# DEVELOPMENT OF A RAPID CONDITION ASSESSMENT TOOL FOR REINFORCED CONCRETE MOMENT-RESISTING FRAME BUILDINGS IN THE PHILIPPINES: GEOTECHNICAL COMPONENT

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Abstract : This paper describes the development of a pre-earthquake assessment tool that is rapid, visual, cost effective and reasonably accurate for identifying geotechnical hazards with respect to reinforced concrete structures. In the Rapid Condition Assessment Tool (RCAsT), scores are assigned on the basis of the type and severity of the geotechnical hazard present. The general framework of the tool is based on the MCEER Screening Guide for Rapid Assessment of Liquefaction Hazards of Highway Bridge Site, which was substantially expanded to include seismic and non-seismic hazards. Seismic hazards considered by the tool include effects of local geotechnical conditions on ground motions, liquefaction, and lateral spreading. Non-seismic hazards considered by the tool include presence of expansive or sensitive soils, excessive differential settlements, and lateral movement due to slope instability. Slope stability is separately assessed using the DOST-KAST rapid assessment tool for rainfall induced landslides. The tool was employed to several buildings wherein the results were evaluated in comparison with assessments of engineers.

Key words: *Rapid visual assessment, Condition evaluation, Geotechnical assessment*

## 1 INTRODUCTION

The geotechnical conditions underlying a structure contribute greatly to the safety and serviceability of an existing structure. The exposure to specific geologic and geotechnical hazards should be taken into consideration when assessing the seismic vulnerability of an existing structure. Such hazards generally include liquefaction, subsidence and settlement, lateral spreading, as well as expansive or sensitive soils. Depending on the foundation system used, exposure to these hazards can result in minimal to severe damage to an existing structure. Identifying the exposure and vulnerability of a structure to these hazards is necessary step when deciding on the need to retrofit an existing structure. This paper describes the of a tool for assessment of the exposure and vulnerability to geotechnical hazards, as well as systematic monitoring of the geotechnical conditions of an existing structure.

The proposed tool is intended for an initial screening existing reinforced concrete structures, with the objective of identifying structures that potentially require further and more detailed investigation. Activities covered in this level include:

- Collection and review of existing data such as foundation plans, geologic maps, hazard maps and previous geotechnical investigation reports.
- Visual inspection of the structural and non-structural components and the geotechnical conditions surrounding the structure.
- Measurement and documentation of observed damage to structure and geotechnical conditions of the site.
- Evaluation of data and formulation of recommendations.

## 2 DEVELOPMENT OF THE TOOL

The proposed tool was developed based available hazard maps and building codes in the Philippines, as well as integrates specific rapid assessment tools developed for Philippine conditions. The tool is formulated so that it can easily be updated as building codes and hazards are revised. This tool is divided into two types of hazard: seismic hazard and non-seismic hazard. The degree of risk in the area depending on the factors considered will determine the level of hazard the structure will be classified.

2.1 Seismic Hazard

Geotechnical seismic hazards can generally be divided into those that are associated with decrease in soil shear strength and stiffness, seismic ground shaking (i.e. accelerations), and seismic induced lateral ground movements and settlement. (SCDOT, 2010) Liquefaction usually takes place as a result of loss of shear strength due to ground shaking and existing soil conditions. The location and geomorphology of the country also makes it prone to seismic-induced lateral spreading and settlement.

2.1.1 Seismic Zone Classification

Seismic design criteria in building codes are defined by seismic zones location of the structures. In general, seismic zones are categorized into Zone 0 to Zone 4 in which zone 0 denoting the weakest earthquake ground motion and zone 4 as the strongest. (Gosh)

The National Structural Code of the Philippines 2010 (NSCP 2010) divided the Philippines into two seismic zones only: Zone 2 and Zone 4 (Association of Structural Engineers of the Philippines). Areas under Zone 2 have low to moderate probability of damaging ground motion whereas areas under Zone 4 have high probability. NSCP 2010 assigned a seismic factor of 0.2 for Zone 2 areas and 0.4 for areas under Zone 4. Figure 1 shows that Palawan, Sulu and Tawi-tawi are under Zone 2 and the rest of the country is under Zone 4.

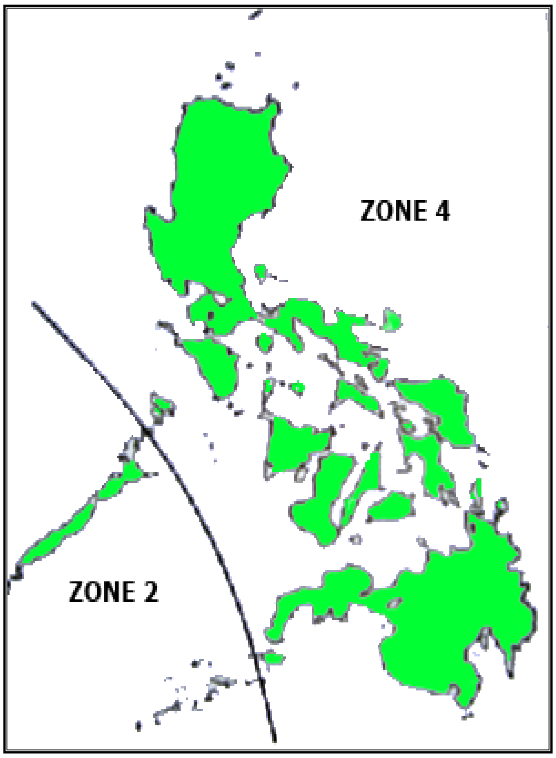


**Figure 1** Seismic Zone Map of the Philippines (NSCP 2010-Figure 208-1)

2.1.2 Soil Profile Type

If the area to be considered is under Zone 4 of seismic zone classification, one of the criteria is the underlying soil profile should be stable and strong enough to support the structure in the event of an earthquake. Soil profile type is categorized as $S_A$, $S_B$, $S_C$, $S_D$, $S_E$, $S_F$. Table 1 shows the difference between these soil profile types.

One of the condition of NSCP 2010 for structures under Zone 4 is that the underlying should fall between $S_A$ to $S_D$ soil profile type, otherwise, the structure will be considered unsafe.

**Table 1** Soil Profile Types

| Soil Profile Type | Soil Profile Name/ Generic Description | Average Soil Properties for Top 30 m of Soil Profile | | |
|---|---|---|---|---|
| | | Shear Wave Velocity (m/s) | SPT,N (blows/300 mm) | Undrained Shear Strength (kPa) |
| $S_A$ | Hard Rock | >1500 | | |
| $S_B$ | Rock | 760 to 1500 | | |
| $S_C$ | Very Dense Soil and Soft Rock | 360 to 760 | >50 | >100 |
| $S_D$ | Stiff Soil Profile | 180 to 360 | 15 to 50 | 50 to 100 |
| $S_E$[1] | Soft Soil Profile | <180 | <15 | <50 |
| $S_F$ | Soil Requiring Site-Specific Evaluation | | | |

[1]Soil Profile Type $S_E$ also includes any soil profile with more than 3.0 m of soft clay defined as a soil with plasticity index, PI > 20, $w_{mc} > 40$ percent and $s_u < 24$ kPa. The Plasticity index, PI and the moisture content, $w_{mc}$, shall be determined in accordance with approved national standards.

NSCP 2010 also defined soil profile falling under soil profile type $S_F$ as follows:

1) Soils vulnerable to potential collapse or collapse under seismic loading, such as liquefiable soils, quick and highly sensitive clay, and collapsible weakly cemented soils.
2) Peats and/or highly organic clay exceeds 3.0 m.
3) Very high plasticity clays with a plasticity index, PI $\geq$ 75, where the depth of clay exceeds 7.5m.
4) Very thick soft/medium stiff clays, where the depth of clay exceeds 35 m.

5.1.3. Types of Foundation

All structures on earth must be supported by an interfacting element called a foundation or substructure (Bowles). Foundation is a part of a structure that transmits the loads it is carrying to the underlying soil or rock. Foundations may be classified based on where the load is carried by the ground: shallow or deep foundations. Shallow foundation, also termed as base or footing, is one in which the ratio of embedment depth to width is D/B $\leq$ 1. Some types would include spread footings and mat foundations. In cases where shallow foundations are inadequate to support the structural loads, deep foundations are employed. Deep foundations, also known as pile foundations, are slender structural members installed on the ground to transfer structural loads to soil at significant depth below the base of the structure. Unlike shallow foundations, deep foundations distribute the load vertically rather that horizontally. Common types of deep foundations are bored and driven pile foundations.

Mat foundations are special used to support several rows of parallel columns and may underlie a portion or the entire building. It can be located at the surface or buried deep into the soil. It is described as raft foundations (Budhu) because they act like rafts when part or all of the loads are compensated by embedment.

A spread footing is a foundation carrying a single column. Its is termed as spread footing because its function is to "spread" the column load literally to the soil so that the stress intensity is reduced to a value that the soil can carry (Bowles). Spread footings with tension reinforcement may be two-way or one-way depending on whether the steel used runs both ways or in one direction. Spread footings may also be reinforced with tie beams for additional support.

Materials for deep foundations may be concrete, steel or timber. Piles can either be driven into the ground (driven piles) or installed in a predrilled hole (bored piles).

5.1.4. Liquefaction Hazard

Static liquefaction is the behavior of a soil as a viscous fluid when seepage reduces the effective stress to zero (Budhu). On the other hand, cyclic liquefaction refers to the response of a soil subjected to dynamic loads or excitation by transient shear waves, which terminates in a complete loss of strength and entry in a liquefied state. Cyclic liquefaction occurs during or after an earthquake (Hunt). Liquefaction-induced ground and foundation displacement has been a major cause of earthquake damage and collapse of structures.

There are several ways of checking for liquefaction susceptibility of an area. The following are the criteria used in this tool:

a) **Liquefaction Maps.** The Philippine Institute of Volcanology and Seismology (PHIVOLCS) is an institute that deals with disaster mitigation fro volcanic eruptions, earthquakes, tsunami, and other related geotectonic phenomena. They released maps showing the Liquefaction Susceptibility Map of the Philippines (Figure 2) and liquefaction hazards in metro manila (Figure 3). These maps can be used if an area is under low, moderate or high risk for liquefaction.

b) **NSCP 303.4.** NSCP 2010 states that a liquefaction evaluation study may be required for a structure during the course of the foundation investigation if the following conditions are discovered:
   a. Area has shallow ground water, 2 m or less.
   b. Area is underlained by unconsolidated saturated sandy allubium (N<15).
   c. Area is under Seismic Zone 4.

5.1.5. Lateral Spreading

Lateral spreading is a form of planar failure occurring in both soil and rock. It is common in river valleys, particularly where erosion removes material from the river banks (Hunt). Tension cracks may occur during the early stages and sudden failure may happen during earthquake loadings. In this tool, structures located within 100 meters from a body of water are considered to be at risk of experiencing lateral spreading. The 100 meter distance is based on the assumption that a 25mm lateral movement will result in severe damage to a structure following Day (2011). Using the empirical relationship of Barlett and Youd (1999), 25mm lateral movements can occur at a distance of 100m from a 10m free face due to a magnitude 7 earthquake with a distance from the nearest fault of 50m or less.

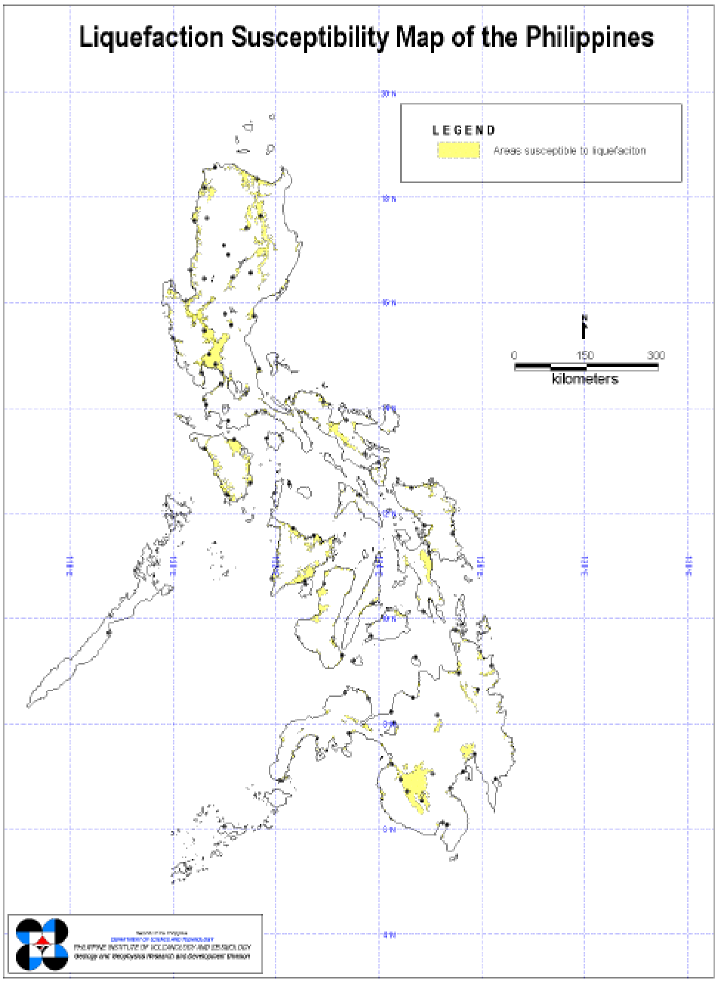


**Figure 2** Liquefaction Susceptibility Map of the Philippines (PHIVOLCS, 2010)

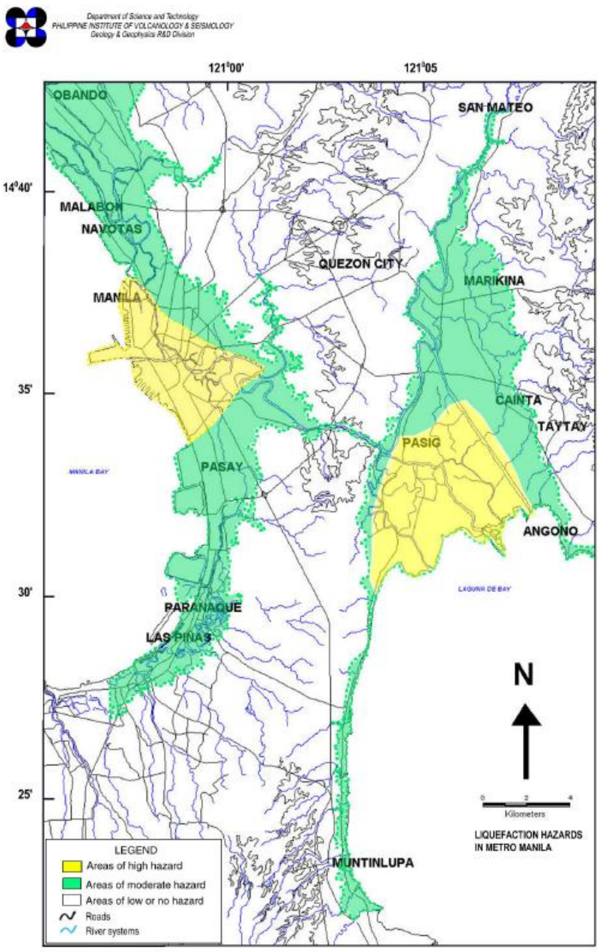


**Figure 3** Liquefaction Hazard Map of Metro Manila (PHIVOLCS, 2010)

## 2.2 Non- Seismic Hazard

Geotechnical hazards not triggered by or related to seismic activity considered in the tool includes settlement, expansive soil, and slope failure. These events are caused by changes in the underlying subsurface conditions resulting to decrease in soil strength, location of structure, and poor construction of foundation.

### 2.2.1 Settlement

Settlement is defined as vertical or differential movement of the ground supporting a structure due to increase of loading or problems with the bearing soil or rock. Other causes may be due to consolidation of soft soil, settlement of fill, limestone cavitation and earthquake loading. Settlement in structures is manifested by gradual subsidence of structure or wall cracks due to settlement of the foundation. Classic wall crack due to settlement of the foundation are near-vertical that is wider at the top than at the bottom. Table 2 describes the cracks due to settlement and the severity of the damage that it may cause the structure. (Day)

### 2.2.2 Presence of Expansive Soil

Expansive soils, which are clayey soils also known as swelling soils, are type of soils that increase in volume with the addition of water. There is a significant shrinkage upon drying resulting to cracks on the surface. These are residual soils of high plasticity which are the result of weathering of the parent rock. Moisture changes in these types of soils bring severe movements of the mass and any structure built on top of it experiences recurring cracks and progressive damage (Murthy).

NSCP 2010 included expansive soils in the building code and the following conditions determines the soil to be expansive if all is satisfied:

1) Plasticity index (PI) of 15 or greater, determined in accordance with ASTM D 4318 and liquid limit > 50.
2) More than 10 percent of the soil particles pass a No.200 sieve (.075 mm), determined in accordance with ASTM D 422.
3) More than 10 percent of the soil particles are less than 5 micrometers in size, determined in accordance with ASTM D 422.
4) Expansion index greater than 20, determined in accordance with ASTM D 4829.

Note that tests to show compliance with Items 1, 2, and 3 shall not be required if the test prescribes in Item 4 is conducted (Association of Structural Engineers of the Philippines).

**Table 2** Crack damage due to Settlement

| Damage Category | Description of typical damage | Approx. Crack width |
|---|---|---|
| Very Slight | Very slight damage includes fine cracks that can be easily treated during normal decoration, perhaps an isolated slight fracture in building, and cracks in external brickwork visible on close inspection | 1 mm |
| Slight | Slight damage includes cracks that can be easily filled and redecoration would probably be required; several slight fractures may appear showing on the inside of the building; cracks that are visible externally and some repointing may be required; and doors and windows may stick. | 3 mm |
| Moderate | Moderate damage includes cracks that require some opening up and can be patched by a mason; recurrent cracks that can be masked by suitable linings; repointing of external brickwork and possibly a small amount of brickwork replacement may be required; doors and windows stick; service pipes may fracture; and weathertightnes is often impaired. | 5 to 15 mm or a number of cracks> 3mm |
| Severe | Severe damage includes large cracks requiring extensive repair work involving breaking out and replacing sections of walls (especially over doors and windows); distorted windows and door frames; noticeably sloping floors; leaning or bulging walls; some loss of bearing in beams; and disrupted service pipes. | 15 to 25 mm but also depends on number of cracks |
| Very Severe | Very severe damage often requires a major repair job involving partial or complete rebuilding; beams lose bearing; walls lean and require shoring;windows are broken with distortion; and there is danger of structural instability. | Usually>25mm but also depends on number of cracks |

### 2.2.3 Lateral Movement (Slope Failure)

Lateral movement or slope failure is determines through the proximity of the structure from a nearby slope. For a structure to be safe, it should be built more than 1:H m away from the slope, or the structure is away from the slope at a distance greater than the measure of the height of the slope. If an existing structure is located less than 1:H near a slope, assessment should be made to determine whether the slope is stable or not. For this study, a landslide assessment tool must be used to determine the level of stability of a slope. It is recommended to use another tool developed through a grant from the Philippine Council on Industry and Energy Research (PCIERD) of the Department of Science and Technology (DOST) entitled "Development of a non-expert tool for site specific evaluation of rain-induced landslide susceptibility".

## 3 SCORING SYSTEM

The proposed scoring system gives separate scores for both seismic hazards, as well as none seismic hazard. Scores of seismic hazards are based on the potential for amplifications of ground shaking, liquefaction and lateral spreading, in relation to the foundation system of the affected structure. Scores of non-seismic hazards are based on the potential for damage due to differential settlement resulting from expansive soils, subsidence, and lateral movements resulting from soil failure.

Structures located in Zone 2 (with estimated peak ground accelerations of 0.2g or less) are considered to have negligible potential for amplification or ground motions, liquefaction and lateral spreading. Based on the 2010 NSCP, soil profile conditions of SD can be assumed if no geotechnical information is available to assess the type of soil profile. The potential for liquefaction is assessed using any of the following three methods: Liquefaction hazard maps as published by PHIVOLCS; Section 303.4 of the 2010 NSCP; previous history of liquefaction induced settlement. The susceptibility of various foundation systems is based on the findings of Ishihara et al (1993) which indicates that structures foundation on isolated spread footings without the use of tie-beams are the most affected by liquefaction induced settlements. Structures founded using rigid shallow foundations such as spread footings with tie-beams and/or mat foundations experience less damage as compared to structures founded solely on isolated spread footing due to the reduced differential settlements although such structures also experience subsidence and tilting. Based on these observations, a 0.75 reduction in the seismic hazard was applied. Although none of the building founded on piles experience any damage due to either differential settlements, subsidence, or tilting, it was noted that driven pile foundation do not offer significant resistance to lateral movements. Recent findings indicate that structures founded on driven piles are vulnerable to lateral spreading . As such, a reduction factor of 0.9 for seismic hazard was assigned to this type of foundation system. As previously mentioned, a distance of 100m from any body of water was set based on the general assumption that lateral spreading resulting in horizontal displacement in excess of 25mm can occur at this distance in the event of a magnitude 7 earthquake.

Settlements due to subsidence that result in damage to the structure were quantified using the scale of described in Day (2011). A maximum score of 20 points was assigned to settlements resulting in very severe effects on the affected structure. Settlements of lesser magnitude were assigned lesser points based on the qualitative description of the effects on the structural integrity of the affected structure. It was assumed that negligible to very slight settlements had no effects on the integrity of the affected structure. It was assumed that the presences of expansive soils had the potential to result in very severe differential movements in the affected structure and were automatically assigned a score of 5 points if present. The presence of expansive soils was identified by either the use of expansion index (if present), Section 303.5 of the 2010 NSCP, or an activity index greater than 1.25 which indicates the swell potential. Lateral movement due to slope failure is quantified through landslide assessment tools. It is recommended to use another tool developed through a grant from the Philippine Council on Industry and Energy Research (PCIERD) of the Department of Science and Technology (DOST) entitled "Development of a non-expert tool for site specific evaluation of rain-induce\d landslide susceptibility". A score of 40 points is assigned to slopes that are highly unstable, 20 points for slopes that are unstable, and 10 points for slopes that are marginally unstable.

Structures obtaining scores of 10 or higher in either the seismic or non-seismic hazard portions of the tool are recommended for level 2 investigation. Structures located adjacent to highly unstable slopes which show visible signs of cracking are considered to be highly unsafe and are recommended for evacuation.

## 4 THE TOOL

A summary of the flow of the tool is presented in a detailed flow chart in Figure 4, to easily guide the user on how to use the tool efficiently and effectively. A sample geotechnical assessment form is shown in Figure 5.

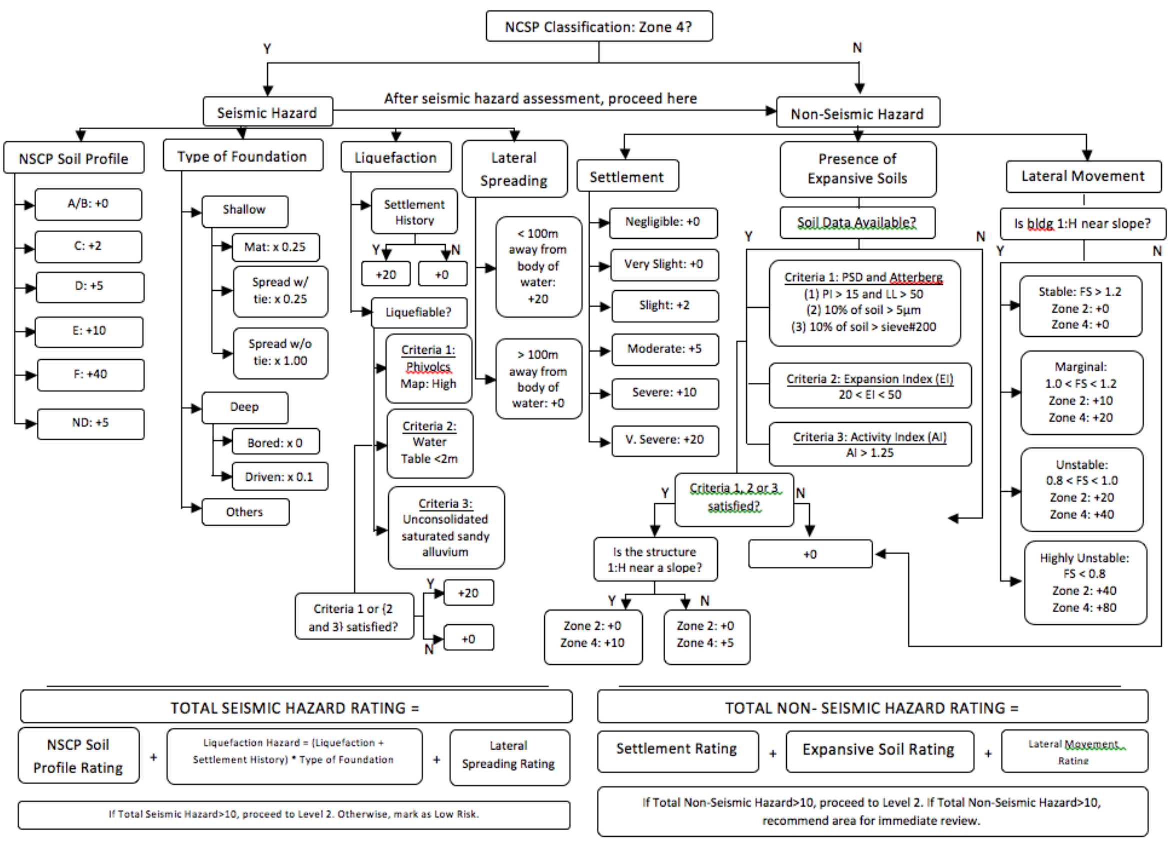


**Figure 4** Rapid Condition Assessment Tool For Geotechnical Hazard Flowchart

# RAPID CONDITION ASSESSMENT TOOL

GEOTECHNICAL HAZARD LEVEL 1

**SEISMIC HAZARD:** | **Remarks**

**A.NSCP classification:** ☐ Zone 2 ☐ Zone 4
(Refer to Appendix 1)
**Remarks: If area is under Zone 2, proceed to Item F.*

**B. NSCP Soil Profile:** ☐ A/B*(+0)* ☐ C*(+2)* ☐ D*(+5)* ☐ E*(+10)* ☐ F*(+40)* ☐ ND*(+5)*
(Refer to Appendix 2)

**C.Type of Foundation:**
(If footing type is unknown, use spread footing w/o tie beam as default value. If under Others, a Geotechnical engineer must review and be the one to assign multiplier.)

☐ Shallow Foundation
- ☐ Mat foundation *(x0.25)*
- ☐ Spread footing w tie beam*(x0.25)*
- ☐ Spread footing w/o tie beam*(x1.0)*
- ☐ Others: (Specify) _______________

☐ Deep Foundation
- ☐ Bored Piles*(x0.0)*
- ☐ Driven Piles*(x0.1)*
- ☐ Others: (Pls. Specify) _______________

**D.Liquefaction Hazard:**
(Refer to Appendix 3)

**1. PHIVOLCS MAP**
- ☐ High
- ☐ Moderate
- ☐ Low

**2. NSCP 303.4** (Check if Area is under Low or Moderate Hazard)
- ☐ Shallow water table < 2m
- ☐ Seismic Zone 4
- ☐ Unconsolidated saturated sandy alluvium

**3. Liquefiable?**
- ☐ Yes*(+20)* (If area is under High Hazard or all criteria under NSCP 303.4 are met)
- ☐ No*(+0)*

**4. History of Settlement?** (Check for previous records)
- ☐ Yes*(+20)*
- ☐ No *(+0)*

**E.Lateral Spreading: Location of structure:**
- ☐ < 100m away from closest body of water*(+20)*
- ☐ > 100m away from closest body of water*(+0)*

**NON-SEISMIC HAZARD:**

**F.Settlement:** (Refer to Appendix 4)
☐ Negligible (*+0)* ☐ Very Slight*(+0)* ☐ Slight *(+2)*
☐ Moderate *(+5)* ☐ Severe *(+10)* ☐ Very Severe (+20)

**G.Presence of Expansive Soils:**
Area is expansive if all items under Criteria 1 or 3 are met & EI>20 ; a rating of 20 is added to the score.

**Criteria 1:**
- ☐ PI>15 & LL>50
- ☐ 10% of soil> 5mm in size
- ☐ 10% of soil > passing No. 200 seive

If no hydrometer analysis is performed, assume soil to be expansive.

**Criteria 2: Expansion Index (EI)**
- ☐ 0-20;Non-Expansive
- ☐ 21-50; Expansive*(+5)*

**Criteria 3:**
- ☐ Activity index >1.25

Remarks: Assume expansive

**H.Lateral Movement (Slope Failure)**
Is the buliding1:H m near a slope? ☐ Yes ☐ No*(+0)*
If yes, what is the state of the slope? (Please refer to Appendix 5 for Landslide Assessment Tool)
☐ Stable; FS>1.2 (+0) ☐ Marginally Stable; 1.0<FS<1.2 *(+10)* ☐ Unstable; 0.8<FS<1.0 *(+20)* ☐ Highly Unstable; FS<0.8 *(+40)*

**RATING TABLE:**

| SEISMIC HAZARD | Rating |
|---|---|
| IBC Soil Profile | |
| Liquefaction Hazard =(Item D.3 + Item D.4)xItem C | |
| Lateral Spreading | |
| **TOTAL** | |

*If TOTAL> 10, proceed to Level 2

| NON-SEISMIC HAZARD | Rating |
|---|---|
| Settlement | |
| Expansive Soils - double score if area is under Zone 4 and near a slope | |
| Lateral Movement - double score if area is under Zone 4 | |
| **TOTAL** | |

*If TOTAL> 10, proceed to Level 2
*If TOTAL>50, recommend area for immediate review

SIGNATURE OVER PRINTED NAME
**EVALUATOR**

**DESIGNATION**

**DATE & TIME OF EVALUATION**

**RECOMMENDATION:** ☐ **LOW RISK** ☐ **PROCEED TO LEVEL 2** ☐ **FOR IMMEDIATE REVIEW**

**Figure 5** Rapid Condition Assessment Tool For Geotechnical Hazard

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