouting of external prestressing works and to enhancing the requirements on post-grouting inspection of external prestressing tendons. Additional requirements on submission of prestressing records to maintenance authorities upon handing over of completed structures were introduced in order to facilitate future maintenance of external prestressing works.

Review on Maintainability Requirements

3. While the failure or defect of external prestressing elements in bridge is uncommon, it has happened in in-service bridges in Hong Kong and other countries. The problems were usually due to the corrosion of steel strands in the external tendons of these post-tensioned bridges. Maintainability of the prestressing elements will be subsequently a major concern to the maintenance authority of the bridges. For bridge structures with prestressing elements, any defect of prestressing elements will likely necessitate the full checking of all prestressing elements and anchorage points and even massive replacement of prestressing elements of the bridge structure in order to ensure the structure safety and integrity of the bridge structures. Sufficient maintainability requirements/provisions should be incorporated in the bridge with external prestressing systems well from the design and construction stages in order to minimise the effort of maintenance and even replacement, if necessary.

4. A further review was conducted to establish the maintainability requirements for external prestressing systems. Subsequently, amendments to both SDM and General Specification for Civil Engineering Works ("GS") are proposed, and this Guidance Notes is formulated. The draft proposed amendments to SDM and GS are attached in **Annex II** and **III**[1].

5. This Guidance Notes sets out the maintainability considerations during the design, construction, take over and maintenance stages for bridge structures with external prestressing systems. Designers and project proponent shall ensure that content contained in this Guidance Notes and its annexes are complied with for bridges structures with external prestressing systems.

Design Stage

6. Incorporation of the operation and maintenance considerations in early planning and design stage of a project can definitely reduce the efforts, time and recurrent cost involved in the operation and maintenance during

[1] Before the promulgation of the updated version of SDM and Section 17 of GS, the proposed amendments in **Annex II** and **III** of this Guidance Notes should be followed, afterwards, the promulgated version of SDM and Section 17 of the GS shall prevail.

the life cycle of the structure. The project proponent should engage the maintenance authority at the preliminary design and detailed design stage. A report on "Assessment of maintainability for future inspection, operation and maintenance of bridge structures with external prestressing system" shall be provided to consult the maintenance authority during the preliminary and detailed design stage. Sufficient time, e.g. 2 months, should be allowed for the maintenance authority to review the report and provide comments. In the report, the designer should provide schematic description on the future inspection and maintenance works, including but not limited to the followings:-

i. Inspection and maintenance access points;
ii. Size of equipment for all possible maintenance activities, including de-tensioning, stressing and grouting for replacement of tendon;
iii. Method statement on the replacement of tendon;
iv. Design and/or set-up for replacement of external tendons;
v. Temporary traffic arrangements;
vi. Delivery route of maintenance equipment;
vii. Remote monitoring and warning system, if any; and
viii. Any other maintainability considerations.

7. With regards to Items 6(iii) and (iv) mentioned above, the designer should pay particular attention that based on past experience, methodology of tendon replacement would be different for individual bridge structure depending on the alignment and location of tendon, its access points, available spatial condition in bridge deck as well as available nearby works area for assembly and grouting works. A tailor-made design / set-up would be required for each bridge structure. Extent of the proposed traffic restriction, if any, shall be agreed with the relevant authorities in advance and included in the method statement.

8. To facilitate the close visual inspection ("CVI") (i.e. visual inspection which is carried out at touching distance) of tendons at high levels (e.g. for external tendons positioned above 2m height), permanent inspection platform should be provided. The proposed arrangement should be agreed with the maintenance authority. Provision using removable scaffold rather than permanent inspection platform may be considered as an alternative solution subject to agreement with the

maintenance authority. However, it would take time for setting up removable scaffold. Furthermore, in accordance with the Construction Sites (Safety) Regulation, temporary working platforms have to be checked by competent person bi-weekly. As such, the maintenance authority should note that immediate inspection of structure may not be feasible under such requirements. Besides, the permanent platform should not pose obstruction to inspection and maintenance works of other elements inside the bridge.

9. In case there is an alternative design proposed by the contractor or additional left-in construction provisions to facilitate the construction works, the project proponent shall agree with the maintenance authority on major deviation from original design of bridge and the additional left-in construction provisions. These should also be reflected in the as-built drawings.

10. Building Information Modelling ("BIM") is a useful tool to identify the maintainability of the bridge structure. It provides a visual aid for maintenance authority to assess the spatial adequacy from the maintainability point of view. Where BIM is adopted, all utilities and bridge installations (external tendons, lighting, anchor blocks, etc.) should be incorporated in the BIM model to ensure that the maintainability has been accounted for in the design.

Construction Stage

11. In an external prestressing system, corrosion attack on the steel strand could cause deterioration of their structural capacity hence reduce the service life of the bridge structures. One of the common causes leading to acceleration of corrosion attack was the existence of air pockets after the completion of grouting operation, which led to insufficient grout protective layer on the steel strands to resist corrosion. The project proponent shall ensure the resident site staff exercise adequate supervision and control to the compliance of materials and prestressing tendon installation works, in particular the grouting works.

12. The project proponent shall ensure the following control measures are taken for site supervision of works contracts involving grouting of

external tendons:-

i. For the first grouting operation of external prestressing tendon on site, site staff with rank not less than Resident Engineer should be present to witness the grouting operation; and

ii. Apart from the full-time presence of site supervisory staff for each grouting of external prestressing tendons, a random check on the grouting of tendons (including the set-up and grouting operation), with a number of tendons not less than 10% of the total number of tendons to be grouted, by a higher rank site supervisory staff should be carried out. The result of the random check should be recorded in the site diary.

13. To inspect the quality of grouting, hammer sounding or other equivalent inspection methods shall be conducted at all grouted tendons. The Contractor shall submit and obtain approval from the Engineer a detailed method statement for hammer sounding (or other equivalent inspection methods), outlining the method of operation and type of apparatus to be used. The Engineer shall also consider the timing which the hammer sounding inspection is to be conducted. Generally, a minimum of three days should be allowed for the grout to harden before hammer sounding inspection is carried out. A guideline on hammer sounding inspection method is attached in **Annex IV** for reference.

14. During the construction stage, if the Contractor proposes alternative schemes and/or modifications to the external prestressing system, the report on "Assessment of maintainability for future inspection, operation and maintenance of bridge structures with external prestressing system", which was submitted in the design stage as mentioned in Paragraph 6 of this Guidance Notes , should be critically reviewed and the revised report together with the update BIM model should be submitted by the project proponent for approval by the maintenance authority before acceptance of the alternative schemes and/or modification works.

Take over & Maintenance Stage

15. To facilitate smooth handover of completed bridge structures with

prestressing tendons, the project proponent should approach the maintenance authority as early as possible in order to allow sufficient time for rectification of defects. An operation and maintenance manual ("O&M Manual") shall be submitted to the maintenance authority upon handover of the prestressing tendon system, which would be used by frontline staff during maintenance works. Hence, the O&M Manual shall contain all relevant drawings / layout plans / TTA plans / material and plant catalogues / warranties / documents made reference to, etc. The O&M Manual shall include, amongst other essential information, the followings:-

i. Detailed method statements (with labour, materials and plants specified) for regular and possible maintenance and repair works required, including CVI and replacement of tendon;
ii. A maintenance schedule with scope and frequency of inspection;
iii. Arrangement for temporary storage of materials and plants;
iv. Temporary traffic arrangement with traffic diversion plan in principle agreed with relevant authorities;
v. Safety procedures; and
vi. Emergency contingency plans, escape routes, and rescue procedures.

16. The project proponent shall arrange to demonstrate the set-up for future maintenance works on site upon request from the maintenance authority. The demonstration may include, but not limited to, the transportation of machineries and installation of the prescribed set-up for future maintenance works. This allows the maintenance authority to have a better understanding, as well as checking the practicality of the prescribed procedures in the O&M Manual. It also provides an opportunity for the maintenance authority to discuss with the project proponent on any maintenance difficulties and necessary modifications to be made, or additional maintenance provisions to be installed.

17. The following references were referred to in the formulation of this Guidance Notes:-

i. Task Force Group on Maintainability Requirements for Bridge Structures with External Prestressing Systems

Final Report

ii. General Specification for Civil Engineering Works (2020 Edition) – *Chapter 17*

iii. Structures Design Manual for Highways and Railways (2013 Edition) – *Sections 5.6 and 16.1*

18. Enquiries on this Guidance Notes may be referred to CHE/NT(M) of New Territories Region of the Highways Department.

(c) shrinkage and creep of concrete;

(d) friction and wobble;

(e) draw-in,

where appropriate giving details of any assumption made, and also making clear whether allowance shall be made for anchorage and jack losses.

(4) Consideration must be given at the design stage to the practicability of fitting one or other of the acceptable proprietary post-tensioning systems into the work being designed, so that the post-tensioning specialists are not set an impossible task. End-block reinforcement depends on the type of anchorage used, and so shall not be detailed, but, again, consideration shall be given at the design stage to likely requirements. The proposals submitted by the main contractor must accordingly include end-block reinforcement details.

5.6.3 External Prestressing

(1) All highway structures and railway bridges adopting external prestressing shall be checked to ensure that the removal or failure either of any two external tendons or 25% of those at any one section, whichever has the more onerous effect, will not lead to collapse at the ultimate limit state under the design ultimate permanent actions.

(2) External tendons that are not located inside the closed cells of box-girder bridge deck can be susceptible to fire and mechanical damages. Project-specific requirements and provisions for the protection of the tendons shall be proposed for agreement by the Chief Highway Engineer/Bridges and Structures and the respective maintenance authorities.

AMD. 1/2020

(3) All external tendons shall be replaceable and provisions shall be made in the design for the de-tensioning, removal and replacement of any external tendon. The use of prestressing components of the types that would facilitate the de-tensioning, removal and replacement of the tendons, such as sheaths/ducts of double casing type at deviators/anchor diaphragms and, where appropriate, tendons with independent strands with individual HDPE sheaths etc. should be considered.

(4) Where the detailing does not enable tendons to be removed and replaced without damage to either the tendons or the structure, a method statement defining in details how the tendons can be removed and replaced shall be provided. A method statement defining in details how the structure can be demolished shall also be provided.

(5) Where it is necessary to restrict traffic on the highway structure to replace the tendons, the extent of this restriction shall be agreed with the relevant authorities and defined in a method statement. It should be noted that traffic restrictions may not be appropriate for highly utilized structures with high delay costs.

(6) Provisions shall also be made in the design to facilitate routine inspection and maintenance of the tendons, particularly at the locations of deviators and anchor diaphragms where the tendons/anchors are encased in concrete. In particular, each tendon shall be provided with an identification tag showing the tendon reference number and anchorages shall be fabricated with inspection holes located to permit a probe or inspection by borescope of the upper part of the duct behind the anchor heads. The holes shall also facilitate the post-grouting inspection. Anchorage caps covering the inspection holes shall be designed to be removable as necessary for access to the inspection holes.

(7) A robust multiple barrier protection system shall be used to protect the external tendons from weathering and corrosion.

(8) For grouted tendons, consideration should be given to the use of vacuum-assisted grouting for improved quality of grouting especially for long horizontal tendons and for tendons without access/vents at the high points of the tendon profiles. **AMD. 1/2020**

(9) Length of tendons shall not exceed 200m, and length between grout injection point and the most distant grout vent/anchor head shall not exceed 100m, unless it can be demonstrated with grouting trials that complete filling of the tendon ducts, with the tendons completely surrounded with grout, can be satisfactorily achieved. Similarly for tendons to be injected with other flexible corrosion-inhibiting products.

(10) It is preferable to provide remote monitoring and warning system for the detection of tendon/strand/wire breakage. At locations where inspection of tendons is difficult, remote monitoring and warning system shall be provided. The need and details of the provision shall be agreed with the respective maintenance offices during the design stage.

(11) Detailed method statements describing the procedures and their purposes as well as the quality checking arrangement shall be approved by the Engineer before commencement of the prestressing works.

(12) To inspect the quality of grouting, hammer sounding or other equivalent inspection methods shall be conducted at all grouted tendons before handing over of the completed structures to the maintenance authority. If suspected voids are detected, further verification by local tendon duct sectioning or borescope inspection through drilled holes shall be carried out. **AMD. 1/2021**

(13) The quality of grouting at anchorages and deviators shall also be inspected. Such inspection can be conducted in form of visual inspections of the grouting condition at grout vents. If suspected abnormalities are found, further verification by borescope inspection through grout vents or pre-installed inspection holes shall be carried out.

(14) The inspection of quality of grouting shall not be conducted by the prestressing works contractor or his agents, and shall be conducted by the site supervisory staff or other independent parties.

(15) Adequate training shall be provided to all supervisory personnel and workers to ensure their awareness of the purposes of every step and detail of the prestressing works.

(16) To facilitate future maintenance, the following records shall also be passed to the respective maintenance authorities upon handing over of completed structures:

(a) Information of prestressing system and components, such as product names, serial numbers, catalogues, materials, details of corrosion protection system, testing records, as-built dimensions and profiles.

(b) Records of grouting operations, including location, date and time, weather conditions, technical personnel supervising or carrying out the grouting operations, prestressing tendon reference numbers, grout mix, admixtures used, grouting equipment, grouting methods and procedures, actual locations of grout vents and taps, grout material test reports, grouting trial reports, air test of grout vents and detailed records of the grouting operation (such as injection pressures, volume of grout used, time and duration of grouting, and details of any interruptions and topping up).

(c) Records of tensioning operations, including location of the operations, coil, heat and bundle numbers of strand used, date and time, weather conditions, technical personnel supervising or carrying out tensioning operations, prestressing tendon reference numbers, tensioning apparatus identification, prestressing sequence, measured extensions, amount of draw-in and pressure gauge or load cell reading. **AMD. 1/2021**

(d) Records of duct friction tests.

(e) Other particulars, records and reports in relation to prestressing works which are required to be submitted by the contractors under the contract specifications.

(f) Records of hammer sounding inspection at tendons, the inspection of grouting condition at anchorages and deviators, and the subsequent remedial and reinstatements works. The inspection records shall be checked and signed by the project office or the resident site staff.

(g) Any abnormality observed during prestessing works.

(h) Method statements on tendon replacement/removal as mentioned in Clauses 5.6.3(4) and 5.6.3(5).

(i) Information on provisions made in the design to facilitate routine inspection and maintenance of tendons as mentioned in Clause 5.6.3(6).

(j) Design calculation and computer model.

(17) Where circumstances justify it, other external prestressing tendon systems comprising of individual strands, each with permanent protective materials and sheating, such as a monostrand system, may be considered in the design as alternatives to grouted tendons. If an alternative system is considered feasible, project-specific design and maintenance requirements shall be proposed for the agreement by Chief Highway Engineer/Bridges and Structures and the respective maintenance authorities.

Proposed Amendments to SDM

Summary of key amendment

Section/ Clause	Content of amendment	Page
5.6.3	***External Presstressing: provisions made in the design to facilitate routine inspection and maintenance of tendons*** ▪ Addition of new requirement	1
(NEW) 16.1.4	New section on specific operation considerations for bridge structures with external prestressing tendons added	2

Note: Proposed amendments are <u>underlined</u>.

5.6 PRESTRESSING

5.6.3 External Prestressing

(3) All external tendons shall be replaceable and provisions shall be made in the design for the de-tensioning, removal and replacement of any external tendon. The use of prestressing components of the types that would facilitate the de-tensioning, removal and replacement of the tendons, such as sheaths/ducts of double casing type at deviators/anchor diaphragms and provision of spare opening for tendon run-through at diaphragms and deviators should be considered. Where appropriate, tendons with independent strands with individual HDPE sheaths etc. should be considered.

……Cl. 5.6.3(4) and (5) not listed here

(6) Provisions shall also be made in the design to facilitate routine inspection, including close visual inspection (i.e. visual inspection which is carried out at touching distance), and maintenance of the tendons, particularly at the locations of deviators and anchor diaphragms where the tendons/anchors are encased in concrete, and at the locations where tendons are located at or above 2m height. In particular, each tendon shall be provided with an identification tag at every span showing the tendon reference number and anchorages shall be fabricated with inspection holes located to permit a probe or inspection by borescope of the upper part of the duct behind the anchor heads. The holes shall also facilitate the post-grouting inspection. Anchorage caps covering the inspection holes shall be designed to be removable as necessary for access to the inspection holes.

……Cl. 5.6.3(7) to (17) continued and not listed here

(18) Bridge structures with external prestressing system shall also be designed for maintainability in accordance with Highways Department Guidance Notes No. NT/GN/050 – "Guidance Notes on Maintainability Requirements for Bridge Structures with External Prestressing Systems".

16.1.4 SPECIFIC CONSIDERATIONS FOR BRIDGE STRUCTURES WITH EXTERNAL PRESTRESSING TENDONS

(1) Access openings of not less than 800mm wide by 1000 mm high should be provided at end diaphragms for entry to deck void via bridge abutments. The access openings should be clear of any obstruction or installation. Lockable doors shall be installed at the access openings to restrict access by unauthorized personnel. The access openings should be easily accessible and do not require temporary traffic arrangement. If such requirement is considered impractical under exceptional circumstances, the project proponent should seek explicit written agreement from the maintenance authority.

(2) Access openings of not less than 800 mm wide by 1000 mm high shall be provided through all diaphragms. The access openings should be clear of any obstruction or installation. If such requirement is considered impractical under exceptional circumstances, the project proponent should seek explicit written agreement from the maintenance authority.

(3) A maintenance corridor with even and continuous path of minimum headroom of not less than 2m and clear width of not less than 800mm should be provided for the passage of personnel and equipment within the deck cell. All temporary installations, such as temporary blisters to facilitate the erection of bridge structure, should be removed after construction. For permanent installations, they should be positioned properly such that a clear maintenance corridor could be provided. Utilities and drainage installations should be properly installed in the deck cell to avoid encroachment on the maintenance corridor. If such requirement(s) is considered impractical under exceptional circumstances, the project proponent should seek explicit written agreement from the maintenance authority.

(4) For structures with substantial lengths, such as sea viaducts, access openings which are safe and easily accessible and do not require temporary traffic arrangement shall be provided at intervals of not more than 1 km along the bridge structures. Permanent access

platforms extended from the road side to the access openings shall be provided.

(5) Bridge structures with external prestressing system shall also be designed for maintainability in accordance with Highways Department Guidance Notes No. NT/GN/050 – "Guidance Notes on Maintainability Requirements for Bridge Structures with External Prestressing Systems". In particular, a report on "Assessment of maintainability for future inspection, operation and maintenance of bridge structures with external prestressing system" shall be provided to consult the maintenance office during the preliminary and detailed design stage.

Proposed Amendments to GS

Summary of key amendment

Section/ Clause	Content of amendment	Page
17.07	***Prestressing components*** ▪ Addition of new requirement	1
17.37	***Installation of grout vents and taps*** ▪ Addition of new requirement	2
17.45	***Grouting effectiveness*** ▪ Addition of new requirement	3
17.46	***Grouting injection*** ▪ Addition of new requirement	5

Note: Proposed amendments are <u>underlined</u>.

MATERIALS

Prestressing components

17.07 (1) Prestressing components shall be of a proprietary type approved by the Engineer.

(2) Prestressing anchorages shall be tested in accordance with BS EN 13391 and shall allow a minimum of 25 mm cover to cropped ends of prestressing tendons.

(3) Anchorages shall be fabricated with inspection holes located to permit a probe or inspection by borescope of the upper part of the duct behind the anchor heads. The holes shall also facilitate the post-grouting inspection.

INSTALLATION OF PRESTRESSING SYSTEMS

Installation of grout vents and taps

17.37 (1) Grout vents and taps shall be provided at the following positions:

(a) All crests of the prestressing tendon profile and 400 mm on each side of each crest.

(b) All low points of the prestressing tendon profile,

(c) All anchorages and couplers,

(d) Intervals not exceeding 15 m.

(e) Beyond each intermediate crest in the direction of grout flow at the point where the duct is one half diameter lower than the crest (but not further than 1 m), and elsewhere as required by the Engineer.

(f) For external tendons, in case the vents cannot be placed because of encroachment upon the diaphragm, vents should be installed on both sides of the diaphragm.

(2) Vents shall not be placed at positions where they will be blocked by the prestressing tendons after tensioning.

(3) Vents at high points shall extend to a minimum of 500 mm above the highest point on the duct profile.

GROUTING OF PRESTRESSING SYSTEMS

Grouting effectiveness

17.45 (1) Grouting of prestressing tendons shall be effective such that the duct and anchorage are completely filled, and the prestressing tendon is completely surrounded, with grout. Vacuum-assisted grouting shall be adopted. For vacuum-assisted grouting, a negative pressure of no less than 0.75bar shall be maintained within the tendon duct for at least one minute before the injection of grout and throughout the whole grouting operation.

(2) For external prestressing tendons, to inspect the quality of grout at ducts, hammer sounding or other equivalent inspection methods shall be conducted at all grouted tendons. The Contractor shall submit for approval by the Engineer a detailed method statement for hammer sounding (or other equivalent inspection methods), outlining the operation and type of apparatus to be used. The inspection of quality of grout shall be conducted by an experienced person from an organization independent of the main contractor and prestressing works contractor, and shall process at least three years of experience in the inspection of grouting quality at ducts. In the case of suspected void within the grouted ducts, drilling of holes on sheathing and remedial measures shall be conducted. The Contractor shall submit for approval by the Engineer a detailed method statement for the drilling and remedial works.

(3) Records on the inspection on quality of

grouting, inspection of grouting condition at anchorages and deviators, and the subsequent remedial and reinstatements works, shall be submitted to the Engineer.

GROUTING OF PRESTRESSING SYSTEMS

Grout injection 17.46

(1) The permission of the Engineer shall be obtained before prestressing tendons are grouted. If grouting is not started within 24 hours of permission having been given, permission shall again be obtained from the Engineer.

(2) Grouting of prestressing tendons shall be carried out as soon as practicable, and not more than 5 days, after tensioning of the prestressing tendons. In cases where grouting could not be carried out within 5 days after tensioning of the prestressing tendons, temporary corrosion protection measures should be implemented. The Contractor shall submit proposal of corrosion protection measures to the Engineer for approval before commencement of tendons prestressing works.

.....Cl. 17.46(3) to (10) continued and not listed here

(11) In addition to the grouting trials stated in Clause 17.19(1), the Contractor shall select and propose for the Engineer's approval an external prestressing tendon to be completed first, and demonstrate to the Engineer that the workmanship and quality of the grouting works for the tendon is satisfactory. Hammer sounding or other equivalent inspection methods shall be conducted in accordance with Clause 17.45 to inspect the quality of grouting. The Contractor shall not commence the grouting works for the remaining external tendons without the prior agreement of the

Engineer.

(12) If the Contractor fails to demonstrate that the workmanship and quality of the grouting works for the tendon is satisfactory, or if in the opinion of the Engineer any aspect of the grouting procedure as demonstrated by the Contractor is unsatisfactory, remedial measures and/or particulars of proposed changes to the method of grouting shall be submitted by the Contractor to the Engineer. Further grouting of external tendons shall not be carried out until in the opinion of the Engineer the remedial measures and/or every aspect of the grouting procedure is satisfactory.

(13) The Contractor shall employ on the Site in connection with execution of grouting works for prestressing systems an experienced site personnel who is required to supervise, witness and take record of the whole grouting process of each tendon. The site personnel shall record the sequence of work and check against the prescribed method statement. Any anomaly shall be recorded and investigated. The record shall be countersigned by a supervising engineer and submitted to the Engineer within 3 days of each grouting operation.

(14) The supervising engineer shall be a holder of a recognized degree in civil/structural engineering with 5 years of relevant experience in tendon prestressing works.

(15) The following particulars of the proposed supervising engineer for grouting works shall be submitted to the Engineer:

(a) Name,

(b) Copy of Hong Kong Identity Card,

(c) Details of qualifications, including copies of certificates, and

(d) Details of previous experience.

(16) The particulars shall be submitted to the Engineer for approval at least 8 weeks before the approval is required.

Disclaimer

Hammer sounding is a common inspection method adopted in the local and overseas industry to detect the presence of void, if any, along the length of the grouted ducts for external prestressing tendons. By comparing the sound through tapping the surface of the ducts at different locations, the suspected presence and location of voids can be detected. The method, however, would depend on human experience and skills and may be subjective due to a number of factors, including thickness, material and stiffness of the ducts, or whether the duct is close to other fixing and solid surrounding. Generally speaking, if suspected voids and other defects are found, further verification to confirm the nature and extent of the defects is required. Corresponding remedial works are needed to be carried out to repair and rectify the defect.

This reference does not constitute a standard, specification, or regulation. It is merely a recommendation for the hammer sounding inspection procedures for external prestressing tendons on bridge structures.

PROCEDURES FOR HAMMER SOUNDING INSPECTION OF EXTERNAL PRESTRESSING TENDONS

The hammer sounding inspection of an external prestressing tendon shall include:

(1) surveying the tendon: and,
(2) void profiling by hammer sounding along the tendon.

Details of the procedures are given below.

1. SURVEYING THE TENDONS

The tendon to be inspected need to be surveyed so that the locations of voids or other damaged area can be quickly located. The survey shall be carried out before the hammer sounding inspection. The main tasks for the survey include (i) marking survey stations at regular spacing along the tendon profile and (ii) marking the locations of anchorage zones (diaphragms, cross beams/walls) and deviator blocks on the inspection form. Sample of the inspection form is given in Appendix A. The tendon survey procedures shall be as follows.

- For the tendon to be inspected, identify the bridge span(s) in which the tendon is to be inspected.
- If more than one bridge span is involved (tendon is continuous over more than one span), start the survey from the lower numbered span. Surveying and inspection are to be performed in the same direction as the increasing span numbers
- Prepare information for surveying
  - Go to the start point of the span. The start point in each span is designated by the order of numbering the spans. The diaphragm located towards the lower numbered span is the starting point in spans.
  - Record all the information in the title block on the inspection form (including Bridge Location Number, Structure Number, Tendon ID, Surveyor's Name and Date, Sheet No. etc.). Each span to be surveyed will require at least one form. (Long spans will require more than one form.)
- Record the starting point
  - Record in the inspection form the pier number under the start point.
- Mark the dimensions along the length of the tendon.

- Mark the tendon ID on the duct using spray and stencils
- Measure the thickness of both diaphragms and record on the inspection form.
- For the portion of the tendon outside the diaphragms, mark survey stations at every 0.50m from the diaphragm the start point until a deviator block is reached. For this purpose, the "start point" is defined as the point at which the tendon comes out of the diaphragm.
- Measure the locations of deviator blocks from the "start point" and mark the deviator blocks on the inspection form.
- Continue marking the tendon until the entire tendon length inside the span is marked. The "end of survey" point for the span is defined as the point at which the far tendon enters into the concrete diaphragm. Mark the "end of survey" point on the inspection form.
- The tendon duct must be marked in a clear and readable manner. The tendon duct shall be wiped and free from dust before marking (but avoid pouring or pressure jetting of water directly onto the duct, especially in areas where there are cracks and other damages in the duct). Perform marking with a paint marking pen. Also, considering the smooth duct surface and the lack of daylight, a yellow paint marker is recommended.

- If more than one bridge span are involved, go to the next span and repeat the above procedures.

  [Note: - For tendon anchored at an intermediate crossbeam/blister within span, the "start point" for the purpose of marking survey stations on the tendon is defined as the point at which the tendon comes out of the crossbeam/blister. Similarly, the "end of survey" point is defined as the point at which the tendon enters into the crossbeam/blister. In such case, make a remark that the tendon is so anchored on the inspection form. The pier no. to be marked on the inspection should still be that under the diaphragm located towards the lower numbered span. Also, measure the location from the diaphragm and dimension in the direction of the tendon of the crossbeams/blisters and record in the inspection form.]

2. VOID PROFILING BY HAMMER SOUNDING INSPECTION OF TENDONS

The hammer sounding inspection of a particular tendon shall be carried out only after completion of survey of the tendon. The procedures for the hammer sounding inspection shall be as follows.

- Initial preparation

- For the tendon to be inspected, identify the bridge span(s) in which the tendon is to be inspected.

- Have the inspection form(s) complete with the information from the tendon survey ready. Record the inspector's name and inspection date on the inspection form. The data from the inspection of each span should be recorded on the inspection form. Each span inspected will require at least one form. (Long spans will require more than one form.)
- Identify the tendon to be inspected.

- Perform hammer sounding inspection of the tendon
  - The objective of the inspection is to detect voids to identify grout-void interface locations. This information should be recorded on the inspection form. The grids on the inspection form indicate the unrolled duct surface by cutting the bottom line of the duct. (See Figure 1 below)
  - Tap all around the tendon duct with a steel tapping hammer starting from the "start point" to the "end of survey" point to identify voids in the duct
  - Mark the voids and draw the void profiles on the inspection form. (See Figure 2 below)
- If more than one span are involved, go to the next span and repeat the above procedures.

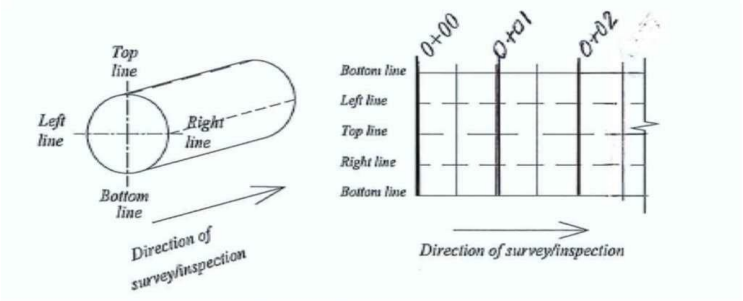


Figure 1 - Unrolled Duct Surface in the Grid on Inspection Form

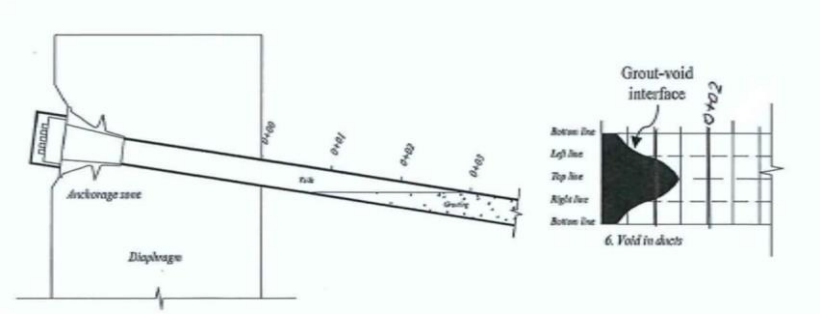


Figure 2 – Marking Voids on the Inspection Form

3. INSPECTION FOR OTHER DAMAGES AND DEFECTS OF THE TENDON DUCT

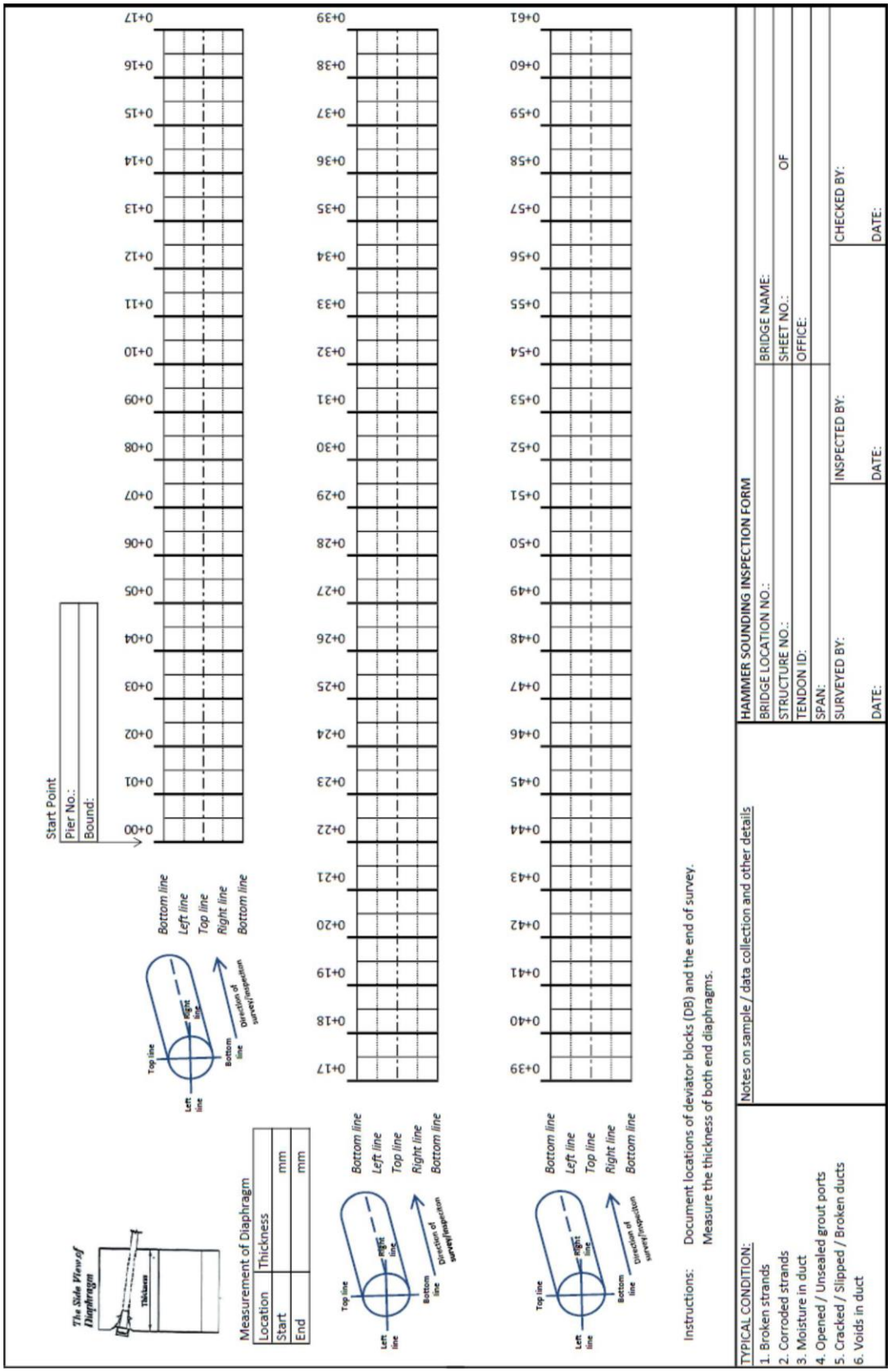
- During the course of the tendon survey/inspection, the tendon duct shall also be inspected for the presence of other damages, such as cracking, local bulging and/or bursting open of the duct, exposed strands/tendon and opened grout holes etc.
- Mark the damages and their locations and types on the inspection form. The damaged areas of the tendon duct shall be marked with spray paint. Take photographs of the damages.
- Should severe damages be identified, the project office shall be alerted immediately.

4. FURTHER INVESTIGATIONS TO BE CARRIED OUT IF INSTRUCTED BY THE PROJECT OFFICE

- Should voids be identified inside the tendon duct, further investigations (e.g. drilling of holes for borescope inspections and material sampling etc.) should be carried out if instructed by the project office.

Appendix A

Inspection Form for Hammer Sounding Inspection



Reference

Trejo et al. (2009). Effect of Voids in Grouted Post-tensioned Concrete Bridge Construction: Inspection and Repair Manual for External Tendons in Segmental, Post-tensioned Bridges