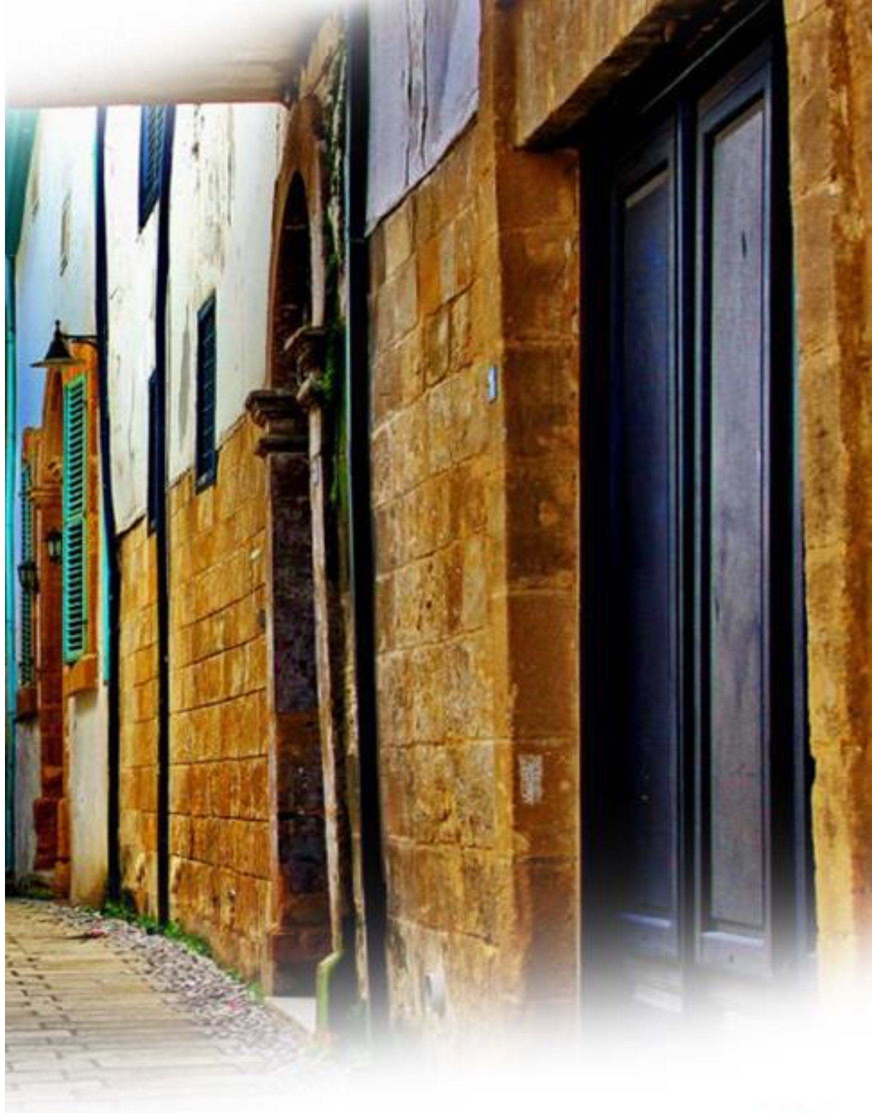
Simple Method of Post-liquefaction Settlement Analysis Based on Shear Wave Velocity



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1. Introduction

The liquefaction-induced settlement of ground surface due to earthquake, stemming from the dissipation of excess pore water pressure, has been represented **as volume changes of fully saturated soil samples** caused by the expulsion of pore water following cyclic load application in undrained cyclic triaxial tests.

The post-liquefaction volumetric strain in laboratory tests in terms of **the relative density** and **the maximum shear strain** have been studied Lee and Albeisa(1974), Tatsuoka et al.(1984), and Nagase and Ishihara (1988). The methodology for the estimation of liquefaction-induced ground settlement has thus been introduced by Tokimatsu and Seed (1987), Ishihara and Yoshimine (1992), Tsukamato et al. (2004), Shamoto and Zhang (1988), Shamoto et al. (1998), and Ishihara et al. (2016), in which post-liquefaction settlement has been determined from **penetration tests such as SPT or CPT**.

The present study, the procedures for determining the settlement of ground level are **alternatively** introduced by using **shear-wave velocity** based on **the maximum shear strain** and **the factor of safety**.

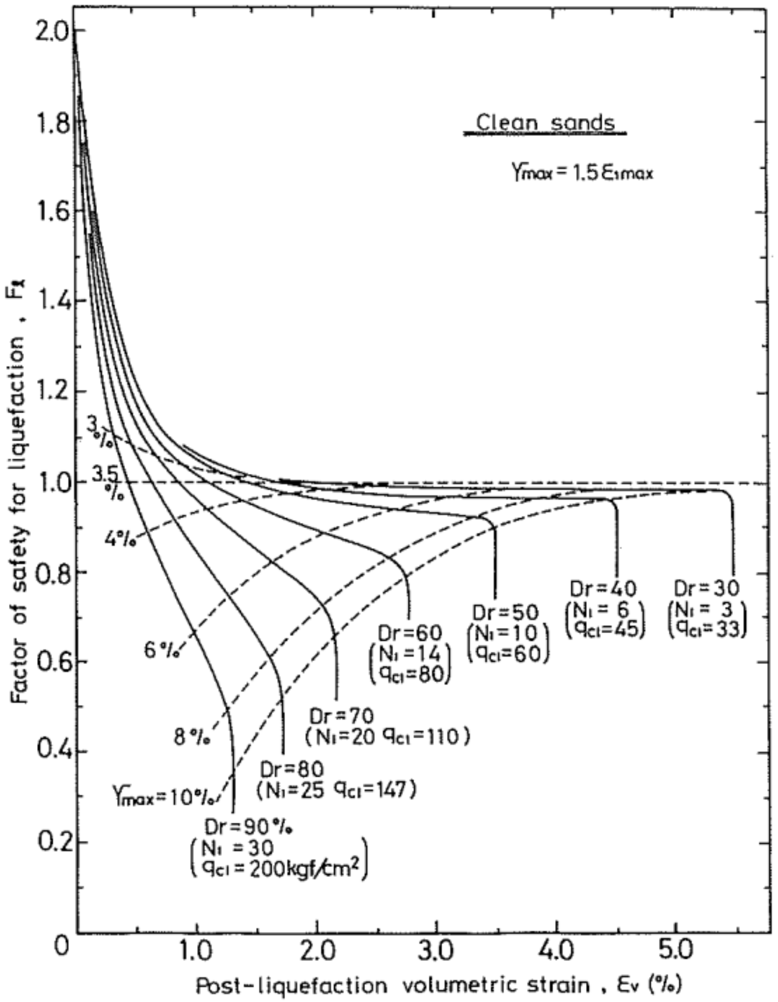


Fig. 1: Chart for determination of post-liquefaction volumetric strain as a function of factor of safety (Ishihara and Yoshimine, 1992)

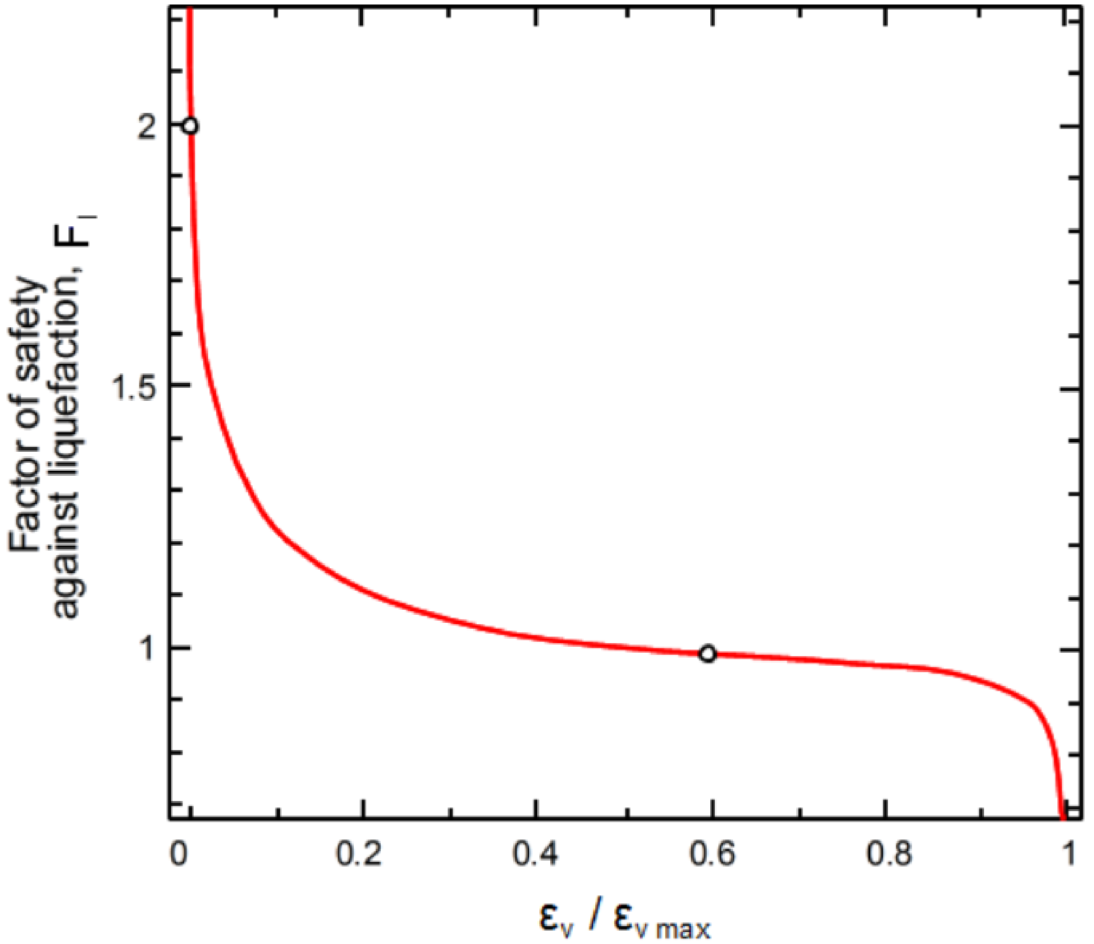


Fig. 2: Relation between the factor of safety and the post-liquefaction volumetric change ε_v normalized to its possible maximum value ε_{vmax} (Tsukamato et al., 2004)

2. Correction of Relative Density

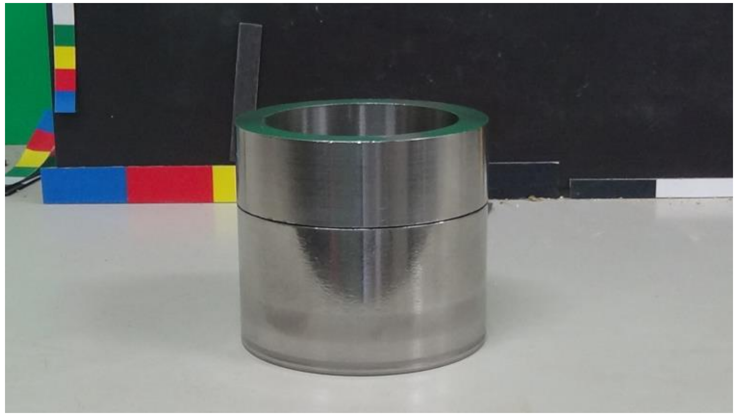
The degree of packing between the maximum and minimum possible states of cohesionless soils, affecting the **post-liquefaction volume change**, as expressed by:

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (1)$$

Where e is the void ratio of cohesionless soil in its current state in the field. However, the value of the relative density can **vary greatly** according to **test procedures**.

The method stipulated by Japanese Geotechnical society (JGS) in JGS0161-2009 is used for evaluating e_{min} and e_{max} .

Dry sand is poured into the mold in **10 layers** using a funnel, and **100 impacts** shall be applies to its flank in each layer using wooden or hammer.



It is known that the values of minimum void ratio by the JGS method are greater than those determined by the ASTM method.

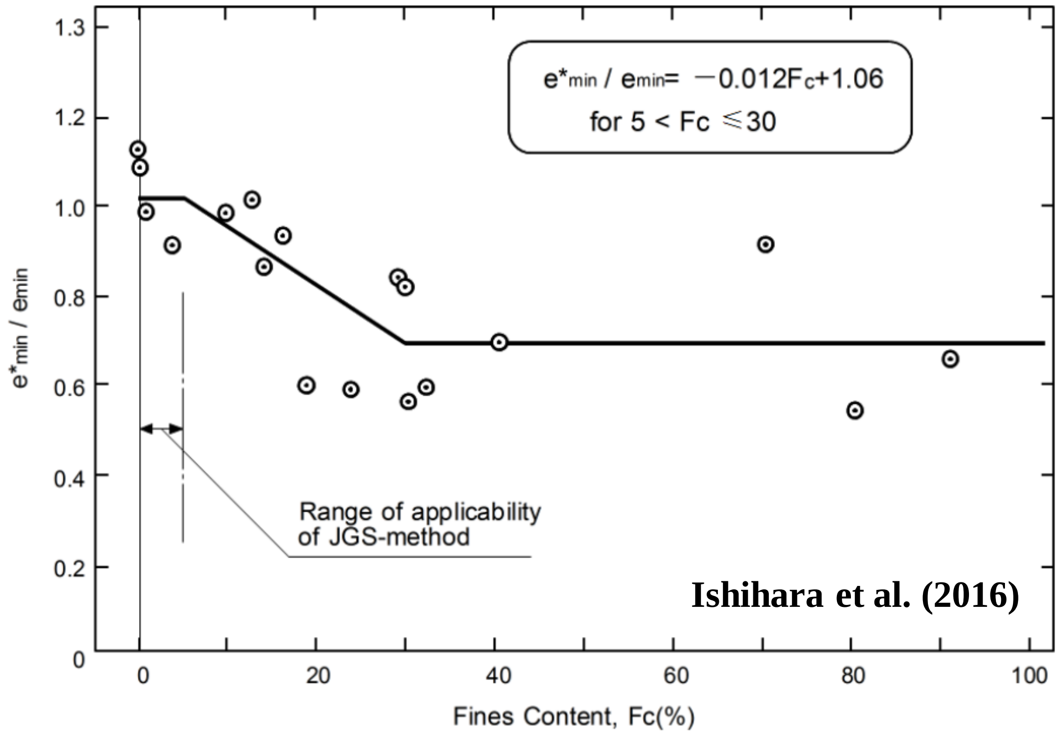


Fig. 3 : Ratio of modified void ratio, e^*_{min} to e_{min} by JGS method

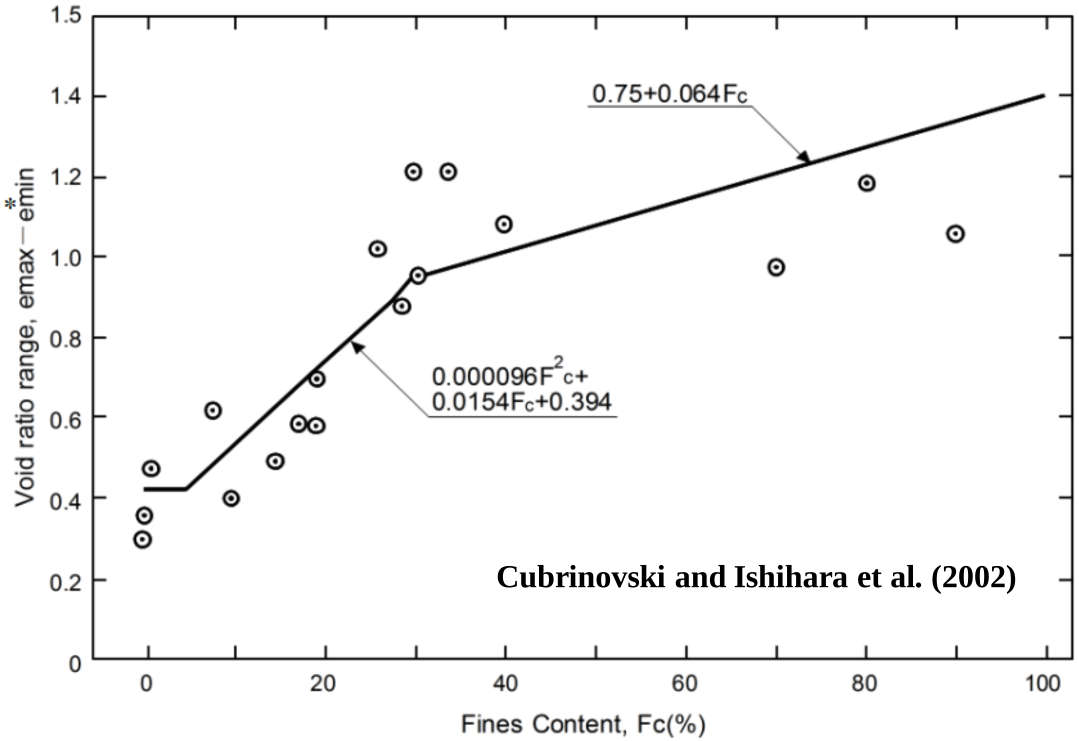


Fig. 4 : Range of void ratio range as functions of fines content

3. Effects of Cyclic Shear Strain

It is known that the onset of liquefaction takes place by definition when 100% pore water pressure builds up in the course of cyclic loading in triaxial tests, or the double amplitude axial strain of $2\ \varepsilon_a = 5\%$ (DA).

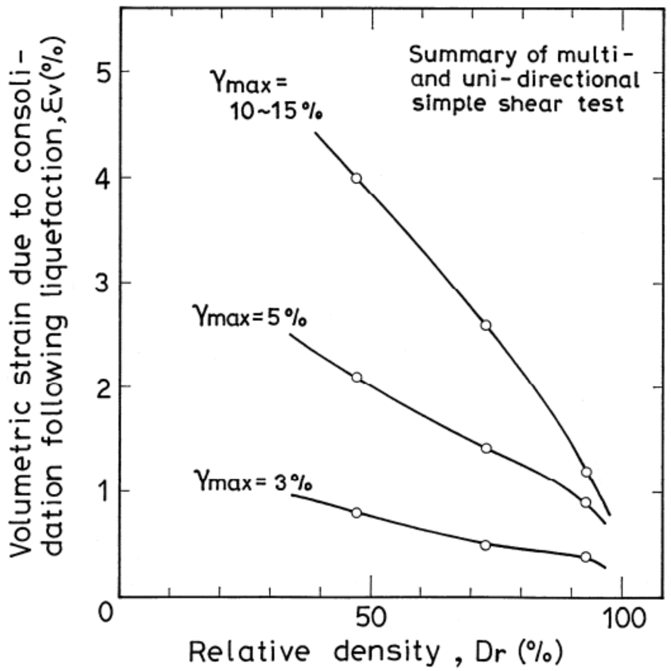


Fig. 5 : Post-liquefaction volumetric strain as related to the shear strain (Nagase-Ishihara, 1988)

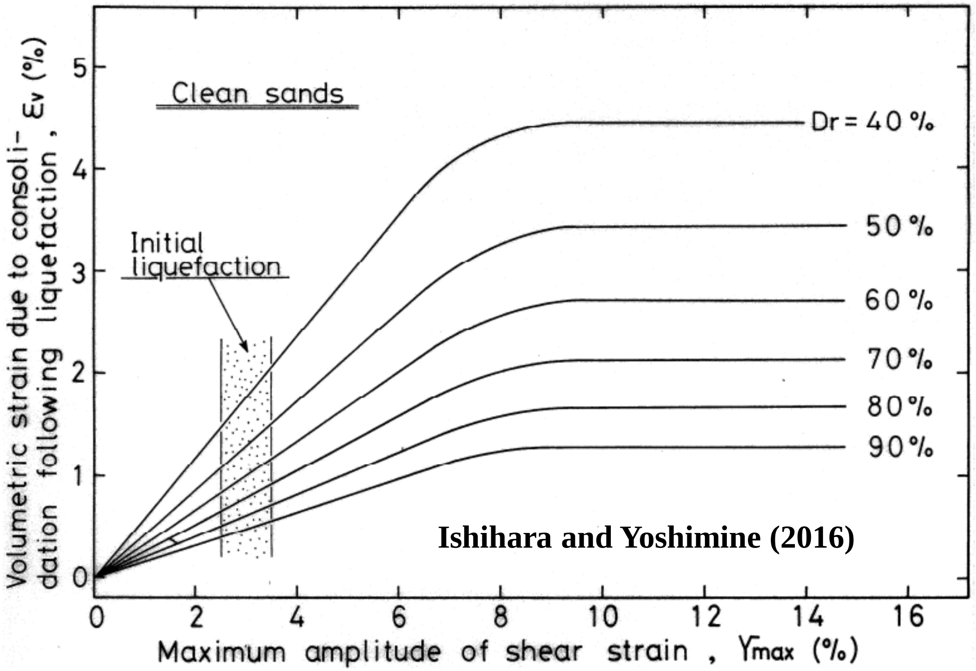


Fig. 6 : Summarized relationships between post-liquefaction volume change and the shear strain

4. Sampling and Testing of Sand Deposits in Asahi City

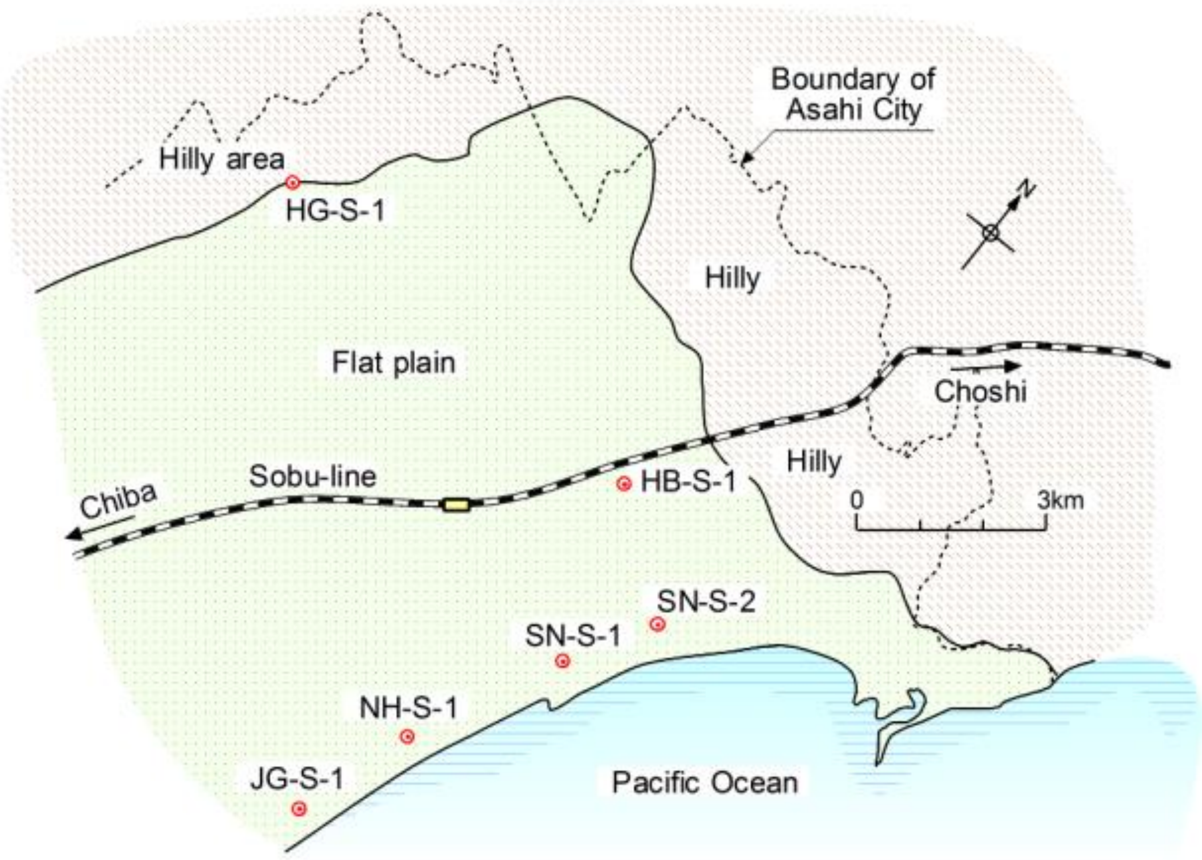
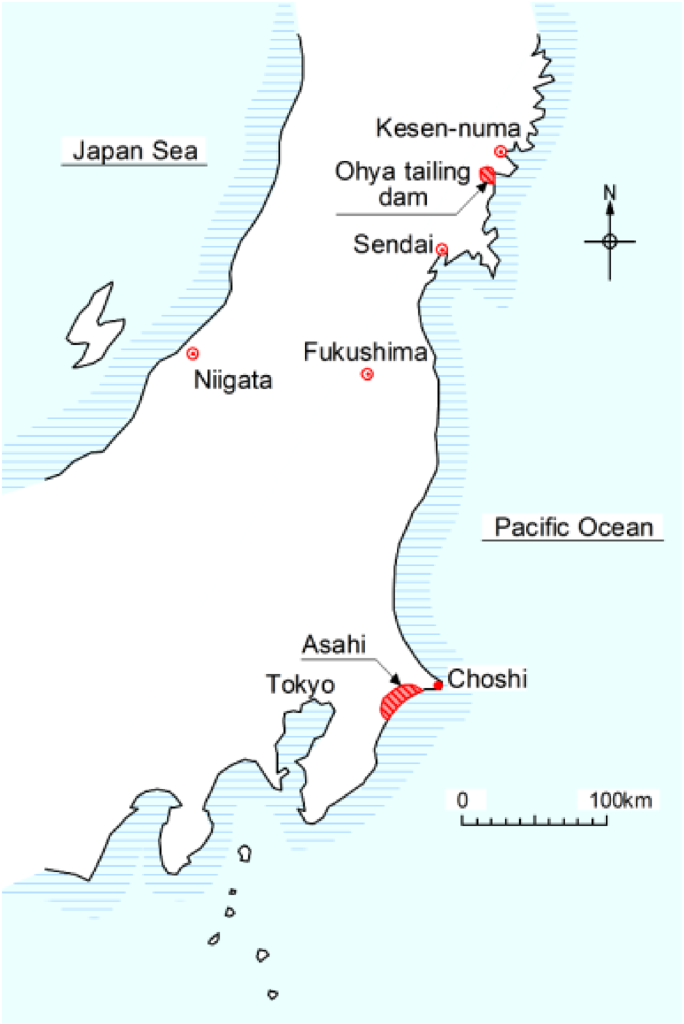


Fig. 7 : Location of undisturbed sampling at Asahi, Chiba



4.1.1. Block Sampling

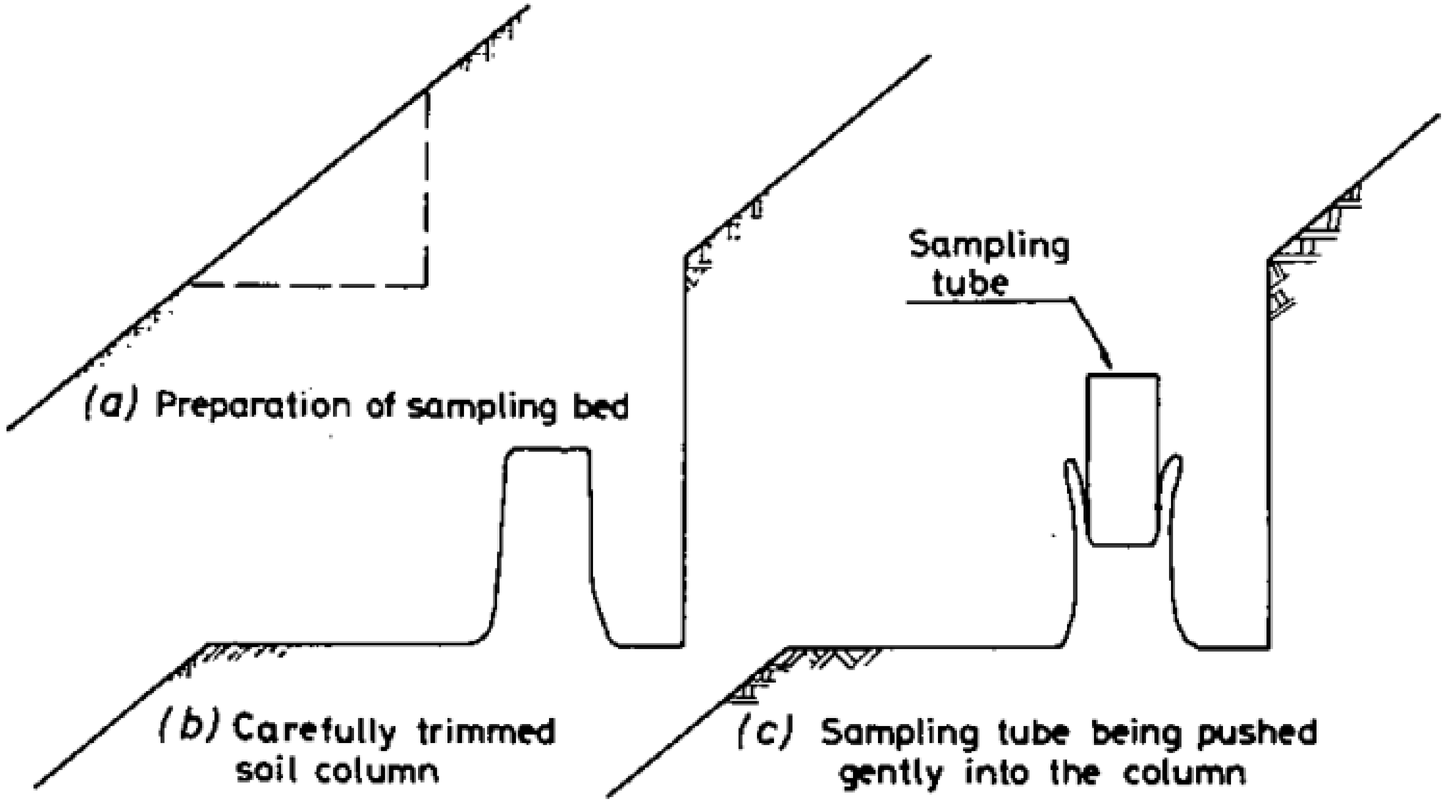


Fig.8: Block sampling procedure

4.1.2. Methods of Undisturbed Soil Sampling

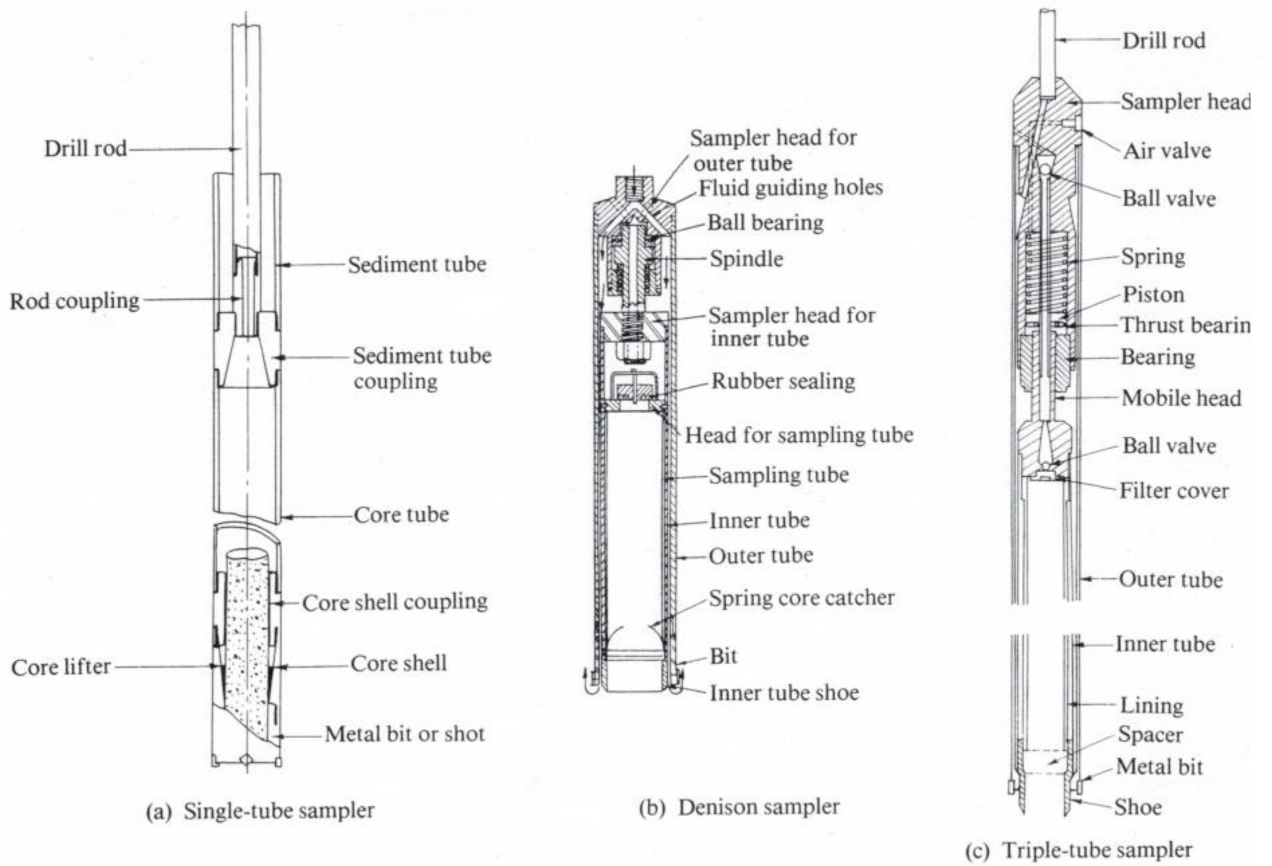


Fig. 9: Single-tube, Denison, and Triple tube samplers

4.1.3. Advanced Method of Gelpush Sampler Developed by Kiso-Jiban Company

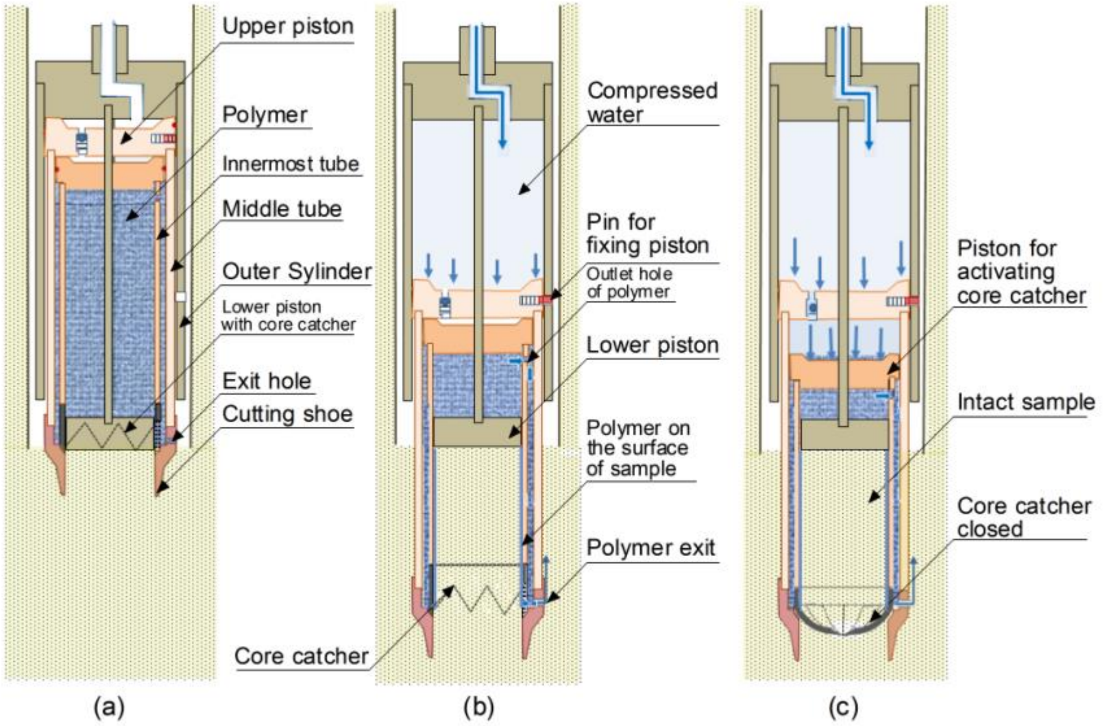
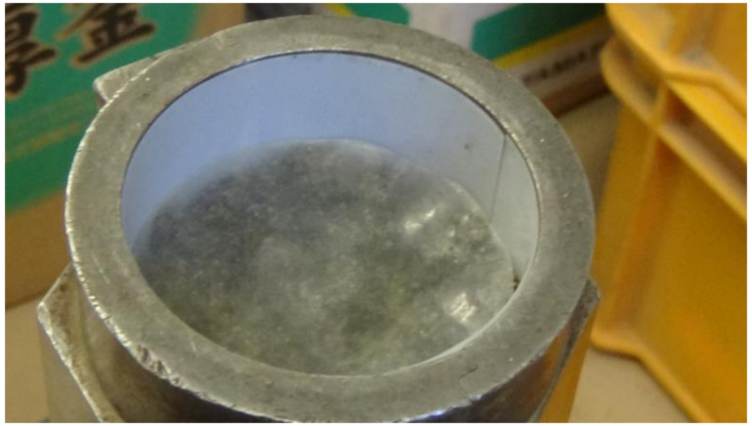
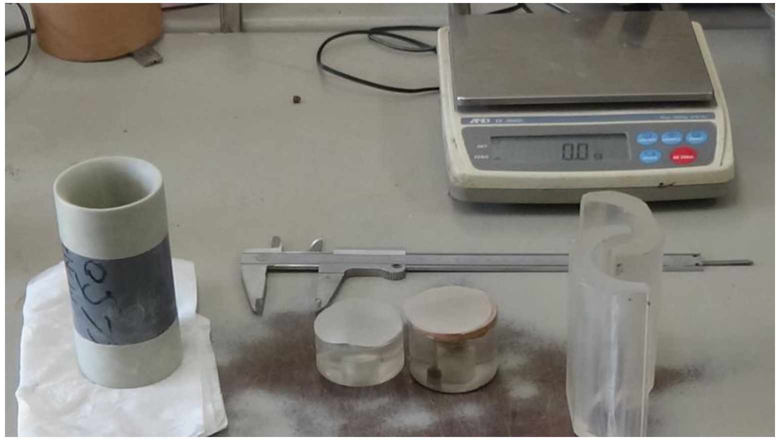


Fig.10: Mechanism of operation in gelpush sampler

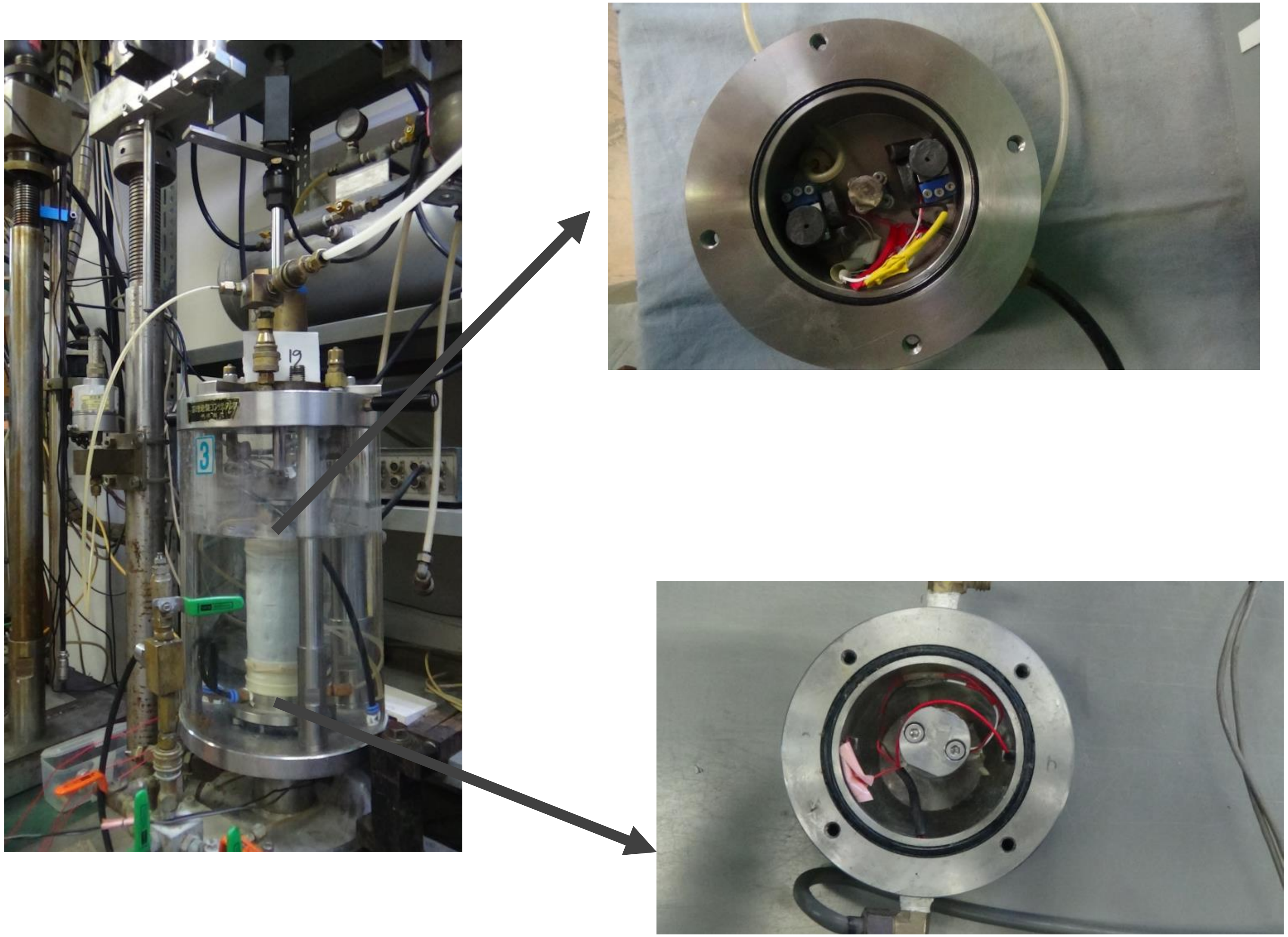
4.2.1. Undisturbed Sample Preparation in Laboratory

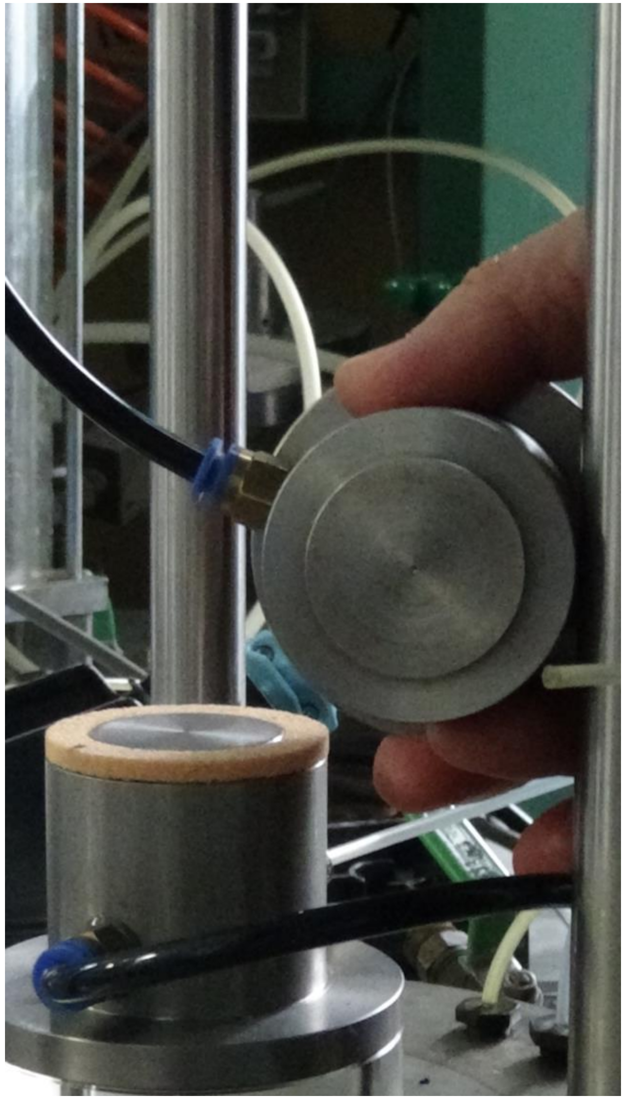
4.2.2. Reconstituted Sample Preparation in Laboratory





4.3.1. Vs measurement in Laboratory





4.3.2. Vs measurement in Field

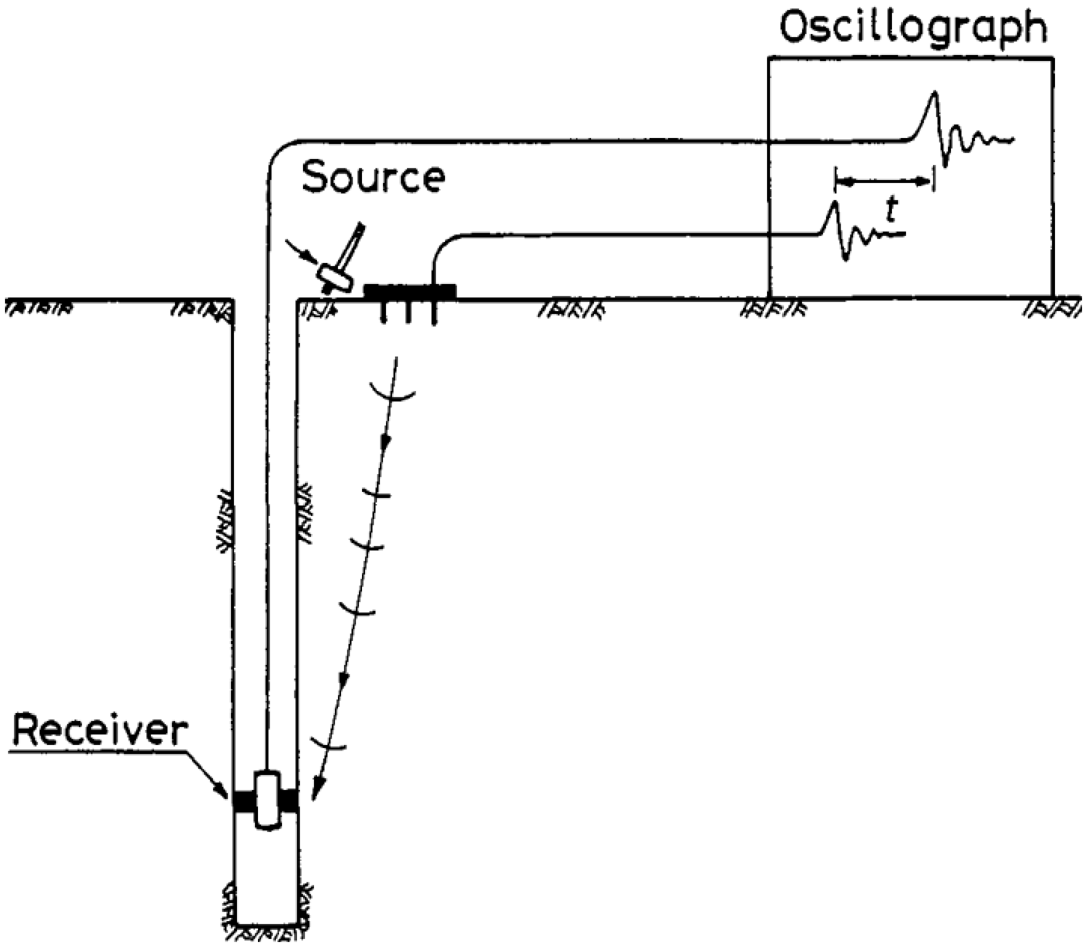


Fig. 11 : Velocity logging by the downhole method.

4.4. Cyclic triaxial test apparatus

4.5. Soil Profiles along with SPT Values and Vs

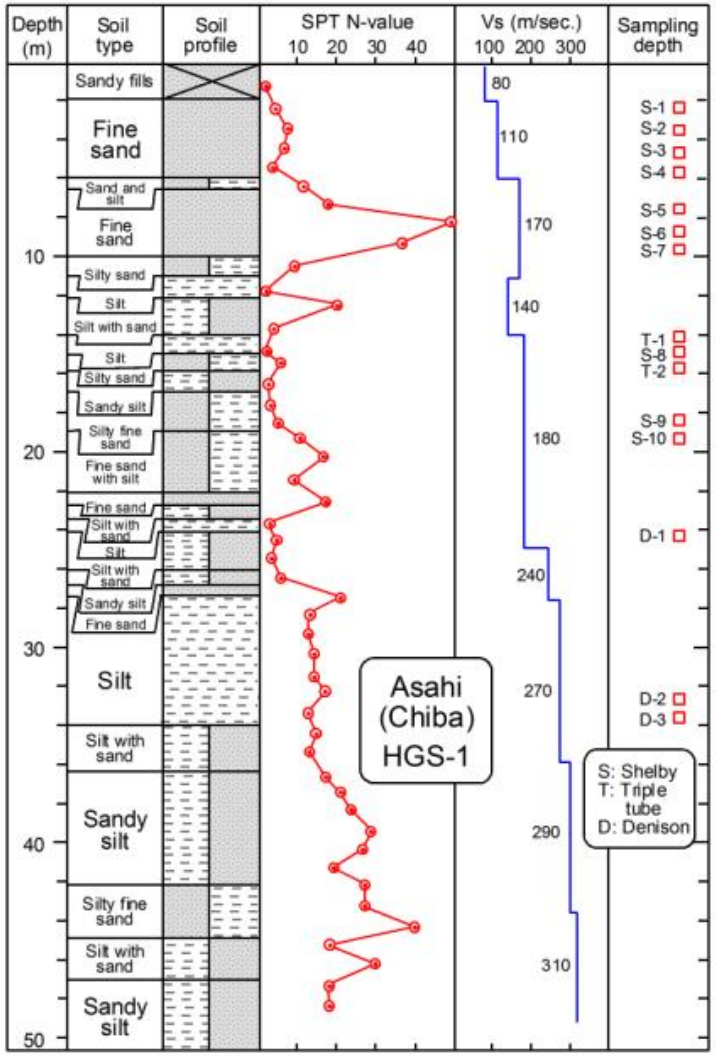


Fig. 12 : Soil profile at the site of sampling in Asahi (HG-S-1)

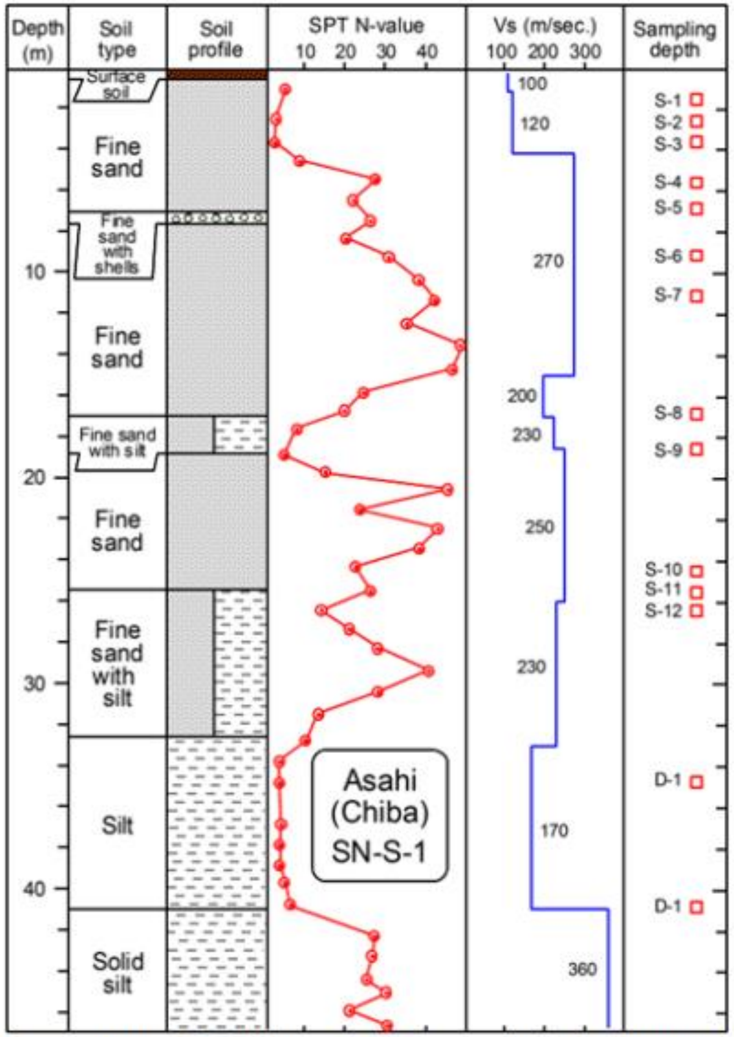
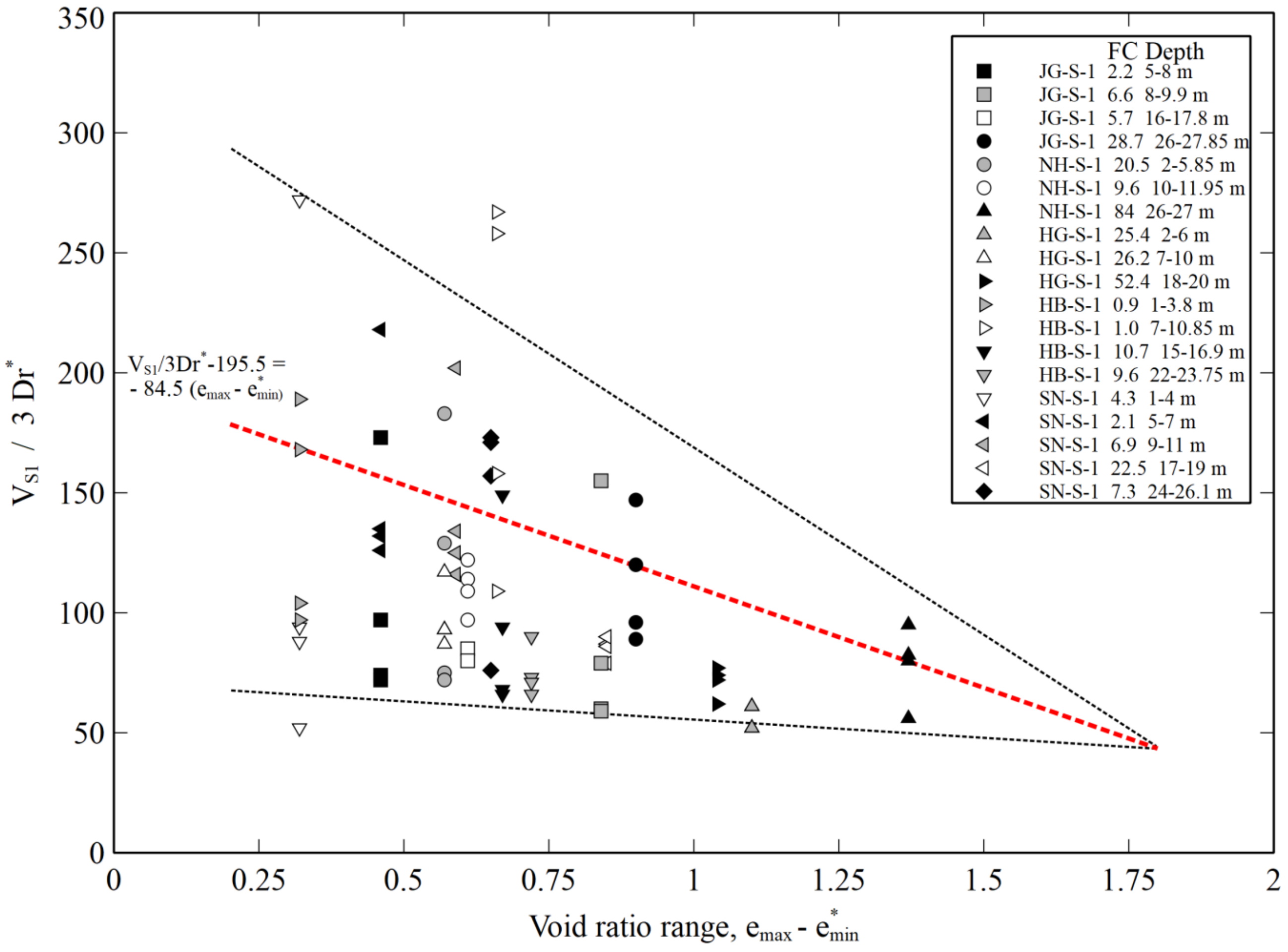


Fig. 13: Soil profile at the site of sampling in Asahi (SN-S-1)

5. Shear-Wave Velocity in the field and Relative Density of Disturbed Samples



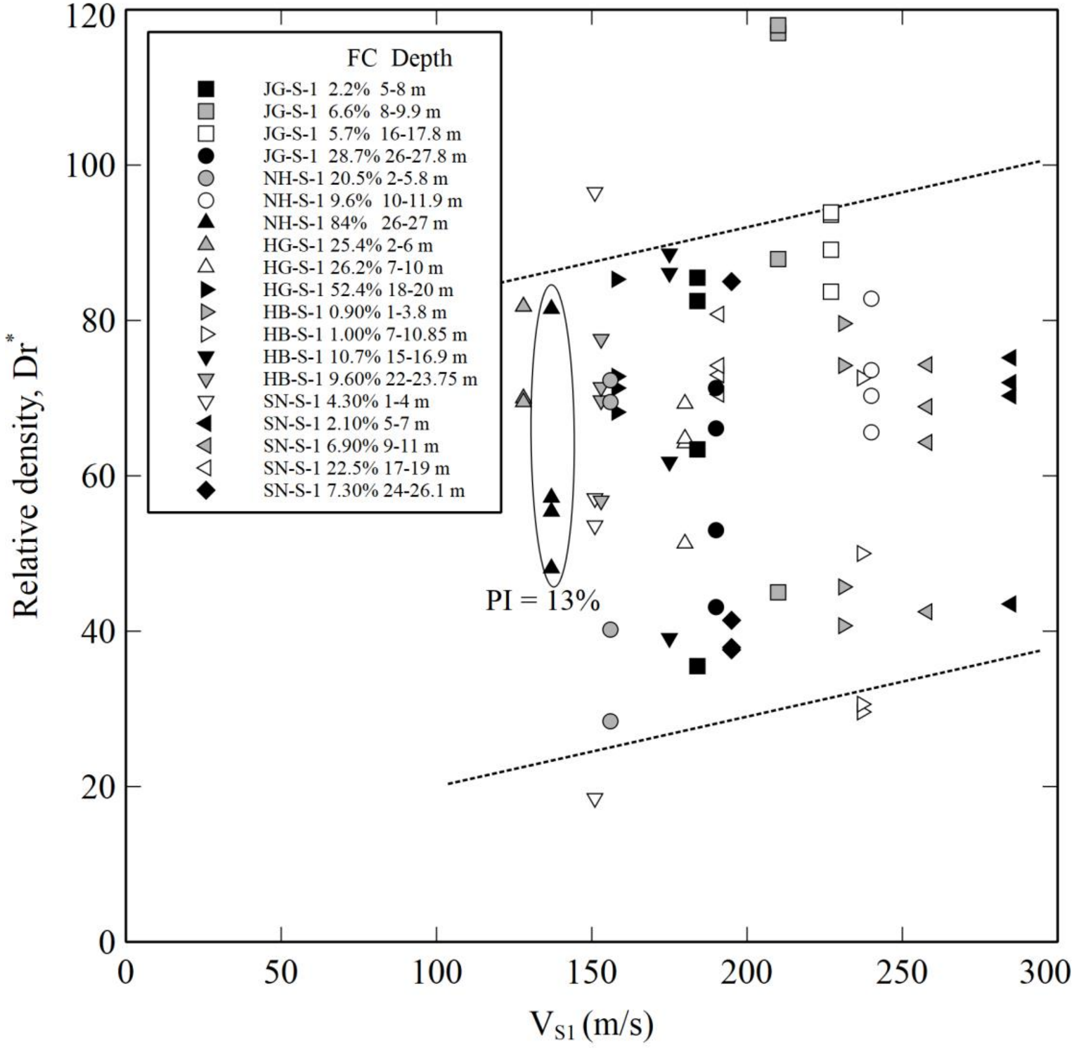
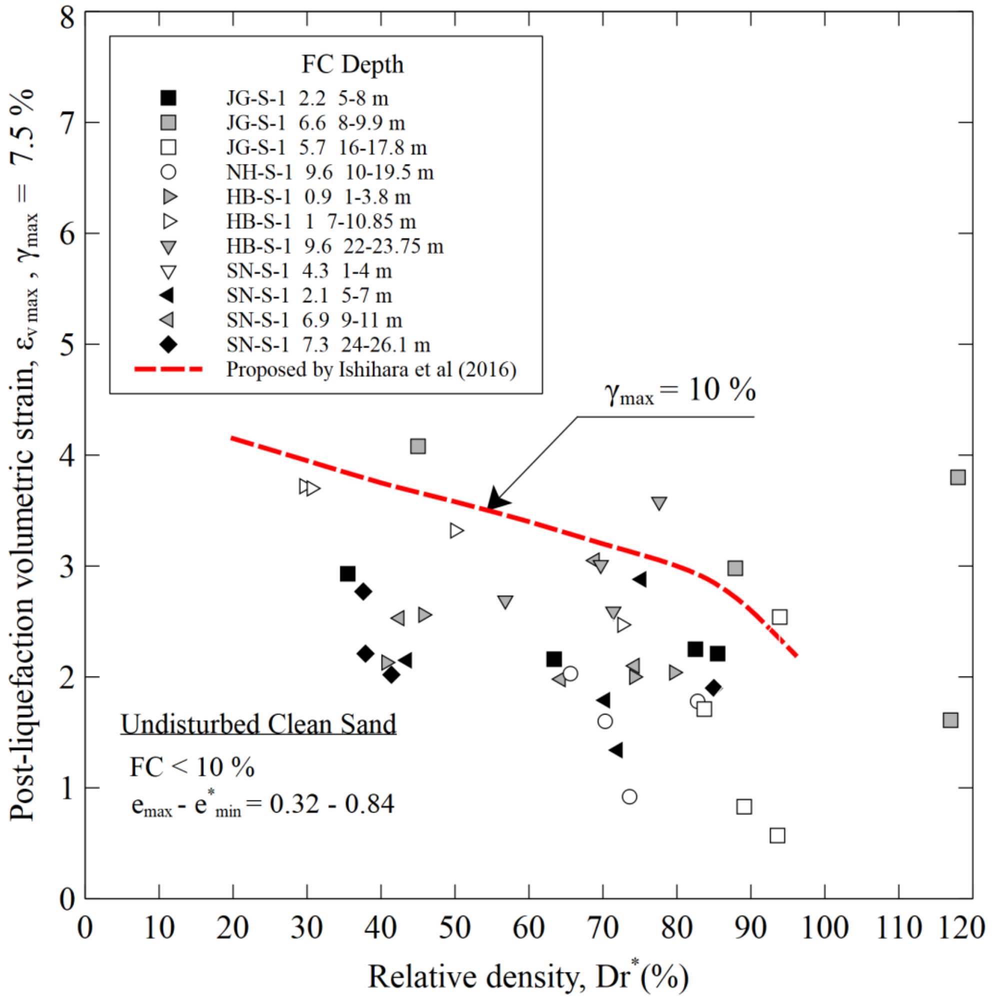


Fig. 14: Charts for the relation between V_{S1} / 3 Dr^* and range in void ratio, and for Relative density versus V_{S1}

6. Post-liquefaction Volume change and Relative Density of Intact and Reconstituted samples



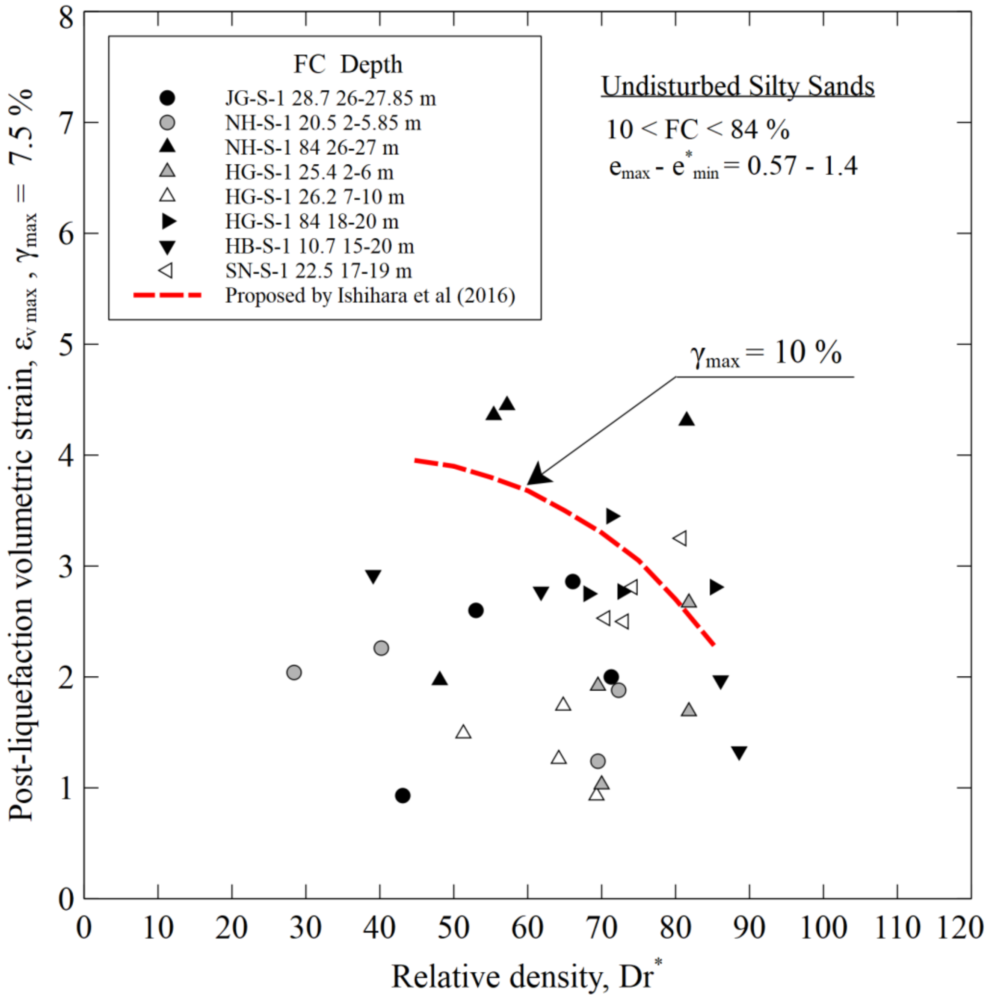


Fig. 15: Post-liquefaction Volume change versus Relative Density of Intact Samples

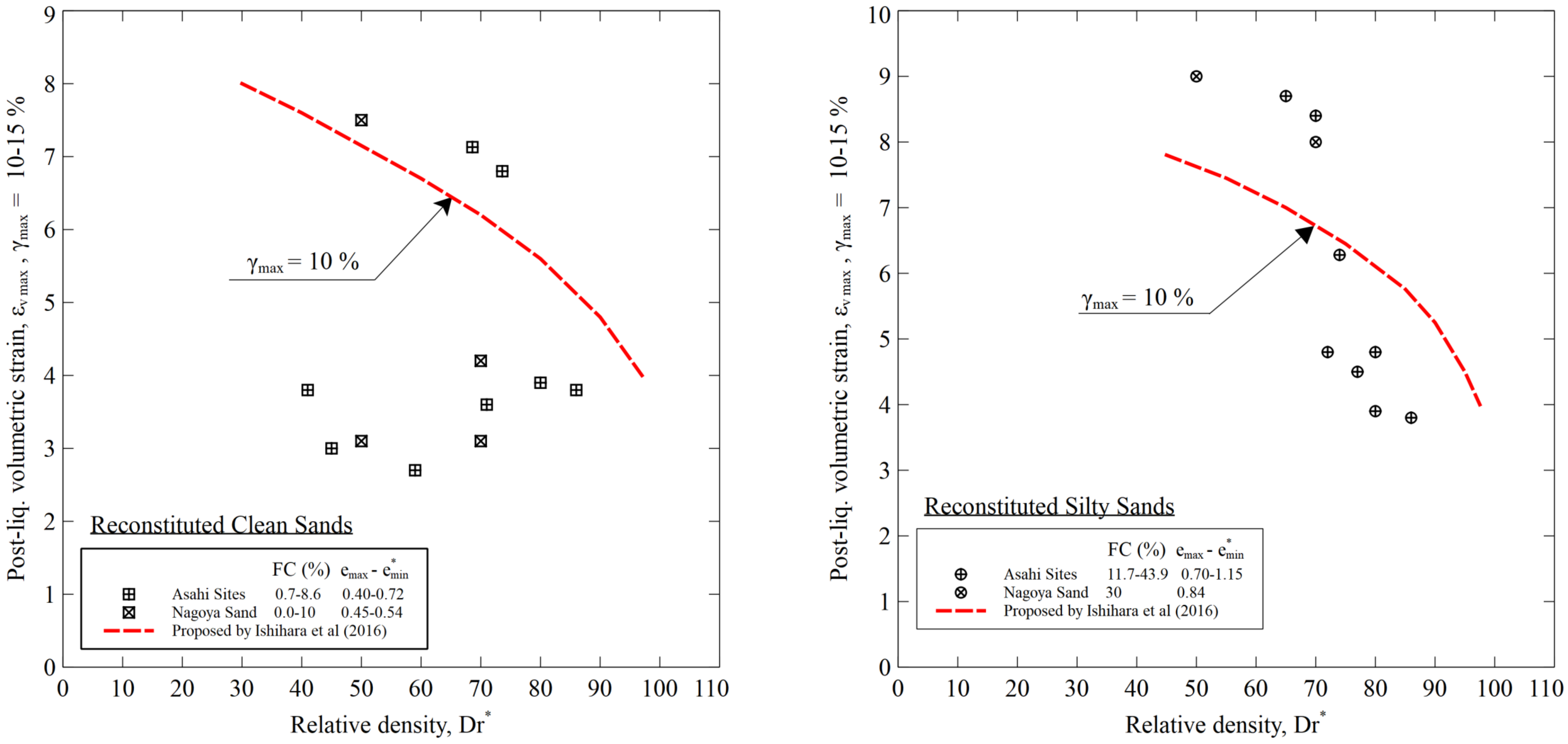
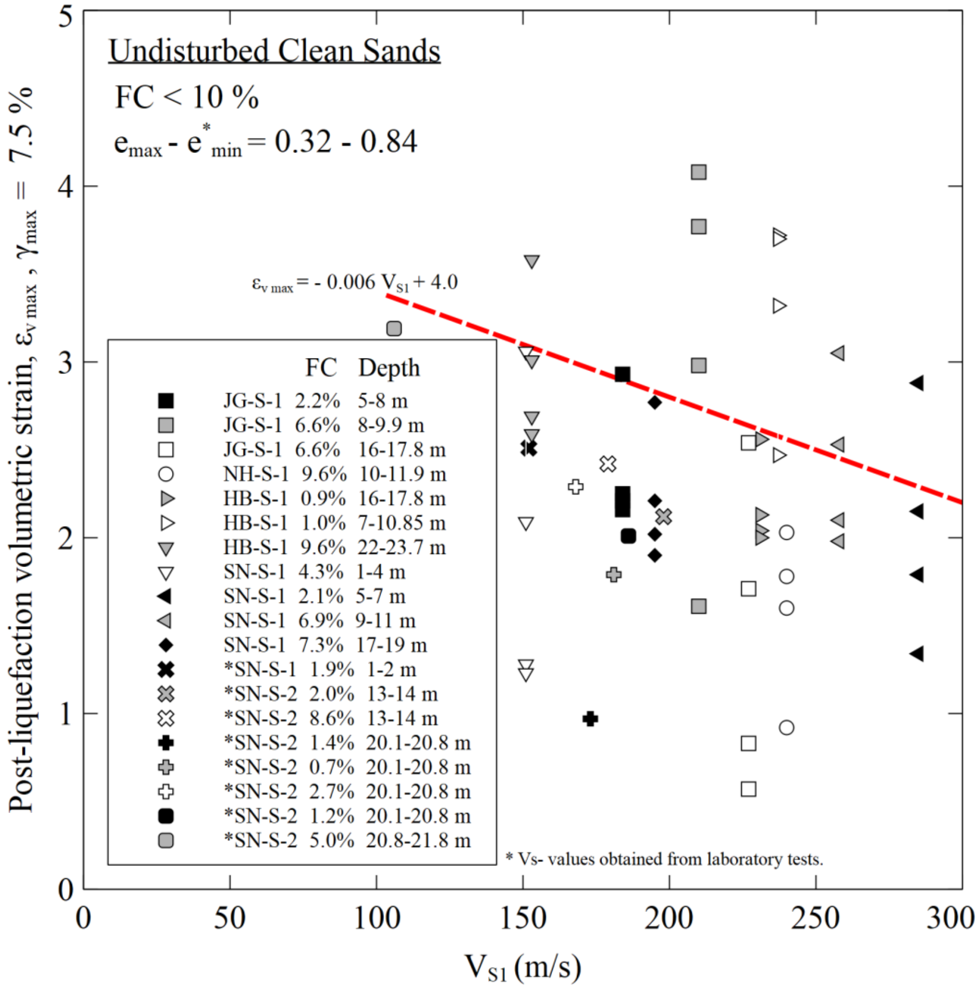


Fig. 16: Post-liquefaction Volume change versus Relative Density of Reconstituted Samples

7. Post-liquefaction Volume change and Shear-Wave Velocity of Intact Samples



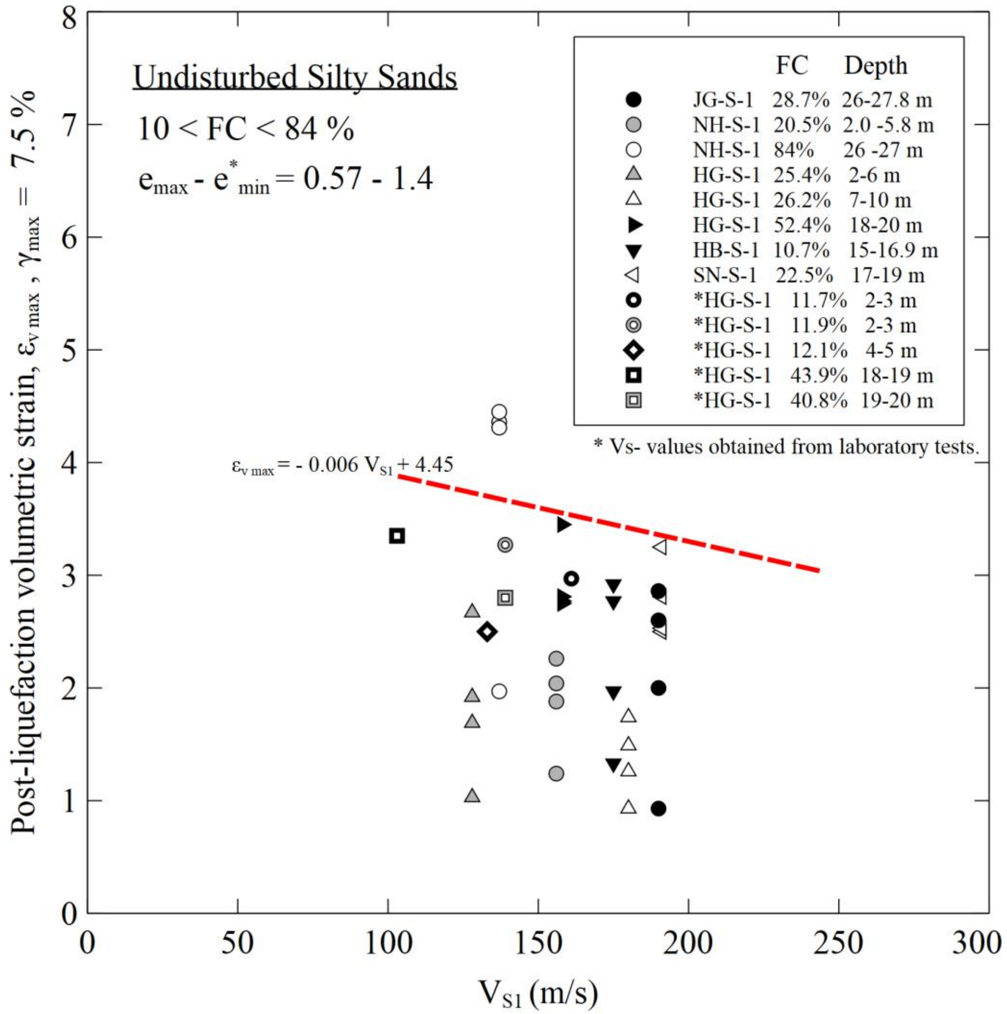


Fig. 17: Post-liquefaction Volume change versus V_{S1} of Intact Samples

8. Post-liquefaction Volume change and Shear-Wave Velocity of Reconstituted Samples

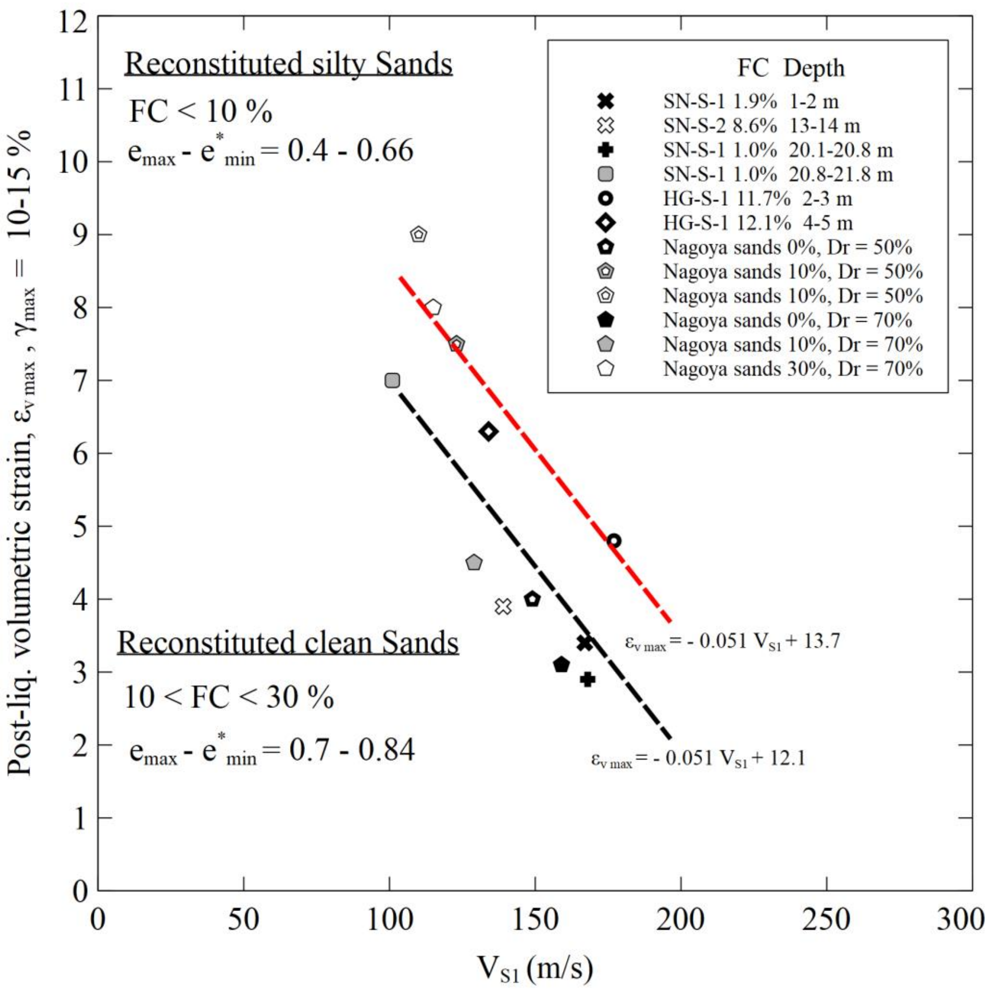


Fig. 18: Post-liquefaction Volume change versus V_{S1} of Reconstituted Samples

9. Post-liquefaction Volume change and Shear-Wave Velocity

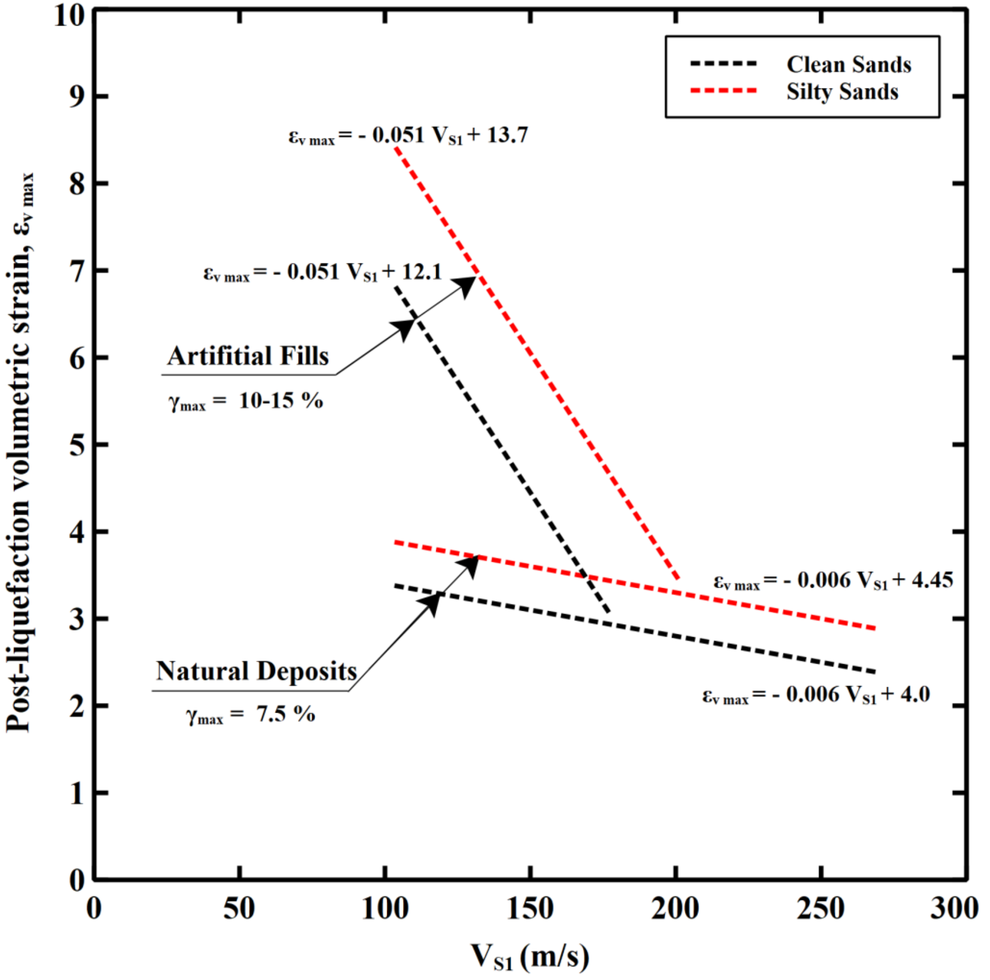


Fig. 17: Post-liquefaction Volume change versus V_{S1}

10. Liquefaction resistance and Shear-Wave Velocity

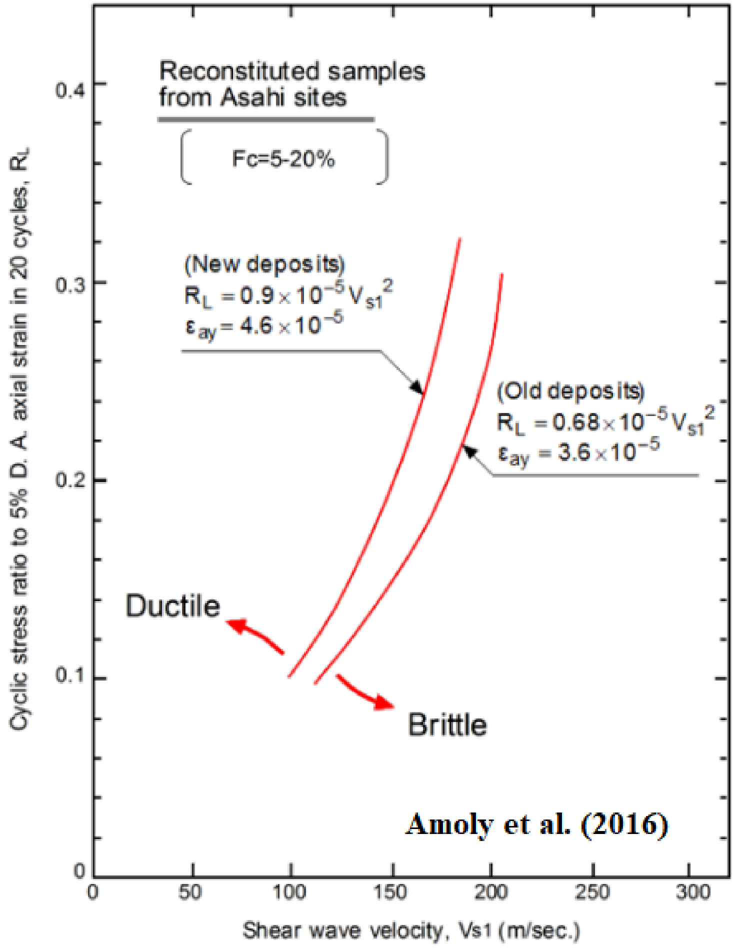


Fig. 18: Summarized two curves for new and old deposi

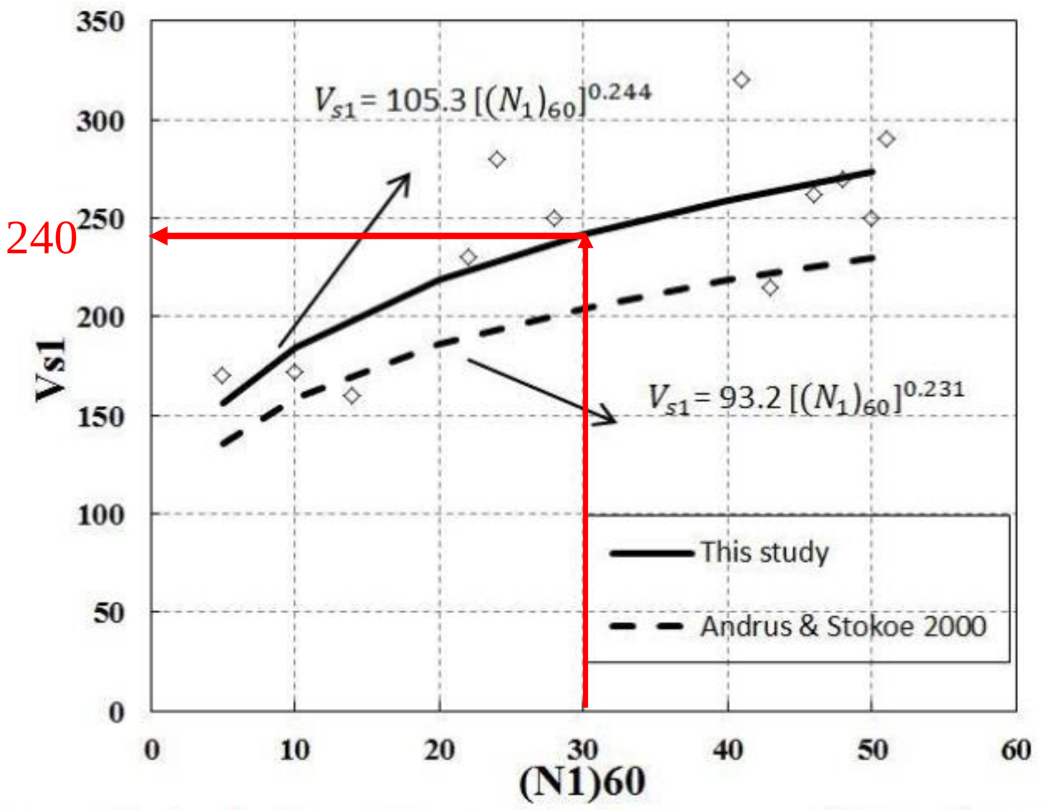
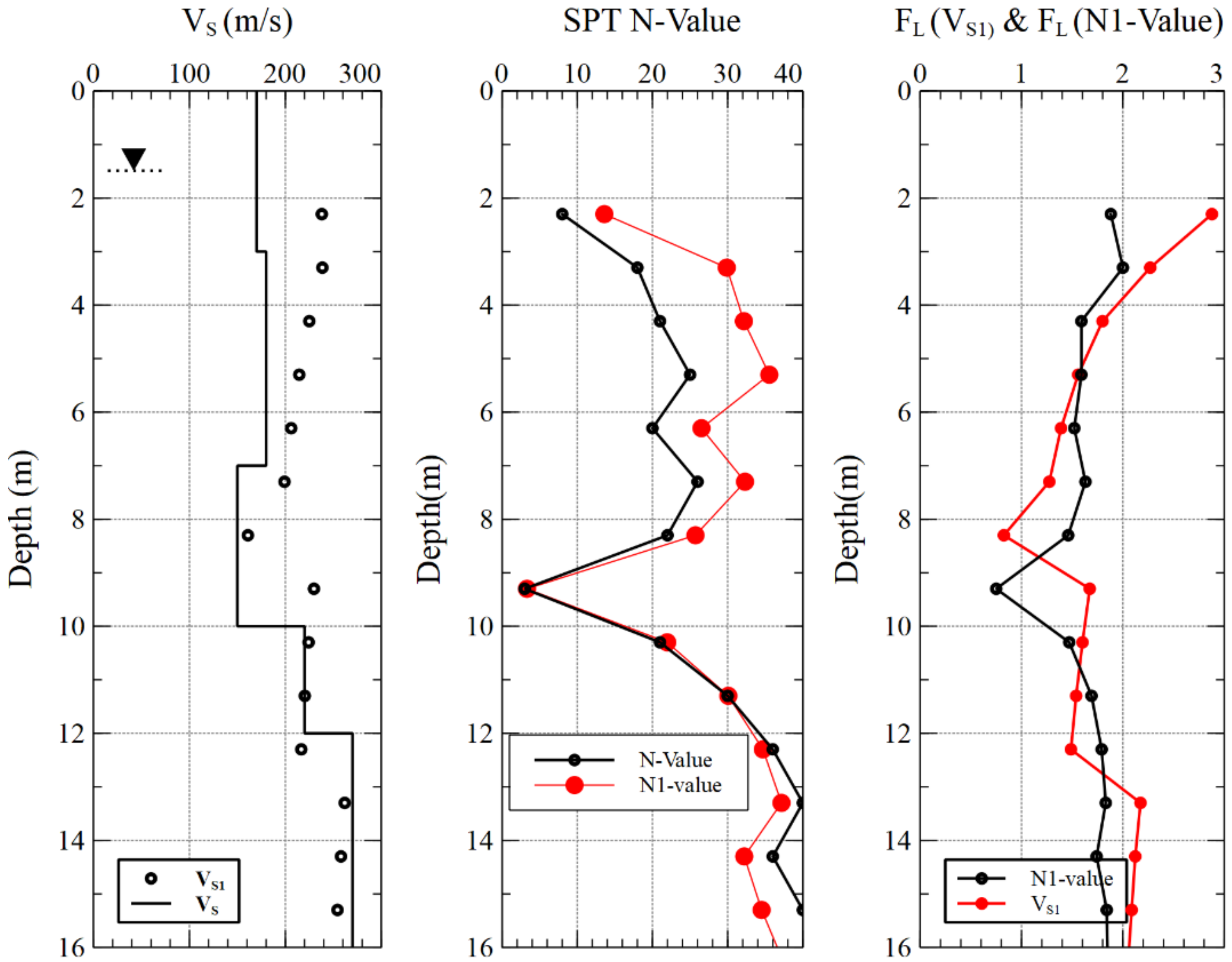


Fig. 19: Correlation between V_{S1} and (N1)60 proposed by Andrus and Stokoe (2000) and the present study

11. Comparison between SPT-based and Vs1-based Liquefaction potential in Asahi City Site (JG-S-1)



12. Procedures for estimating liquefaction-induced Settlements of the Ground Surface

12.1 Procedure A

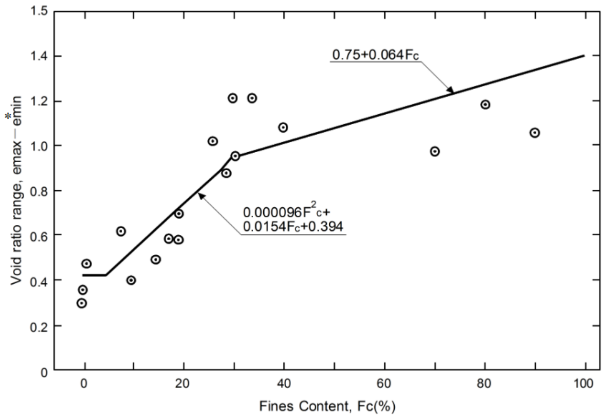
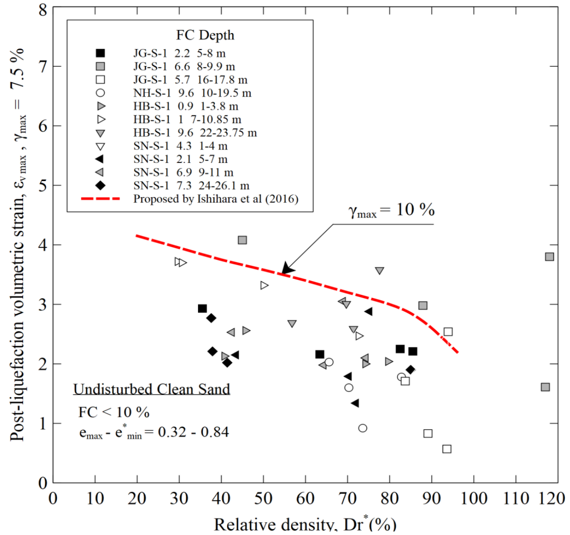
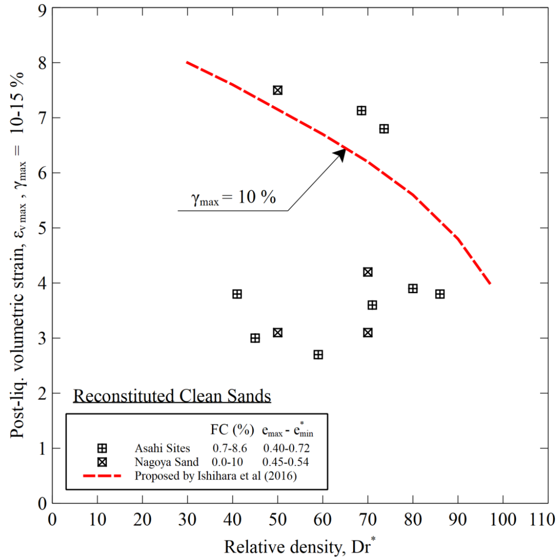
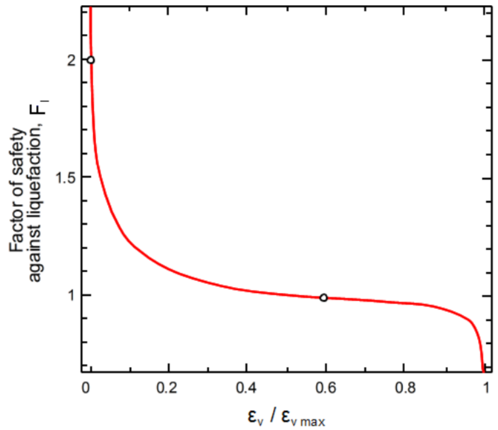
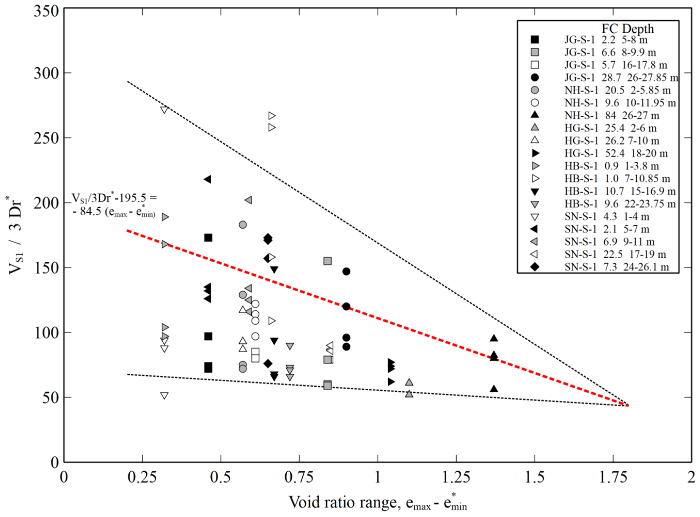


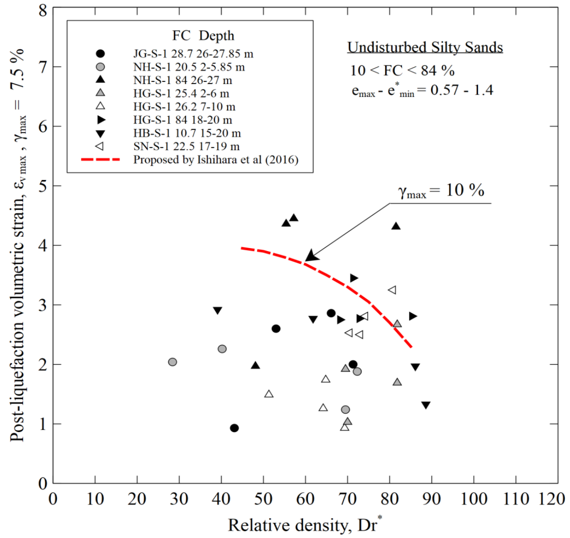
Fig. 4 : Range of void ratio range as functions of fines content

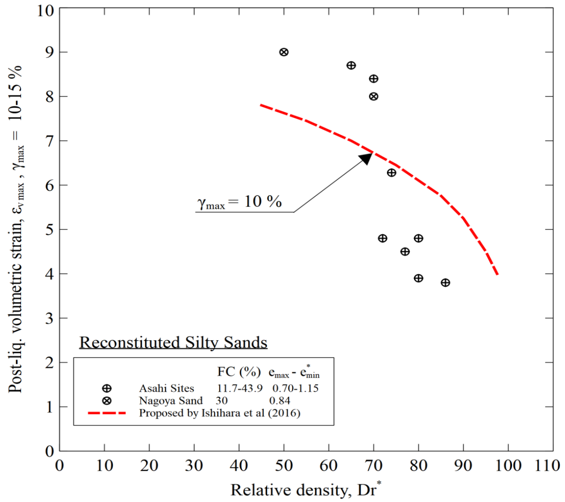




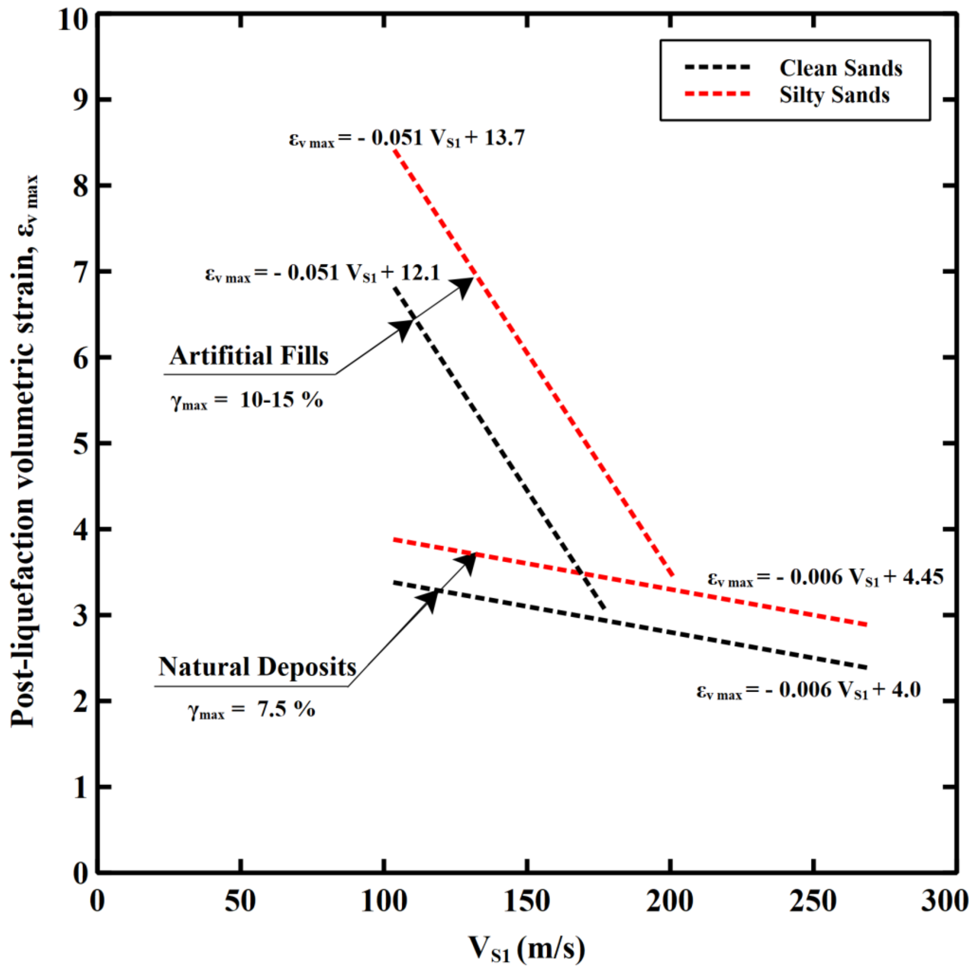


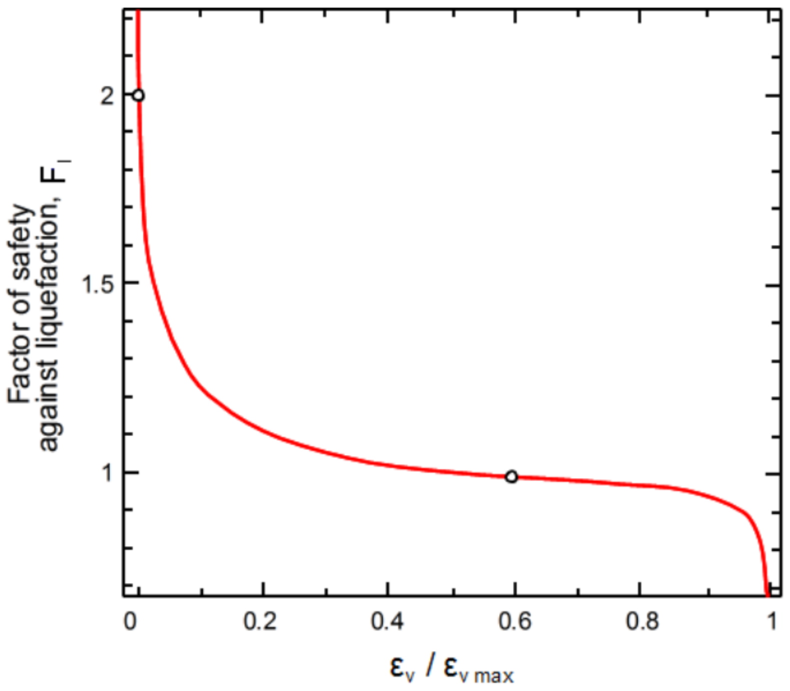






12.1 Procedure B





13. Settlement Analysis based on Shear-Wave Velocity

Fig.21: Locations of the sites for settlement analyses

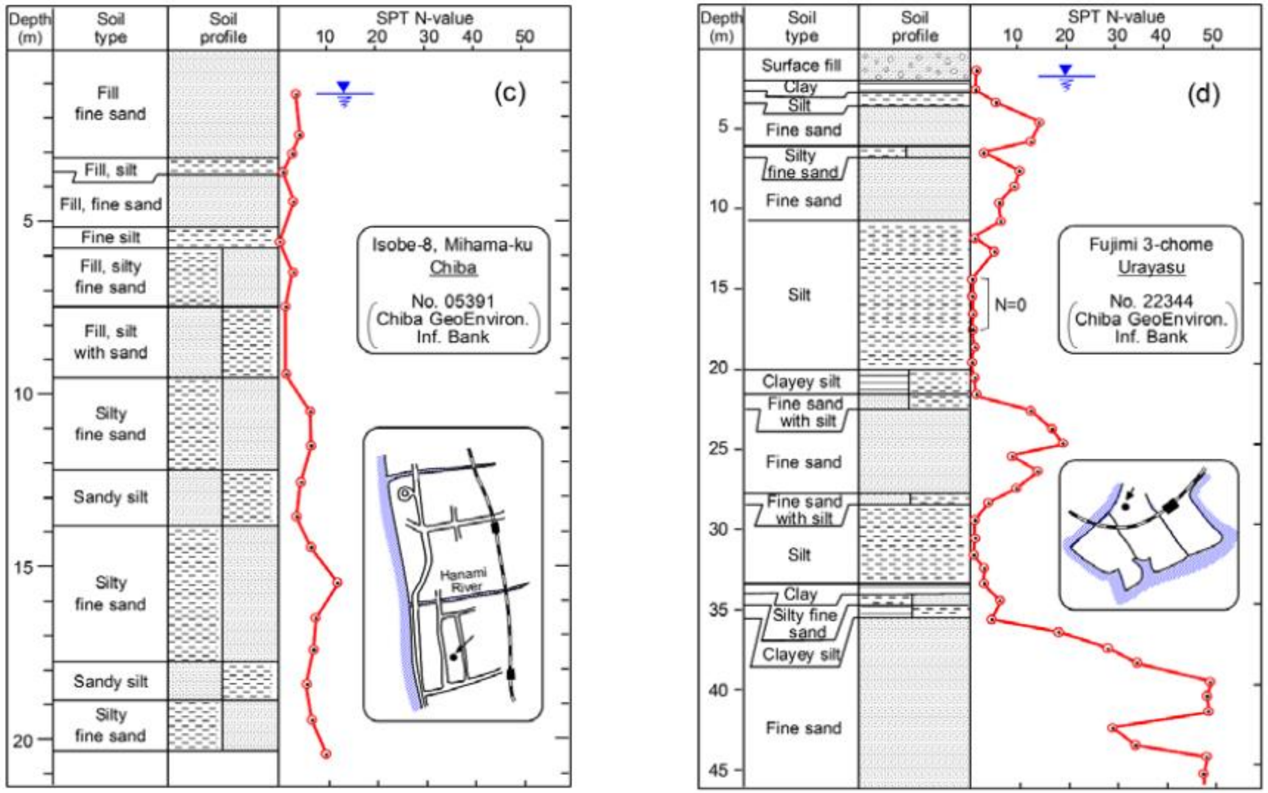


Fig.21 (c), (d) : Soil Profile at respective sites where settlement analyses are performed.

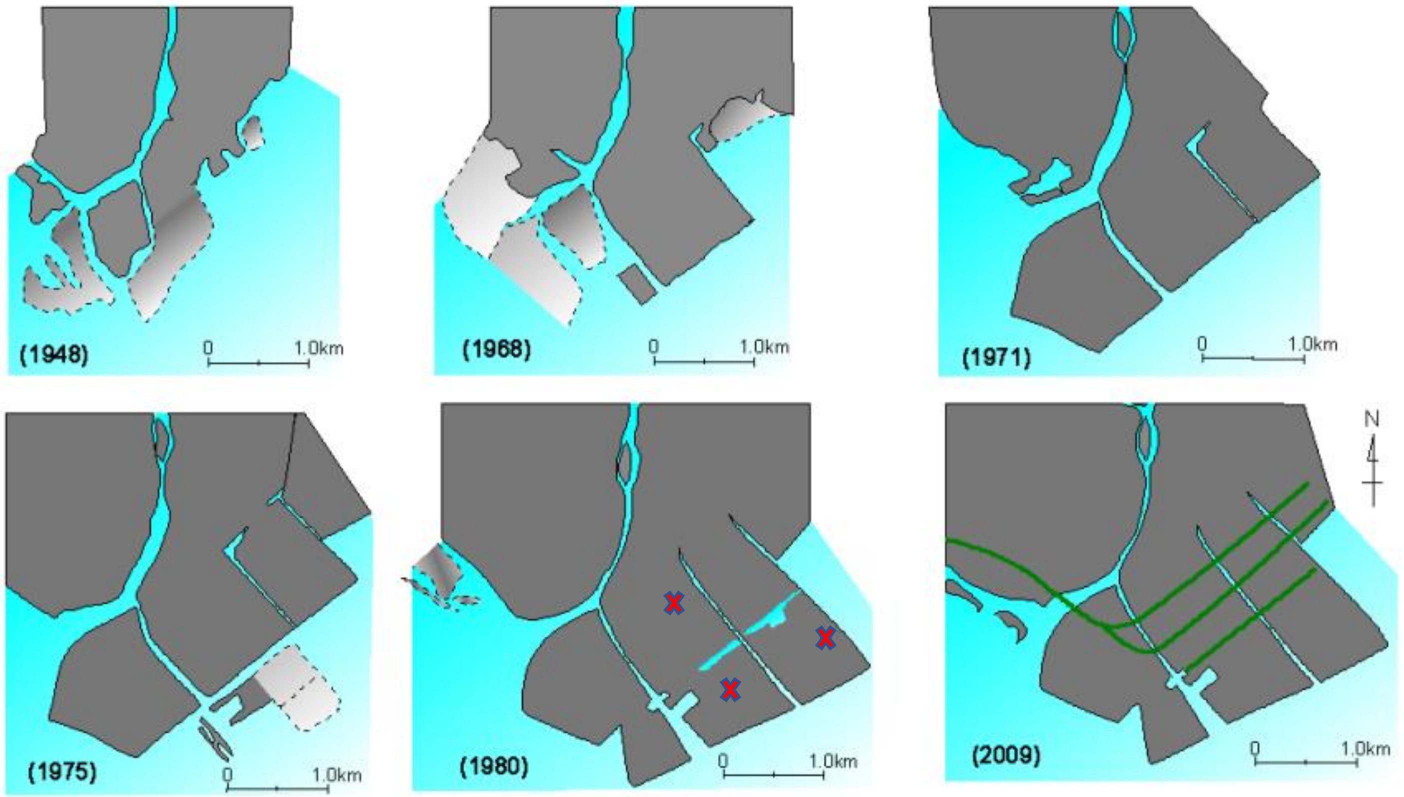
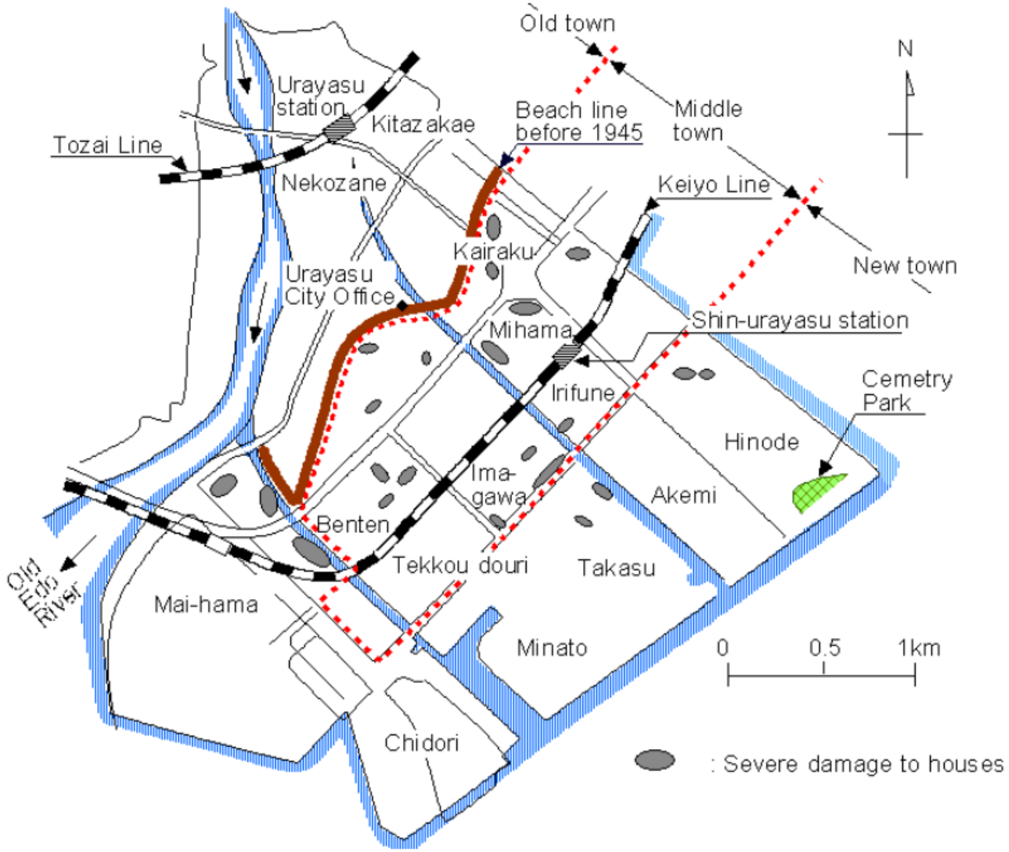
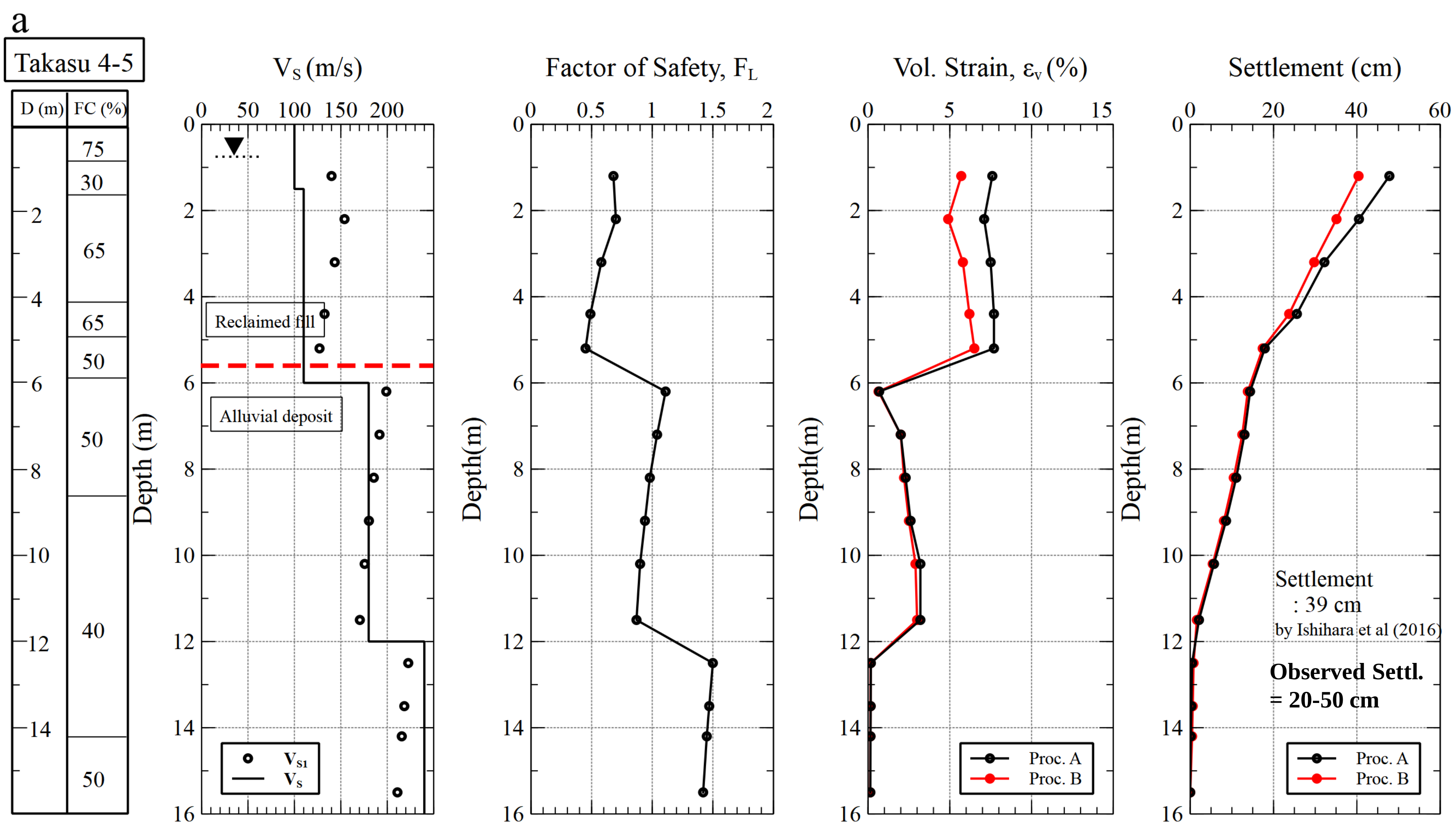
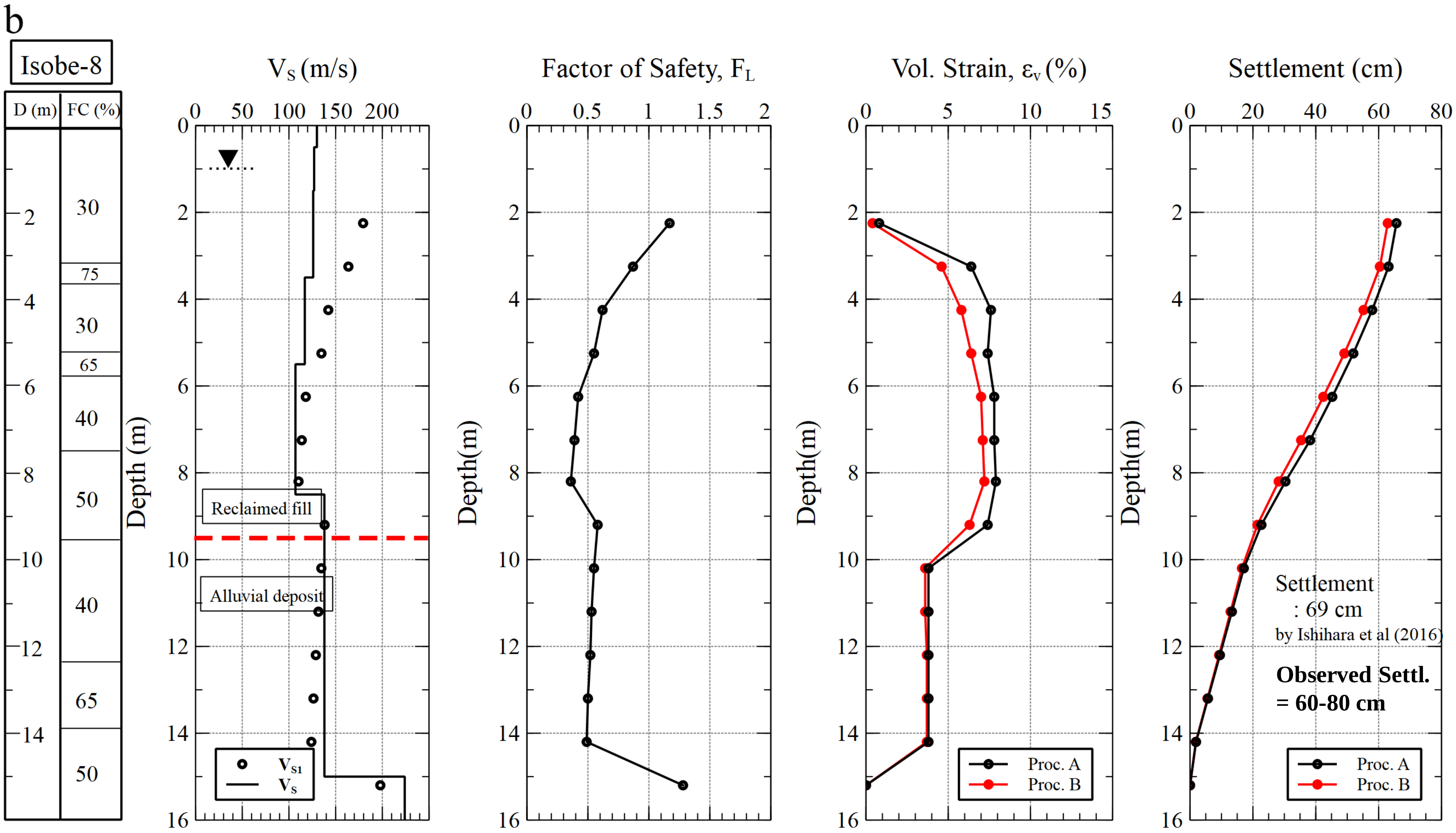


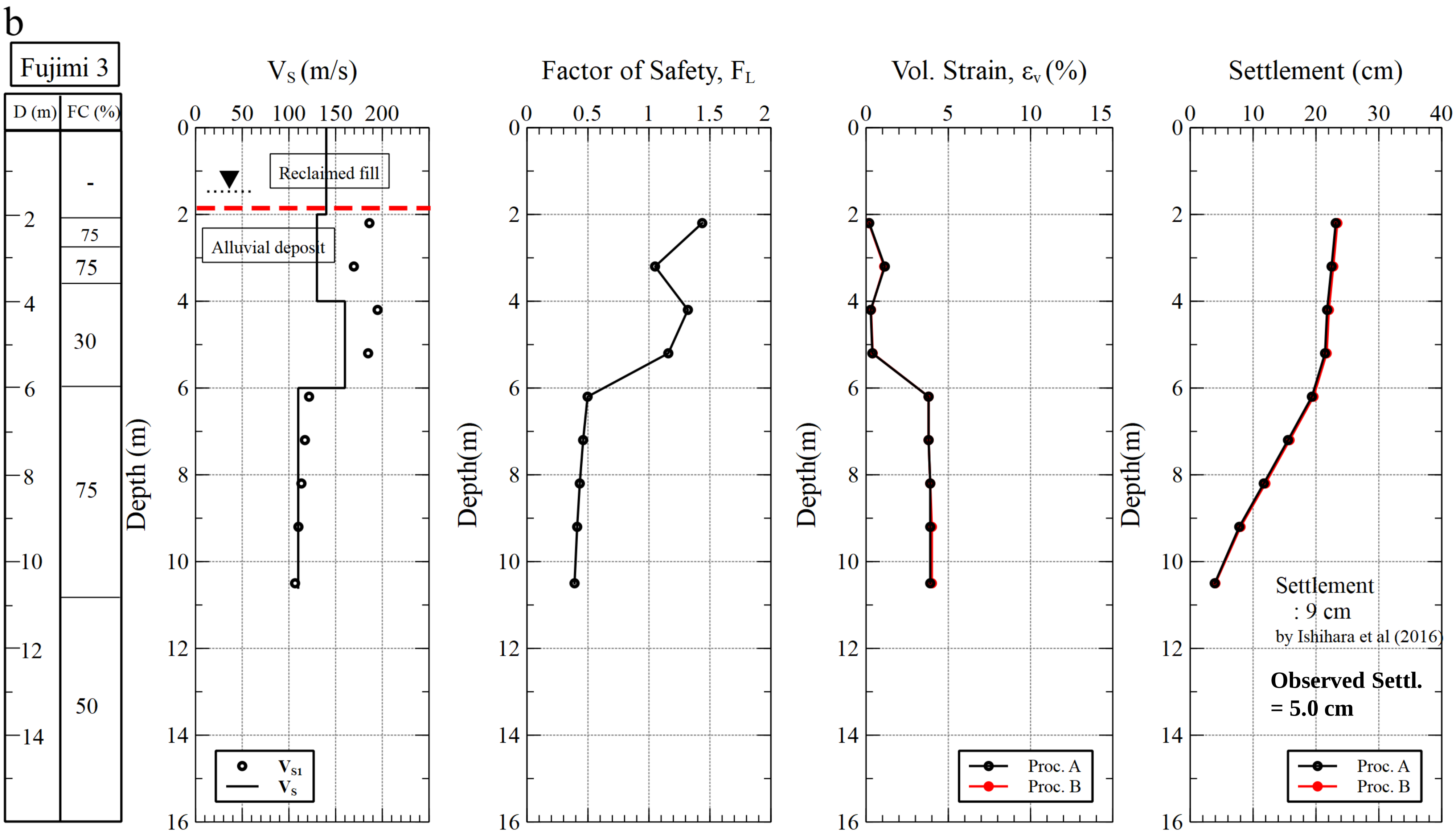
Fig . 23 : Progress of reclamation work in Urayasu



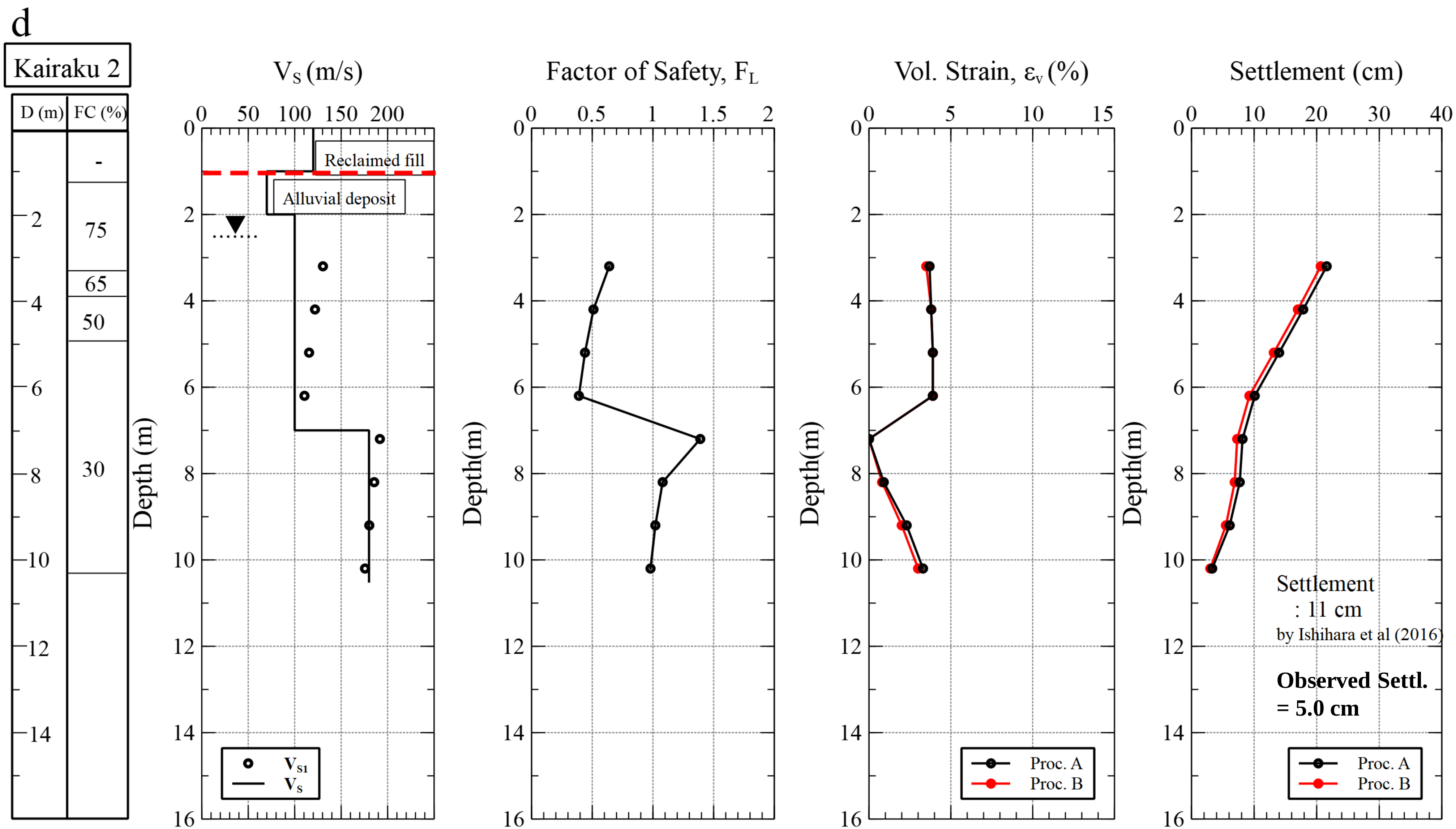

a
Takasu 4-5
D (m)
FC (%)
75
30
65
65
50
50
40
50
Vs (m/s)
Depth (m)
Reclaimed fill
Alluvial deposit
Vs1
Vs
Factor of Safety, FL
Depth(m)
Vol. Strain, εv (%)
Proc. A
Proc. B
Settlement (cm)
Settlement
: 39 cm
by Ishihara et al (2016)
Observed Settl.
= 20-50 cm



b
Isobe-8
D (m)
FC (%)
30
75
30
65
40
50
40
65
50
Vs (m/s)
Reclaimed fill
Alluvial deposit
Vs1
Vs
Depth (m)
Factor of Safety, FL
Vol. Strain, εv (%)
Proc. A
Proc. B
Settlement (cm)
Settlement
: 69 cm
by Ishihara et al (2016)
Observed Settl.
= 60-80 cm



b
Fujimi 3
D (m)
FC (%)
-
75
75
30
75
50
V_S (m/s)
Reclaimed fill
Alluvial deposit
Depth (m)
V_{S1}
V_S
Factor of Safety, F_L
Depth(m)
Vol. Strain, ε_v (%)
Depth(m)
Proc. A
Proc. B
Settlement (cm)
Depth(m)
Settlement
: 9 cm
by Ishihara et al (2016)
Observed Settl.
= 5.0 cm
Proc. A
Proc. B


d
Kairaku 2
D (m)
FC (%)
-
75
65
50
30
Vs (m/s)
Reclaimed fill
Alluvial deposit
Depth (m)
Vs1
Vs
Factor of Safety, FL
Depth(m)
Vol. Strain, εv (%)
Proc. A
Proc. B
Settlement (cm)
Settlement
: 11 cm
by Ishihara et al (2016)
Observed Settl.
= 5.0 cm

13. Concluding Remarks

As a result of the field and laboratory these outcomes, settlement analyses were preformed for **four sites along the coast of Tokyo Bay** where liquefaction-induced was considerable and the amount of the liquefaction-induced settlements were somewhat measured by observations.

A comparison between **Vs1-based procedures** and **SPT N1-based procedures**, used for computing liquefaction-induced settlements, have indicated a reasonable level of coincidence. **However, thin liquefiable soil layers are practically impossible to detect by Vs1-based procedures owing the fact that the test interval is much greater than the thickness of such strata.**

In addition, there is **a reasonable level of consistency** between the settlements computed by **Vs1-based procedures** and **those indeed observed** in the corresponding areas, **despite of a range of scattering data reflecting uncertainty as to measuring the observed settlements, compaction piles installed in some sites, and the assumption of estimating the settlements.**

Urayasu, Chiba, Japan, 2011.03.11 Earthquake

Thank You For Your Attention