

Ground-borne Vibration and Ground Settlement arising from Pile Foundation and Excavation and Lateral Support Works

Pile driving, boring and withdrawal in foundation works, similar operations in excavation and lateral support (ELS) works such as installation or extraction of temporary pile walls, collectively known as pile installation works, may cause vibrations and settlements. Improper control of pile installation works may have adverse effects on, or cause damage to, adjacent buildings/structures/land/services, in particular, non-structural elements therein.

2. This practice note aims to provide guidelines on the control of ground-borne vibrations and ground settlements arising from pile installation works with a view to minimising possible damage to adjacent properties and streets. Authorized persons (AP), registered structural engineers (RSE) and registered geotechnical engineers (RGE) are reminded that under the Buildings Ordinance (BO), it is their responsibility to ensure that the building works carried out will not impair the stability of, or cause damage to any buildings/structures/land/services. They should also exercise their professional judgment in choosing suitable and safe construction methods and provide vigilant supervision over the works throughout the construction period.

Pile Foundation Plan and ELS Plan Submissions

3. Pile foundation plans and ELS plans submitted for approval should, in general, follow the requirements laid down in the Code of Practice for Foundations 2017 (Foundation Code) and Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers (PNAP) APP-18. AP/RSE/RGE's particular attention should be paid to the monitoring requirements and the required assessment at clause 7.2 of the Foundation Code for adjacent buildings/structures/land/services in relation to the pile installation works. Depending on the structural condition of the adjacent buildings/structures/land/services, the Building Authority (BA) may require the following details to be included in the assessment report:

- (a) Pre-construction condition survey with a full set of photographic record of the external and common areas of the buildings/structures/land/services that are vulnerable to vibration and settlement damage. If access to some internal areas can be gained, the condition therein should also be recorded.

- (b) Preliminary assessment including a vibration and settlement assessment of the stability of the structural and non-structural elements of adjacent buildings/structures/land/services under the effect of the expected ground-borne vibrations and ground settlements. The assessment should cover the whole course of pile installation works setting out clearly the types and duration of the major vibration-generating construction activities.
- (c) Proposed vibration and settlement control limits (with due consideration of the recommendations given in Appendix A of this practice note) and a monitoring proposal to monitor the movements of adjacent grounds and buildings/structures/land/services. Critical locations for monitoring should be identified by RSE/RGE and included in the monitoring proposal.
- (d) If vibration control limits greater than those given in Appendix A are to be adopted, a detailed assessment of the magnitude of the ground-borne vibrations generated by the pile installation works should be made. Under such circumstances, reference could be made to the Foundation Code, BS ISO 4866¹ and Technical Note 142² published by the Construction Industry Research Information Association (CIRIA)³ of the UK for such assessment or to any other relevant references acceptable to the BA. Consideration should also be given to the cumulative effects from the installation of all piles at the site. The structural stability of all adjacent buildings/structures/land/services due to the effects of ground-borne vibrations in item (c) above should also be appraised by detailed engineering analyses. In respect of the vibration control of building works carried out within railway protection areas, reference should be made to the requirements given in Appendix B of PNAP APP-24.
- (e) If the site is situated close to buildings/structures/land/services that are vulnerable to damage caused by the pile installation works, a trial pile proposal to validate the accuracy of the assessments on the vibration and settlement and the effects of the pile installation works on adjacent buildings/structures/land/services (see paragraphs 9, 11 and 12 below).

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¹ BS ISO 4866 – Mechanical vibration and shock – Vibration of fixed structures – Guidelines for the measurement of vibrations and evaluation of their effects on structures.

² Technical Note 142 – Ground-borne vibrations arising from pile installation.

³ The website of CIRIA is <http://www.ciria.org>.

4. It should be noted that certain types of piles installed by percussive/vibratory equipment may cause significant damage to vibration sensitive buildings/structures/land/services such as those mentioned in clause 7.2.6 of the Foundation Code. Such method will not normally be accepted by the BA unless it can be satisfactorily demonstrated to the BA by means of installation of trial pile(s) as described below. Prior to the installation of the trial piles, precautionary measures such as the provision of shoring for temporary support to cracked structural members of adjacent buildings may need to be provided.

5. If site formation plans involve ELS works such as the installation of temporary pile walls including steel sheet piles, pipe piles or steel channel plankings, a detailed vibration and settlement monitoring proposal on all adjacent buildings/structures/land/services with details described in the above paragraph 3(a) to (d) should also be included in the plans to be submitted to the BA for approval. If the site is situated close to buildings/structures/land/services that are vulnerable to damage caused by the installation of temporary pile walls, a trial pile proposal as described in the above paragraph 3(e) should also be included in the plans for approval.

Required Actions prior to Commencement of Pile Installation Works

6. Prior to the commencement of pile installation works, RSE is required to confirm with the registered general building contractor (RGBC)/registered specialist contractor (RSC) the method of construction including the maximum number of piles to be installed concurrently and the relevant details of the construction plants. AP/RSE/RGE is also required to fulfill the requirements imposed by other government departments. In case there are changes from the approved details, RSE should submit an amendment plan together with a re-assessment of the ground-borne vibrations and ground settlements and, if necessary, revise and submit the assessment report for items 3(b) and (c) above together with the amendment plan.

7. To address the concerns of the occupants of adjacent buildings affected by the vibrations of pile installation works, AP/RSE/RGE/RGBC/RSC are advised to formulate a Public Relations Plan (PR Plan), setting out the actions to be carried out before and after the commencement of the pile installations, with reference to clause 7.2.7 of the Foundation Code. RSE is advised to submit the PR Plan to the BA for agreement prior to the commencement of pile installation works.

Test/Trial Pile(s) for Vibration and Settlement Control

8. If the adjacent buildings/structures/land/services are not vulnerable to the effects of vibration from the pile installation works, the magnitude of ground-borne vibrations and ground settlements as assessed above can be verified during the installation of test pile(s). Ground-borne vibrations should be measured as detailed in paragraph 11 below and the associated settlements should be recorded upon the completion of the test installation. The effects of the pile installation works on the adjacent buildings/structures/land/services should also be assessed by the RSE/RGE during the installation of the test pile(s).

9. In cases where buildings or structures that are particularly vulnerable to the effects of vibration, such as declared monuments or masonry buildings, are in the proximity of the pile installation site, RSE/RGE should submit for approval a trial pile proposal to confirm the magnitude of ground-borne vibrations and ground settlements as assessed above, at each critical ground condition where generation of maximum ground-borne vibrations and ground settlements will be expected (usually at the highest founding level/obstruction at shallow depth/interbedded strata of rock and soil). The number of such trial pile(s) would depend on the actual site condition in particular for very large construction site.

10. AP/RSE/RGE will be required, under section 17 of the BO and in accordance with the Code of Practice for Site Supervision to provide quality supervision of the installation of test/trial piles to ensure the allowable limits of the ground-borne vibrations and ground settlements will not be exceeded.

11. For the vibration monitoring of test/trial pile installation, the maximum ground-borne vibrations, measured in terms of peak particle velocity (ppv), should be recorded at every meter length of penetration of pile, at final set and at levels where obstructions are encountered. The maximum ppv should be evaluated at three orthogonal axes measured at ground levels of the buildings/structures/land/services in the vicinity. The monitoring readings should be taken by a properly calibrated device under the direction of RSE/RGE with the agreement of the BA and the supervision of the technically competent persons (TCP) of AP/RSE/RGE/RGBC/RSC's stream. If the measured ground-borne vibrations have been found to exceed the allowable values or if damage to either the structural or non-structural elements of the adjacent buildings/structures/land/services has been observed, all pile installation works should be ceased and the agreed precautionary measures referred to clause 7.2 of the Foundation Code should be reviewed by RSE/RGE. The suspended pile installation works should not be resumed until RSE/RGE's review report and revision of precautionary measures, where necessary, have been submitted to the satisfaction of the BA.

12. A condition survey of all adjacent buildings/structures/land/services should be carried out after the completion of the trial piles for confirmation of the effects of the pile installation works. Two sets⁴ of trial pile installation report on ground-borne vibrations and ground settlements and their effects on adjacent buildings/structures/land/services should be submitted to the BA for consideration prior to the application for consent to the commencement of the installation of the working piles.

Required Actions during the Pile Installation Works

13. AP/RSE/RGE should review the site situation from time to time and if found necessary, suspend the pile installation works, revise the precautionary measures and/or vibration monitoring proposal and submit them to the BA for agreement prior to resumption of the works. Reference should be made to clause 7.2 of the Foundation Code.

/Enhanced ...

⁴ Only one set of trial pile installation report is required if submission is made via BD's Electronic Submission Hub.

Enhanced Control Mechanism

14. Clauses 7.2.4 and 7.2.6 of the Foundation Code have set out a system of three triggering levels (i.e. Alert, Alarm and Action Levels) as a useful tool for systematic monitoring of any settlement and vibration arising from the pile installation works. With a view to enhancing the monitoring of ground and service settlements, as well as the response of buildings in vibration, it is advisable to elaborate the system to a five-tier system by sub-dividing the third tier Action Level into three sub-levels (i.e. Action Levels 1, 2 and 3) so that AP/RSE/RGE could step-up actions earlier corresponding to the respective trigger values of the Action Levels reached. The provisional trigger values and the recommended contingency measures are given in Appendix A.

Engineering Approach for Assessment of Ground and Services Settlement

15. In addition to the adoption of the empirical limits given in the tables of Appendix A, RSE/RGE may adopt an engineering approach to establish a set of site-specific limits for monitoring, by referring to Appendix C of PNAP APP-24. The site-specific limits for ground and services movement control derived by the engineering approach should be subject to the availability of information for conducting the engineering assessment and analysis. Acceptance of the assessment and analysis by the relevant government authorities and/or permission of using the site-specific limits from the owners of the adjacent buildings/structures/land/services to be affected by the pile installation works are required prior to plan approval by the BA on a case-by-case basis.

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Recommended Ground Settlement and Ground-borne Vibration Limits

Ground Movements

Ground movements arising from pile installation works depend on several factors including installation or extraction method, construction sequence, sub-soil geology, groundwater conditions, layout of the pile installation works and workmanship. Excessive ground movements in the vicinity of the pile installation works may be detrimental to adjacent buildings or structures with piles of inadequate lateral resistance or foundations with inherently low factors of safety, especially those supported by shallow foundations.

Tolerable Ground Settlement, Services Settlement and Building Tilting Limits

2. As different structures will have different tolerance in accommodating movements of their foundations, acceptance of estimated ground settlements should be considered on a case-by-case basis with respect to the integrity, stability and functionality of the supported structures.

3. Provided that there are no particularly sensitive buildings/structures/land/services in the vicinity, the following empirical limits may be taken as the provisional trigger values of the Alert, Alarm, Action Levels 1, 2 and 3 (generally referred to as “5A”) for the monitoring of pile installation works:

Instrument	Criterion	Alert	Alarm	Action		
				Level 1	Level 2	Level 3
Ground settlement marker	Total settlement	12mm	18mm	20mm	22mm	25mm
Services settlement marker	Total settlement and angular distortion	12mm or 1:600	18mm or 1:450	20mm or 1:400	22mm or 1:350	25mm or 1:300
Building tilting marker	Angular distortion	1:1000	1:750	1:600	1:550	1:500

/Ground-borne ...

Ground-borne Vibration Limits

4. Similarly, in the absence of an engineering analysis on the response of vibration for buildings in the vicinity, the following empirical limits with the provisional 5A trigger values may be used for reference:

Building Condition	Guide Values of Maximum ppv (mm/sec)									
	Transient Vibration (eg. drop hammer)					Continuous Vibration (eg. vibratory hammer)				
	Alert	Alarm	Action			Alert	Alarm	Action		
			Level 1	Level 2	Level 3			Level 1	Level 2	Level 3
Robust and stable buildings in general	9	12	13	14	15	4.5	6	6.5	7	7.5
Vibration-sensitive/dilapidated buildings	4.5	6	6.5	7	7.5	1.8	2.4	2.6	2.8	3

5. The recommended contingency measures for exceedance of the triggering levels are listed as follows:

Triggering Level	Contingency Measures
Alert	The monitoring should be enhanced by increasing the frequency of monitoring measurements and the number of check points.
Alarm	The method of installation of the piles should be reviewed with the purpose of mitigating the detrimental effects arising from vibration or ground settlement.
Action Level 1	A joint site inspection by AP/RSE/RGE/RGBC/RSC and relevant stakeholders should be carried out. RSE/RGE should check the stability and serviceability of the affected buildings/structures/land/services. AP/RSE/RGE should propose and implement necessary remedial works after consulting the relevant stakeholders.

/Action Level 2 ...

Action Level 2	RGBC/RSC should immediately notify the AP/RSE/RGE, relevant authorities and relevant stakeholders. A detailed investigation, and checking the stability and serviceability of the affected buildings/structures/land/services should be conducted by RGBC/RSC. A joint site inspection should be carried out by AP/RSE/RGE/RGBC/RSC. RSE/RGE should review, and revise, if necessary, the design and method statements for the pile installation or the works likely to have induced the trigger values.
Action Level 3	The corresponding site works should be suspended. Construction activities should not be resumed until the necessary remedial and preventive measures have been completed satisfactorily.

6. The “Action Level 3” contingency measures should be taken if any of the following situations occurs:

- (a) Any monitoring station has a reading reaching the specific trigger value based on serviceability limit¹, or in the absence of such engineering assessment, the provisional trigger value for Action Level 3 is reached, whichever is applicable;
- (b) Undue settlement as indicated in any check points (e.g. an increase of 5mm between two consecutive daily readings); or
- (c) Sign of distress or damages is observed in any adjacent buildings/structures/land/services.

(11/2024)

¹ Serviceability limit is defined as the maximum calculated movements estimated in the design or the maximum allowable movement or response of the adjacent ground, groundwater regime, structures and services.