Technical Note

Correlations of SPT and DCPT data for sandy soils in Ghana

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ARTICLE INFORMATION

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ABSTRACT

Standard penetration test (SPT) is the most commonly used in-situ test for site investigations and foundation design with well-established correlations between the SPT and soil properties. However for simple structures in developing countries the SPT is considered uneconomical. The dynamic cone penetration test (DCPT) is a rapid inexpensive field test that can be used to determine the material properties of soils. In this study the two in-situ tests are carried out side by side in sandy soils and a correlation of the DCPT results with SPT results and allowable bearing capacity investigated. The results indicate that the relation between the results of the two in-situ tests is linear for sandy soils. The local DCPT – SPT and DCPT – allowable bearing capacity correlations obtained compare well with those in literature.

1. Introduction

The standard penetration test (SPT) is the most commonly used test for site investigations and foundation design in Ghana. The advantages of this test are that it offers the retrieval of samples for further testing in the laboratory and has standardized equipment for the test, in terms of hammer mass, sampler dimensions and height of hammer fall. There are also well-established correlations between SPT and soil properties. However the test is costly, time consuming and impractical for sites where space is limited.

The dynamic cone penetration test (DCPT) is a rapid and inexpensive test for determining the material properties of soils. However, around the world, the DCPT is less popular than the SPT (Spagnioli, 2007). Correlations between the results of DCPT and soil properties or any other trusted field test is not well established yet (Abuel-Naga et al., 2011). This is partly because there are many designs of the DCPT equipment. The DCPT is also not applicable to depths greater than eight metres below the ground surface (Stefanoff et al., 1988) making it reliable only for shallow foundations. The DCPT has traditionally been used to determine the in-situ California bearing ratio (CBR) for subgrade soils for pavement design and construction (for example Livneh, 1987; Kleyn and Savage, 1982; Scala, 1956). Some attempts have been made to extend the use of DCPT to determine the allowable bearing capacity of shallow foundations. Ligwanda et al. (2015) correlated SPT, CPT and DCPT results for sandy soils in Tanzania. Ibrahim and Nyaoro (2011) correlated SPT and DCPT results for analysis and design of foundations. Sanglerat (1972) used a semi-empirical approach to derive an equation for

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computing the allowable bearing capacity from DCPT readings. Sowers and Hedges (1966) produced a correlation between the SPT and DCPT readings. In Ghana, Ampadu (2009, 2005) correlated allowable bearing stresses with DCPT results for lateritic soils. This study contributes to the search for reasonable local correlations between allowable bearing stress and DCPT results.

2. Methodology

2.1 Equipment

The equipment for the SPT consisted of the DANDO 2000 percussion drilling rig with the standard split spoon sampler, a 63.5 kg automatic trip hammer with a drop of 760 mm capable of delivering on average 80% of the theoretical energy as measured during equipment calibration by the manufacturer. The DCPT equipment consisted of the German model DIN 4094 comprising a 10 kg hammer, with a falling height of 500 mm and rods of 22 mm diameter fitted to a cone of apex angle 90° and 10 cm^2 base area.

2.2 Testing

For the four different sites the SPT was carried out at 1 or 1.5 m below the ground surface, depending on the site conditions. A total of fifteen boreholes were drilled. **Figure 1** shows the four different sites where the study was conducted.

Fig. 1. Locations of the four different sites where the study was conducted.

The results were recorded as standard number of blows per 300 mm penetration denoted as *N*. Undisturbed and disturbed samples were obtained from the boreholes for further laboratory testing.

The DCPT was conducted near the locations where the SPT tests were conducted. Care was taken to ensure that the location of each pair of borehole and DCP test point was within a 0.5 m radius. **Figure 2** shows the relative locations of the SPT and DCPT points at Kintampo, one of the four sites investigated. For the test, the DCPT equipment was held upright and the hammer was allowed to drop onto the anvil. The number of blows required to drive in each 100 mm of the rod was recorded as N_{10}.

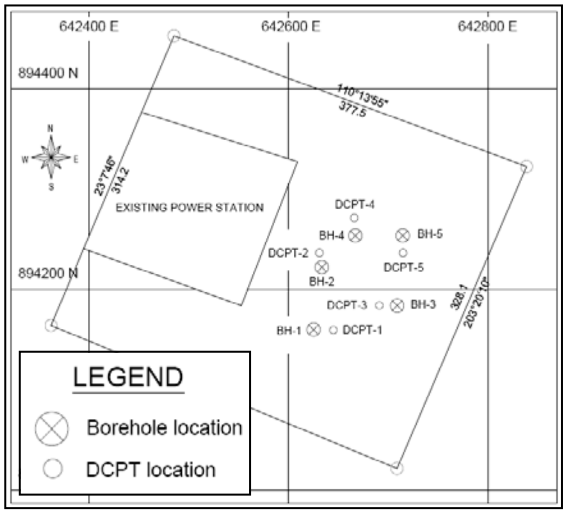

Fig. 2. Relative locations of SPT and DCPT points at Kintampo.

3. Discussion of Results

3.1 Characteristics of test soils

A summary of the soil properties from the laboratory test of each of the four sites is given in **Tables 1** and **2**. It can be seen that the soils at the four sites are mostly silty sands or sandy silts with some clay and very little gravel.

3.2 SPT results

To correct for SPT results collected with different hammer systems, it is common to convert the measured SPT-N values to equivalent measurements at 70% of the theoretical driving energy (Riggs, 1986). Corrections that need to be applied to the SPT-N values include the overburden pressure correction, C_N, the hammer energy correction, η_1, rod length correction, η_2, the sampler correction, η_3 and the borehole diameter correction, η_4. The hammer system of the equipment used in this study is capable of delivering 80% of the maximum theoretical energy on average. The standardized SPT-N values is therefore given by,

Table 1. Representative results of natural moisture content, specific gravity and natural moisture content

Site	Depth	Natural Moisture Content (%)	Atterberg Limits (%) LL	PL	PI	Specific Gravity
Anloga, Kumasi (Ashanti Region)	0- 2.5	21.77	47.0	35.6	11.4	2.56
	2.5 – 5.5	28.31	54.0	41.9	12.1	2.51
	5.5 – 7.6	37.41	44.0	38.0	7.0	2.59
Breman, Kumasi (Ashanti Region)	1.0 - 5.0	18.20	43.1	22.9	20.2	2.48
	5.0 – 7.0	21.95	56.3	33.1	23.2	2.60
	7.0 – 10.0	28.91		Non - Plastic		2.95
Kwaso (Ashanti Region)	0.5 – 2.0	15.32	39.3	25.3	13.9	2.84
	2.0 – 5.0	21.68	47.6	27.5	20.1	2.84
	5.0 – 14.9	22.72	53.0	36.9	16.1	2.61
Kintampo (Brong-Ahafo Region)	1.0-2.0	16.76	32.7	16.1	16.6	2.64
	2.0-3.0	13.15	33.7	14.4	19.2	2.48
	3.0-4.0	10.64	24.0	15.5	8.5	2.68

Table 2. Representative results of grading test

Site	Depth	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Description
Anloga, Kumasi (Ashanti Region)	0- 2.5	30.8	18.2	48.4	2.6	Silty, Clayey, **SAND** with trace Gravel
	2.5 – 5.5	11.0	38.3	47.7	3.0	Clayey, Silty, **SAND** with trace Gravel
	5.5 – 7.6	3.5	42.5	53.0	1.0	Silty, **SAND** with traces of Clay and Gravel
Breman, Kumasi (Ashanti Region)	1.0 - 5.0	26.00	14.00	56.00	4.00	Silty, Clayey **SAND** with some gravel
	5.0 – 7.0	11.00	34.00	46.00	9.00	Clayey, Silty **SAND** with some and Gravel
	7.0 – 10.0	0.00	40.00	47.00	13.00	Silty **SAND** with some Gravel
Kwaso (Ashanti Region)	0.5 – 2.0	21.70	42.60	33.70	2.00	Clayey Sandy **SILT** with traces of gravel
	2.0 – 5.0	31.80	37.80	20.70	9.70	Sandy Clayey **SILT** with some gravel
	5.0 – 14.9	9.90	62.40	26.10	1.60	Sandy **SILT** with some clay and trace gravel
Kintampo (Brong-Ahafo Region)	1.0-2.0	28.2	14.2	53.4	4.2	Silty, Clayey **SAND** with trace gravel
	2.0-3.0	29.7	14.5	55.7	0.1	Silty, Clayey **SAND**
	3.0-4.0	13.9	18.3	67.6	0.2	Clayey, Silty **SAND**

$$N_{70} = C_N N \eta_1 \eta_2 \eta_3 \eta_4 \quad [1]$$

$$C_N = \left(\frac{95.76}{P'_o}\right)^{0.5}$$

$$\eta_1 = \frac{80\%}{70\%}$$

$$\eta_2 = varies$$

$$\eta_3 = varies$$

$$\eta_4 = 1.15$$

$$N_{70} = \left(\frac{95.76}{P'_o}\right)^{0.5} \times N \times \frac{80\%}{70\%} \times \eta_2 \times \eta_3 \times 1.15 \quad [2]$$

Where N is the raw number of blows per 300 mm penetration and N_{70} is the standardized value. The correction factors are obtained from Bowles (1997).

DCPT measurements are obtained continuously at 100 mm intervals while SPT data represent discreet measurements at 1 or 1.5 m apart. As such it was necessary to condition the results so that reference is made at common locations while creating data pairs for correlation. It is also important to consider the influence zones created in each test due to the different driving mechanism. The zone of influence of the SPT sampler is in the order of 4 – 7 times the sampler diameter plus the 300 mm that is presumably tested. With the standard sampler of 51 mm diameter, taking an average of 5 sampler diameters, the SPT influence zone in this study is taken as 560 mm. With smaller dimensions, the DCPT is expected to create less influence zones than the SPT.

The 560 mm zone was taken as reference for both tests and a moving window average of 560 mm was taken through the DCPT data to establish pairs corresponding to SPT data. The DCPT values used were the average of DCPT values within the influence zone. **Figure 3** shows the soil profile with borehole 4 (BH4) and DCPT point 4 (DCPT4) at Kintampo and the pair of values used in the correlation.

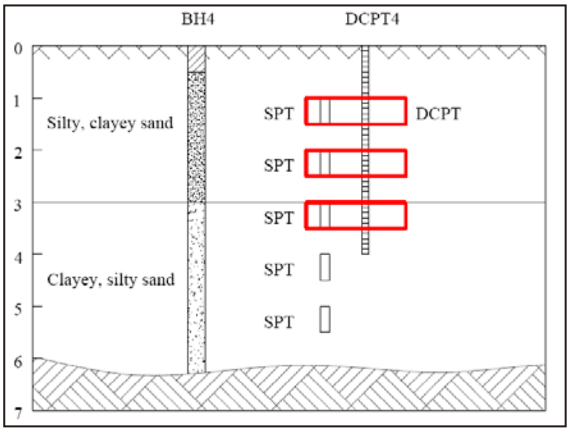

Fig. 3. Soil profile showing borehole 4 (BH4) and DCPT point 4 (DCPT4) at Kintampo and the pair of values (in red box) used in the correlation.

3.3 Bearing Capacity

The SPT is widely used to obtain the bearing capacity of soils directly. The allowable bearing capacity of the soils tested can be obtained from the SPT-N values by applying the Bowles equation (1997) given by,

$$q_a = \frac{N}{F_1} K_d, \qquad B \leq F_4 \qquad \ldots \qquad [3]$$

Where q_a is the allowable bearing capacity, B is the width of footing, F_1 and F_4 are factors and K_d is given by,

$$K_d = 1 + 0.33\frac{D}{B} \leq 1.33 \qquad [4]$$

Where D is the depth of footing in the soil.
Assuming a foundation with footing width, B = 1 m and depth of foundation, D = 1 m,

$F_1 = 0.04$ and $F_4 = 1.2$

From equation 3, the allowable bearing capacity is given by,

$$q_a = \frac{N_{70}}{0.04} \times 1.33$$

$$q_a = 33.25 N_{70}$$

From this equation, the bearing capacity at the various depths in each of the boreholes was obtained by inserting the corrected N-values, (N_{70}), into the equation.

3.4 DCPT results

The DCPT results are expressed in terms of number of blows required to drive in 100 mm of the standard rod length. A total of 31 DCPT-N results were obtained for corresponding SPT-N values. The DCPT-N values were obtained by taking the average blow count required to drive in 100 mm rod length within the influence zone.

3.5 Correlations

3.5.1 Correlation between allowable bearing capacity, q_a and N_{10}

A total of 31 DCPT-N to q_a data pairs were obtained and plotted as shown in **Figure 4**. Using regression analysis, an expression of $q_a = 15.75N_{10} + 54.19$ was obtained with an associated coefficient of determination, $R^2 = 0.5588$. The coefficient of determination indicates that there is a moderate correlation between q_a and N_{10}.

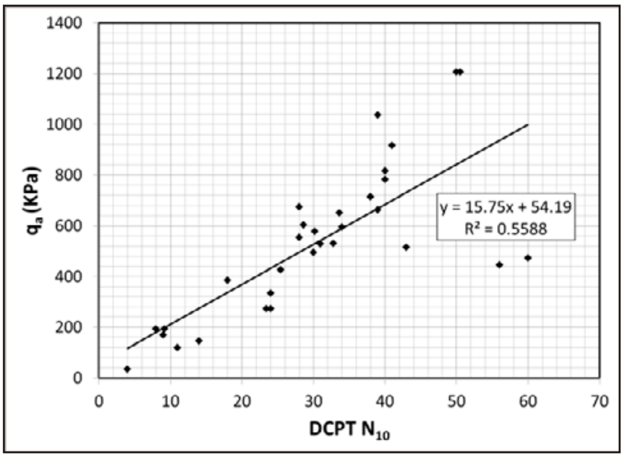

Fig. 4. Relationship between allowable bearing capacity, q_a, and DCPT-N_{10}.

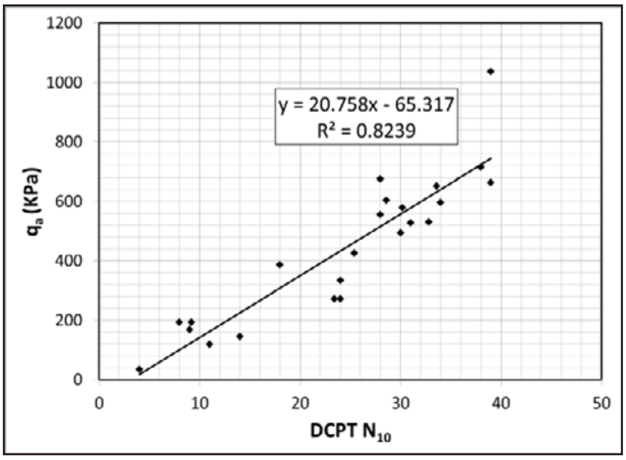

Fig. 5. Relationship between allowable bearing capacity, q_a, and DCPT-$N_{10} < 40$.

A careful look at the plot in **Figure 4** indicates a higher degree of scatter after an $N_{10} > 40$ blows. This observation is consistent with Ligwanda et al. (2015) and Figueiredo et al. (2012). Hence values for N_{10} greater than 40 were filtered out of the results and the remaining data plotted as shown in Figure 5. The regression analysis gave the expression $q_a = 20.758N_{10} + 65.317$ with an associated coefficient of determination, $R^2 = 0.8239$. The coefficient of determination indicates that there is a strong correlation between q_a and N_{10} for N_{10} values less than 40 blows.

3.5.2 Correlation between SPTN_{70} and DCPT N_{10}

In a manner similar to the q_a and N_{10} correlation, a total of 31 SPT N_{70} to DCPT N_{10} data pairs were obtained and plotted as shown in **Figure 6**. Using regression analysis, an expression of $N_{70} = 0.4737N_{10} + 1.6298$ was obtained with an associated coefficient of determination, $R^2 = 0.5588$. The coefficient of determination indicates that there is moderate correlation between N_{70} and N_{10}.

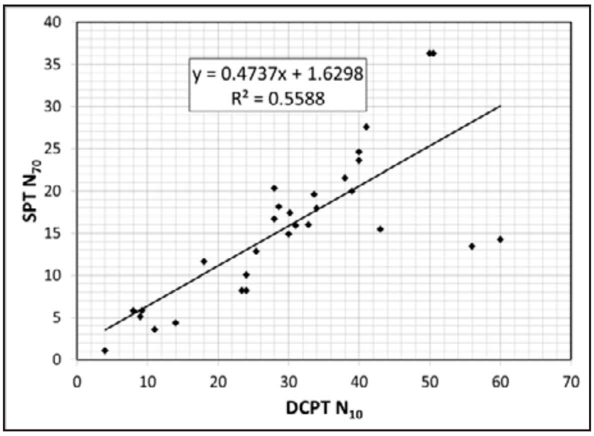

Fig. 6. Relationship between SPT N_{70} and DCPT-N_{10}.

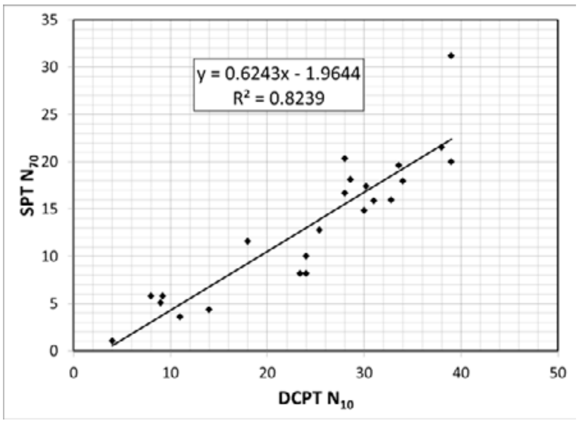

Fig. 7. Relationship between SPT N_{70} and DCPT-N_{10} < 40.

A careful look at the plot in **Figure 6** also indicates a higher degree of scatter after an N_{10} > 40 blows. Hence values for N_{10} greater than 40 were filtered out of the results and the remaining data plotted as shown in **Figure 7**. The regression analysis gave the expression $N_{70} = 0.6243N_{10} + 1.9644$ with an associated coefficient of determination, $R^2 = 0.8239$. The coefficient of determination indicates that there is a strong correlation between N_{70} and N_{10} for N_{10} values less than 40 blows.

3.6 Comparing obtained correlations with that in literature

3.6.1 Correlation for allowable bearing capacity, q_a and N_{10} proposed by Sanglerat

Sanglerat (1972) proposed an expression for allowable bearing capacity, q_{all}, for shallow foundations based on the dynamic point resistance of the DCPT equipment by the relation;

$q_{all} = \frac{q_d}{20}$, where q_d is the dynamic point resistance (Sanglerat, 1972).

This expression is valid for the DIN 4094 equipment with a 90° cone for which the side friction of the rods can be ignored. The test standard, BS EN ISO 22476-2:2005/A1:2011, gives the equipment requirements for execution of and reporting on dynamic probing, including probing conducted with the Dynamic Probing Light, DPL. The procedures given in the standard may be used in determining the strength and deformation of cohesion less soils and possibly fine-grained soils through appropriate correlations.

The bearing capacity is obtained from the dynamic point resistance, q_d , given by;

$$q_d = \left(\frac{m}{m + m'}\right) r_d \qquad \text{(BS EN ISO 22476-2:2005)}$$

Where r_d = unit point resistance given by $\frac{E}{A \times e}$

E is energy of the falling hammer given by mgh
m is the mass of falling hammer in kg.
m' is the total mass of the extension rods, the anvil and the guide rods at the length under consideration in kg.
g is the acceleration due to gravity in m/s^2.
h is the falling height of the hammer in m.
A is the area at the base of the cone in m^2 (0.001m^2)
E is average penetration in m per blow $(0.1/N_{10})$

N_{10} is the number of blows per 10cm.

For the 10kg hammer, 0.5m fall height and 90° cone DCP equipment, assuming the energy from the falling hammer is equal to the theoretical energy,
$q_{all} = 12.9N_{10}$

The correlation obtained in this study for all data, $q_a = 15.75N_{10} + 54.19$ compares well with the allowable bearing capacity expression from Sanglerat, $q_{all} = 12.9N_{10}$. Ampadu and Dzitse-Awuku (2009) also reported a correlation between allowable bearing capacity for a model footing and N_{10} as $q_{all} = 14.2N_{10} + 22.6$. This compares well with the correlation obtained in this study for all data, $q_a = 15.75N_{10} + 54.19$. It should be noted that the equipment used by Ampadu and Dzitse-Awuku was slightly different from that used for this study.

3.6.2 Correlation for SPT, N_{70} and DCPT, N_{10} compared with those in literature

The correlation obtained in this study for DCPT-N_{10} < 40, $N_{70} = 0.6243N_{10} + 1.9644$ compares well with that of Ibrahim and Nyaoro (2011) who obtained the correlation, $N = 0.514N_{10} + 2.122$ for clayey sand tested at 2 – 4 m depth. Ligwanda et al. (2015) reported a correlation of $N_{60} = 1.01N_{10} + 0.44$. It is believed that the seeming discrepancy between the correlation obtained in this study and that of Ligwanda et al. is that the latter reported on N_{60} while this study reported on N_{70}.

4. Conclusions

This study has enabled the formulation of a correlation between allowable bearing capacity and DCPT-N values as well as a correlation between SPT-N and DCPT-N values. It has been shown that a strong correlation exists between the parameters considered. It was also observed that the correlations were more pronounced for DCPT-N values less than 40. These correlations will be of benefit for site investigations where the number of boreholes drilled to obtain SPT-N values can be reduced and supplemented with DCP tests thus saving cost. For sites where budget is limited and the foundation is expected to be shallow, the DCP test can provide basic information for foundation design.

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Lowland Technology International journal is the official journal of the International Association of Lowland Technology, IALT. The journal aims to provide the media through which engineers and scientists engaged in the research of lowland technology could exchange technical and professional knowledge. The journal publishes high-quality original work on research papers and technical notes/reports in English, which assists in bringing new knowledge and insights to practitioners and decision makers concerning all aspects of lowland technology, particularly, the aspects of **geotechnical and geo-environmental science and engineering, water and environmental science and engineering, urban/city planning and development, coastal science and engineering.** All submissions are peer reviewed.

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The issues of LTI journal has been increased from the Fiscal Year 2015 (Volume 17)

Since the number of submittal papers are increasing, the IALT council meeting, editorial board and staffs of Institute of Lowland and Marine Research (ILMR) have officially decided and announced to increase the number of issues from 2 to 4 from the fiscal year (FY 2015).

The first issue was published in June, 2015. The next issues were published in September 2015, December 2015 and March 2016 respectively of Volume 17.

Announcement for the next issues

The Lowland Technology International (LTI) journal is publishing the **Special Issue on: Kumamoto Earthquake and Disasters** in Volume 19, Issue Numbers 3 and 4 on December, 2017 and March, 2018. The special issue will be peer reviewed expanded form of the Joint Japan-US International Workshop on the 2016 Kumamoto Earthquake held at Kyushu University, Fukuoka, on March 06, 2017. Further, the LTI journal will tentatively publish the Volume 20 (1) and 20 (2) on September and December, 2018 incorporating the peer reviewed Journal papers from **International Convention on Civil Engineering (ICCE 2017)** which was held in Suranaree, Thailand.

Guidelines of LTI Journal for authors

1. Journal aims and scopes

Lowland Technology International (LTI) journal is the official journal of the International Association of Lowland Technology (IALT). The journal aims to provide the media through which engineers and scientists engaged in the research of lowland technology could exchange technical and professional knowledge. The journal publish high-quality original work on research papers and technical notes/reports in English, which assists in bringing new knowledge and insights to practitioners and decision makers concerning all aspects of lowland technology, particularly, the aspects of geotechnical engineering, water management, environment, urban planning and development. English is the language of the journal. All submissions are peer reviewed. Most are substantially revised and improved before they are accepted and published.

2. Manuscript submission

Prior to acceptance four copies of the manuscript and an electronic copy (MS-Word format) should be submitted to one of the three Editors in Chief and to the email address: journal_of_LTI@ilt.saga-u.ac.jp. It should be accompanied by a cover letter mentioning the title of the paper and the name of all the author(s) and their affiliation(s) together with mailing address, telephone, fax (with country and area code) and e-mail address. In the case of co-authors, it should be clearly indicated which author is to receive correspondence and proofs for correction. Authors can also submitted their manuscript through the online submission system from the website.

Submission of a manuscript implies that (1) the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis, or modified version of proceeding), that (2) it is not being submitted to any other journal, that (3) its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, (4) if accepted, it will not be republished elsewhere, in English or in any other languages without the written consent of the IALT publisher. In most cases, a written report with at least two referees' reports will be sent to the author within six months from the date the paper is received. If more time is needed for review, the author will be sent an up-date on progress at the end of the sixth month after submission.

Upon acceptance, all authors must sign the 'Transfer of Copyright' agreement before the manuscript can be published. Authors are responsible for obtaining from the copyright holder permission to reproduce any figures for which copyright exists. Prior to publication, one set of page proofs will be sent to the corresponding author, to be checked for typesetting/editing. No changes in, or additions to, the accepted manuscript will be allowed at this stage. The IALT publisher reserves the right to proceed with publication if corrections are not communicated. Return corrections within 3 days of receipt of the proofs. Should there be no corrections, please confirm this.

3. Manuscript style

Prior to acceptance, the manuscripts should be typed double-spaced 10-point Arial font on one side of the page only with wide (3 cm) margins, in A4 paper size. Present figures and tables on separate pages at the end of the manuscript. The position of tables in the manuscript should be indicated. Number all pages consecutively at the bottom right corner.

Upon the acceptance, the author(s) should reformat the manuscript into single-space double columns 9 point Arial font as current journal layout and convention. MS-Word template file is available at the LTI website for the formatting.

The whole texts that appear in the paper should be consistently Arial font, except symbols used in equations. All paragraphs are 5 mm indented and 13 pt line spacing for the first line and the line spacing is set exactly at 13 pt.

Normally, a published research paper should not exceed 14 pages and a published technical note should not exceed 8 pages, including reference, figures and tables. Moreover, page numbers should be in the order of even page numbers viz. 4, 6, 8, 10, 12, or 14 pages for the research paper and 4, 6, or 8 pages for the technical note. The author(s) should consult the Editor-in-Chief for the review article before submitting to the journal.The following are general information regarding manuscript style:

Article type: Mention the type of the article at the top of the page after leaving 1 line blank space from the top of the page (Research Paper/Technical Note/Review Article), in 10.5 point font.

Paper's title: Provide concise and informative titles since they are used in information-retrieval systems. Avoid abbreviations and formula where possible. Title must be left aligned at the top of the first page, leaving 1 line blank space below the article type (Research Paper/Technical Note/Review Article), in 16 point Arial font and bold it. Leave 1 line blank space after the title.

Author names and affiliations: The author(s) first name and middle name in abbreviation followed by surname(s) should appear left-aligned below the title. Indicate all affiliations as a footnote to that author's name. The address at which the author(s) actually did the work must be retained as the main affiliation address. Superscript Arabic numerals are used for such footnotes. Use 8 point font for the footnotes indented with 2 mm hanging.

Abstract: A concise abstract is required (maximum length 200 words). The abstract should state briefly the purpose of the research, the essential new information, the principal results and major conclusions. The abstract must be able to stand-alone and references to the manuscript should therefore be avoided. Use 9 point font and leave 2-line spacings after the underbar whose left bottom side of the abstract is represented by key words.

Keywords. On the left side of the abstract, below the article history separated with a line, provide minimum 3 and do not exceed more than 6 keywords. These keywords will be used for indexing purposes. Use 9 point font starting with initial first capital letter as shown in the template of the LTI format.

Headings. Use at most three levels of headings that correspond to chapters, sections and subsections. The first level headings for chapter titles should be in 9 point bold Arial font. Leave two-blank lines and one-blank line before and after the first level headings, respectively.

The second level heading: It should be in 9 point italic font. Leave one blank line both before and after the heading.

The third level heading: It should be in 9 point Italic font. Insert one blank line before and no blank line after the headings. The further lower level headings should be avoided. It has a hanging indent of 12.7 mm.

Paragraphs: Each new paragraph must be indented. The indent should be 5 mm. All text should be left and right justified. No underlines or footnotes. The text should be in clear, concise, and proper English, type in 9 point Arial font or equivalent for final draft and 10 point font for the first submission.

Equations and symbols: Equations and symbols should be typed using the equation editor and numbered in sequence. The equation number should be enclosed in parentheses and right justified. Symbols and notations should be defined when they first appear. Use one blank line before and after the equation.

Figures and tables: In general, figures or tables should be vertically aligned ***at the top or bottom relative to margin***, on the same page where they are referred for the first time. Do not place them altogether at the end of the manuscript. They should be numbered consecutively, and should have informative titles which make the data in the table understandable without reference to the text. Figure and table caption uses the 8 point font as the text, left-aligned or left-right justified. In the case of figures and tables occupied whole two columns, texts should be placed at the center if the text is short, otherwise left-aligned or left-right justified, leaving no line spacing above and below the table or figure caption.

Figures or tables should be sized the whole width of a column, as shown in **Table 1** or **Fig. 1** (**Figs. 1, 2** and **3)** in the present example, or the whole width over two columns. Do not place any text besides the figures or tables. If a figure number starts from the beginning of the line in the text, full form should be given such as **"Figure 1"** and/or **"Figures 2, 3, and 4"**. Please *avoid vertical border lines in Table if possible*.

Quality of figures and photos: Figures and photos should be computer-generated, not simply scanned in. Aside from the inserted to the manuscript, they should also be sent in the following file formats only: EPS (for vector graphics) and TIFF and BMP (for raster graphics) with resolution must be no less than 600 dpi (300 dpi for grey scale). All figures and illustrations should be professionally drawn the same as the final printed version (without enlargement or reduction). Color printing can be undertaken but is expensive, and authors will be charged with a cost. Please do not send figures in any other format (JPG, GIF, Word, Excel, etc). If the figure is not available in any of these formats, please supply the original photographs for reproduction, printed on glossy paper, very sharp and with good contrast (not a photocopy) of the figure for us to scan.

Acknowledgements: If it exists, it should appear at the end of the text, before the references, otherwise eliminate it.

References: Ensure that every reference cited in the text is also present in the reference list (and vice versa). The citation should appear in the text as the author(s) last name(s) followed by the year of publication in parentheses, e.g. (Manandhar et al., 2014; Lognatham et al., 1993; Ankum et al., 1988;), (Preissmann, 1961), (Manandhar and Yasufuku, 2013; Madhav and Miura, 1994; Nishida and Kubo, 1991; Perkins and Gunarartnam, 1970), the Ministry of the Environment (2010), Taylor (2003), Hino et al. (2012), Moustakas (1990), etc.

A list of reference should be given at the end of the text in alphabetical order of first author's last names and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters "a", "b", "c", etc., placed after the year of publication. Titles of papers, books, reports, etc. should follow the regular font and should not capitalize after the first initial word.

Unpublished results and personal communications should be indicated at the end of the reference in the bracket using the word “unpublished”. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Citing and listing of web references. As a minimum, the full URL should be given. Any further information, if known (author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

For anonymous reports and standards, alphabetize by the issuing institution.

The reference list must be summarized at the end of the main text. Make sure reference information is complete and accurate in the following order: last names and initials of all authors; year of publication; title of paper, report, or book chapter; title of book or periodical; volume and issue numbers; name and location of publisher (for books), name and location of publisher or sponsor (for proceedings); and inclusive page numbers. The references should be in 5 mm hanging indentation. Following examples will provide you the details of usage of references which should be enlisted at the references section in alphabetical and chronological orders. Please follow the references lists at the end of this section.

Journal papers

Manandhar, S. and Yasufuku, N., 2013. Vertical bearing capacity of tapered piles in sands using cavity expansion theory. Soils and Foundations, **53** (6): 853-867.

Hino, T., Jia, R., Sueyoshi, S. and Harianto, T., 2012. Effect of environment change on the strength of cement/lime treated clays. Frontiers of Structural and Civil Engineering, Springer, **6** (2): 123-165.

Book and monograph

Taylor, H.F.W., 2003. Cement chemistry. Thomas Telford Publishing, Thomas Telford Services Ltd., 1 Heron Quay, London E144JD, Second Eds.: pp 465.

Unpublished papers and theses

Moustakas, N., 1990. Relationship of morphological and physicochemical properties of vertisols under Greek climate conditions. Ph.D. Thesis, Agricultural Univ. Athens, Greek (unpublished).

Edited volume papers

Madhav M.R. and Miura N., 1994. Lowlands, development and management. Introduction In: Miura, N., Madahav, M.R. and Koga, K. (Editors), A.A. Balkema, Netherlands and U.S.A.: 31-37.

Symposium proceedings papers

Manandhar, S., Suetsugu, D., Hara, and S., Hayashi, S., 2014. Performance of waste quarry by-products as a supplementary recycled subgrade material. Proc. 9th International Symposium on Lowland Technology (ISLT 2014), September 29-October 1, 2014, Saga Univ., Saga, Japan: 271-278.

Websites

The Ministry of the Environment, Japan (2010). Japan’s National Greenhouse Gas Emissions, FY-2010, http://www.nies.go.jp/whatsnew/2011/20111213/20111213-e.html, 2011.

Symbols and abbreviations: Symbols and abbreviations should be kept at the last section after references if have any. The font should be Arial 8 point for descriptions of parameters used inside the text in the form of equation or by any other means. Leave 1 line space and do not indent.

A, B	Constants of integration
b	Outer radius of the plastic zone during loading
c	Internal cohesion of the ground
D	Depth of footing
d	Pile tip diameter
F	Skin friction of pile
f_s	Unit skin friction
F_c	Percent fines
I_D	Relative density of soil
I_R	Function of relative density
I_r	Rigidity index
I_{rr}	Reduced rigidity index
N	Standard penetration resistance value
n	Integer from zero to infinity
P_B	Total end bearing resistance
P_S	Total skin friction
P_T	Total bearing capacity
p_0	Initial cavity pressure
p'	Mean effective stress
σ_r	Radial stress
τ_0	Initial yield stress of interface