

Ground-borne Vibrations and Ground Settlements Arising from Pile Driving and Similar Operations

Pile driving (including pile withdrawal) operations and the like generate vibrations and settlements which, if not properly controlled, may have adverse effects on, or cause damage to, adjacent buildings/structures/services, in particular, non-structural elements therein. For the purpose of this practice note, such operations are termed as “pile driving operations”.

2. This practice note aims to provide guidelines on the control of ground-borne vibrations and ground settlements generated from pile driving or similar operations with a view to minimizing possible damage to adjacent properties and streets. Authorized Persons (AP)/Registered Structural Engineers (RSE) are reminded that under the Buildings Ordinance, it is their responsibility to ensure that the building works carried out will not impair the stability of, or cause damage to any building, structure, land, street or 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.

Piling Plan Submission

3. Piling plans submitted for approval should, in general, follow the requirements laid down in PNAP APP-18. AP/RSE’s particular attention should be paid to the monitoring requirements and the required appraisal report at items 4(k) and 4(o) therein respectively for adjacent buildings/structures/services. Depending on the structural condition of the adjacent buildings/structures/services, the Building Authority (BA) may require the following details to be included in the appraisal report :

- (a) Pre-construction condition survey with a full set of photographic record of the external and common areas of the buildings/structures/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) Recommended vibration and settlement control limits (with due consideration of the recommendations given in Appendix A and Appendix B of this practice note) and monitoring proposal. Critical locations for monitoring should be identified by the RSE and included in the monitoring proposal.
- (c) Preliminary appraisal including a vibration and settlement assessment of the stability of the structural and non-structural elements of adjacent buildings/structures/services under the expected ground-borne vibrations and ground settlements.

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- (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 piling operations should be made. Under such circumstances, reference could be made to Technical Note 142 published by CIRIA 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 driving of all piles at the site. The structural stability of all adjacent buildings/structures/services due to the effects of ground-borne vibrations in item (c) above should also be appraised by detailed engineering analyses.
- (e) A monitoring proposal to monitor the movements of adjacent grounds and buildings/structures/services.
- (f) If the site is situated close to buildings/structures/services that are vulnerable to damage caused by the piling operations, a trial pile proposal to confirm the accuracy of the vibration and settlement assessments and the effects of the pile driving operations on adjacent buildings/structures/services (see paragraphs 7 to 8 below).

Required actions from the RSE prior to consent application for piling works

4. Prior to consent application, the RSE is required to confirm with the Registered Specialist Contractor (RSC) the method of construction including the maximum number of piles to be driven concurrently and the relevant details of the construction plants. In case there are changes from the approved details, the RSE should submit an amendment plan together with a re-assessment of the ground-borne vibrations and ground settlements and, if necessary, revise the appraisal report for item 3(c) above. Final reports for items 3(b) & (c) above shall be submitted together with the amendment submission.

5. It should be noted that certain types of piles installed by percussive/vibratory equipment may cause significant damage to vibration sensitive buildings/structures/services such as those mentioned in Appendix A of this practice note. Such method will not normally be accepted by the BA unless it can be satisfactorily demonstrated to the BA by means of trial piling 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.

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

6. If the adjacent buildings/structures/services are not vulnerable to the effects of vibration from the pile driving operations, the magnitude of ground-borne vibrations and ground settlements as assessed at item 3(b) or the re-assessed values at paragraph 4 above, as appropriate, can be verified during the driving test of piles. Ground-borne vibrations should be measured during the driving of the test pile(s) as

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detailed in paragraph 8 below and the associated settlements recorded upon the completion of the test. The RSE will be required, under BO section 17 and in accordance with the Code of Practice for Site Supervision to provide quality supervision of the pile driving works to ensure that the allowable limits of the ground-borne vibrations and ground settlements will not be exceeded. The effects of the pile driving operations on the adjacent buildings/structures/services should also be assessed by the RSE during the driving of the test pile(s).

7. 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 piling site, the AP/RSE should submit for approval a trial pile proposal to confirm the magnitude of ground-borne vibrations assessed at item 3(b) or the re-assessed values at paragraph 4 above, as appropriate, at each critical ground condition where generation of maximum ground-borne vibrations 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. The RSE will be required, under BO section 17 and in accordance with the Code of Practice for Site Supervision to provide quality supervision of the pile driving works to ensure the allowable limits of the ground-borne vibrations will not be exceeded.

8. For the vibration monitoring of trial/test pile(s), 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 monitoring readings should be taken by a properly calibrated device under the direction of the RSE with the agreement of the BA. 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/services has been observed, all pile driving operations should be stopped and the agreed precautionary measures referred to at item 4(o) of PNAP APP-18 should be reviewed and revised as necessary, and submitted by the RSE to the BA for agreement. The suspended pile driving operations should not be resumed without the prior agreement of the BA.

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

10. To address the concerns of the occupants of adjacent buildings affected by the vibrations of pile driving operations, the AP/RSE/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 driving operations. Guidelines on the PR Plan are given in Appendix C of this practice note. The purpose of the PR Plan is to put in place a system to notify in advance the nearby occupants of the forthcoming pile driving

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operations, to facilitate communication between the affected occupants and the contractor, to minimize possible complaints, and to enable the AP/RSE/RSC to handle complaints in a timely and effective manner. The RSE is advised to submit the PR Plan to the BA for agreement prior to the commencement of pile driving operations.

Required actions from the RSE during the pile driving operations

11. The RSE is required to submit the related works programme of the pile driving operations setting out clearly the types and duration of the major vibration-generating construction activities to the BA prior to the commencement of pile driving operations. The supervision of the monitoring works should be provided in accordance with the Code of Practice for Site Supervision. The RSE should review the site situation from time to time and if found necessary, suspend the pile driving operations, revise the precautionary measures and/or vibration monitoring proposal and submit them to the BA for agreement prior to the resumption of the pile driving operations. Reference shall be made to item 4(k) of PNAP APP-18.

Requirements for controlling vibrations and settlements arising from site formation and excavation and lateral support works

12. The installation of temporary pile walls such as steel sheet piles, pipe piles or steel channel plankings are often included in the site formation and excavation and lateral support works. Such temporary pile walls, if installed by percussive or vibratory methods, are likely to generate vibrations and settlements that may cause damage to adjacent buildings/structures/services, particularly those that are vulnerable to vibrations. Excessive vibrations are also likely to be experienced during the removal of underground obstructions. Guide values on limits of vibration and ground settlements are given in Appendices A and B respectively to this practice note. A detailed vibration and settlement monitoring proposal on all adjacent buildings, structures, land, streets or services should be included in the site formation or excavation and lateral supports plans to be submitted to the BA for approval/acceptance. If there are vibration sensitive buildings in the proximity of the site, a test pile proposal to confirm the accuracy of the vibration assessments and effects of the piling works on adjacent buildings/structures/services shall be included in the plans for the approval/acceptance of the BA. The AP/RSE/RGE will be required, under BO Section 17 and in accordance with the Code of Practice for Site Supervision to provide quality supervision of the piling works.

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**Vibration Measurement and Recommended Ground-borne Vibration Limits
Resulting from Piling and Similar Operations**

Vibration measurement

The effect of ground-borne vibration from piling works on adjacent structures should be assessed by the maximum peak particle velocity (ppv). The maximum ppv should be evaluated from the peak particle velocities at three orthogonal axes measured at ground levels of the structures in question. All such measurements should be made by properly calibrated device and under the supervision of the RSE or his representatives.

Recommended Ground-borne vibration limits

2. For the detailed assessment of the effects of ground-borne vibrations on adjacent buildings/structures/services, an engineering analysis should be carried out. Reference could be made to BS 7385 Part 1 : 1990 or similar references.
3. In the absence of an engineering analysis, the following empirical guidelines may be used for reference :

Type of building	Guide values of maximum ppv (mm/sec)	
	Transient Vibration (eg. Drop hammer)	Continuous Vibration (eg. Vibratory hammer)
Robust and stable buildings in general	15	7.5
Vibration-sensitive/ dilapidated buildings	7.5	3.0

4. The above guide values of maximum ppv are suggested to give minimal risks of vibration-induced damage. Due attention should also be paid to sensitive buildings close to the piling site such as hospitals, academic institutes, declared monuments, old buildings with shallow foundations, old tunnels/caverns, buildings installed with sensitive equipment, masonry retaining walls or sites with history of instability, monuments or buildings with historical significance etc. A more stringent control on the allowable limit of ppv for these buildings may have to be specified based on site and building conditions together with the duration and frequency of the exciting source.
5. The AP/RSE/RGE is also required to fulfill the requirements imposed by other government departments.
6. For vibration impacts on existing railway and related structures, technical requirements given in PNAP APP-24 may be useful.

**Recommended Ground Settlement Limits
Resulting from Piling and Similar Operations**

Ground movements

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

Tolerable ground settlement 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 adjacent buildings, structures and services, the following empirical limits may be taken as the provisional AAA trigger values for the purposes of item 4(k) of PNAP APP- 18:

Instrument	Criterion	Alert	Alarm	Action
Ground settlement marker	Total settlement	12mm	18mm	25mm
Services settlement marker	Total settlement & Angular distortion	12mm or 1:600	18mm or 1:450	25mm or 1:300
Building tilting marker	Angular distortion	1:1000	1:750	1:500

Remarks :

The “Action Level” response actions should be taken if any of the following criteria occurs:

- 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, whichever is applicable.
- Undue settlement as indicated in any check points (e.g. an increase of 5mm between two consecutive daily readings).
- Sign of distress or damages observed in any adjacent structures and/or services.

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.

Guidelines on Public Relations Plan (PR Plan)

A PR Plan should include the following information :

- i) Background of the project, including list of vibration-generating construction activities and its tentative construction programme;
- ii) Details of AP, RSE, RGE and RSC of the project;
- iii) Organization chart including the appointment of a PR Officer;
- iv) Objectives of the PR Plan;
- v) List of concerned groups (eg Owners' Corporation, Mutual Aid Committee, District Council etc.);
- vi) List of vibration and/or settlement sensitive buildings/structures/services;
- vii) List of public relation activities (e.g. briefing session; posting notices; issuing notifications on works programme etc.);
- viii) List of telephone hotlines and contact persons for public enquiries;
- ix) Arrangement for issuing notification letters to the relevant stakeholders of nearby building/structure/services informing that they would be notified immediately upon any monitoring reading(s) in relation to their building/structure/services reaching the "Action Level" trigger value during the construction period, and the relevant monitoring readings could be made available upon request; and
- x) Complaint handling system to resolve complaints or incidents in timely and effective manner.