A SAND–SPREADER USED FOR THE RECONSTITUTION OF GRANULAR SOIL MODELS

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ABSTRACT
If one is to deal with experimental analysis of soil–foundation interactions, the first problem to consider is that of reconstituting soil models.
This paper presents the results obtained by using a sand–spreader which was designed and built by the author for this purpose. The paper also looks at design criteria and the calibration of the assembly. The dimensions of the sand sample, which is sprinkled into and contained inside an iron caisson, are 1.60 meters in width, 2.50 meters in length, and 1.70 meters in height, giving a total volume of 6.80 cubic meters.
The preparation of sand beds can be accomplished with relative densities ranging from 25% to 70% and can be repeated within an error margin of ±1%; the relative density inside the bed itself is fairly constant, having a mean standard deviation equal to 1.47%.

Key words: density, model test, sand, test equipment, (IGC: D0/D2/D3)

INTRODUCTION
From the geotechnical point of view, the reproduction of soil bed samples in the laboratory has turned out to be very useful for experimentation. Soil modelling samples can be used to investigate practical applications such as determining the most suitable means of calibrating field instruments [Bellotti, 1979–Baldi, 1981], as well as to investigate the behaviour of strip foundations (Uzuner, 1975) and deep foundations (Chon, 1977), to study soil dynamics (Schmertmann, 1978), or to test numerical models (Passalacqua, 1986).

The essential features to consider are the exact estimation of relative density values and their repetition accuracy.

SAND–SPREADER ASSEMBLY
Seed et al. (1975) carried out a comprehensive investigation of the effects of the preparation methods of soil samples on cyclic tests on sand.
They reached the conclusion that pouring techniques give a good degree of accuracy in reproducing the sample, and that if certain specified conditions are maintained a good

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fabric–skeleton can be obtained. In order to meet the need of casting a large volume sample, the author designed and built a special apparatus which is herein referred to as a Sand–Spreader Assembly (SSA).

The SSA consists of a hopper (see part "A" in Fig. 1) which lets the sand pass through a calibrated opening (B) at the lower end. The hopper rises (by means of the electric motor “C”) when a touch sensor, fitted to the hopper for this purpose, comes into contact with the sand bed. The touch sensor is comprised of a thin steel wire (10 cm. long) extending down from a copper circlet; when the lower point of the wire hits the sand surface, it bends and consequently closes the contact against the circlet, controlling the electric motor (C). The touch sensor is connected to the hopper by means of a support rod which is designed to adjust the height of fall of the sand and to keep it constant during the filling process.

The hopper is attached to a railed frame (D) and is driven back and forth (by electric motor “E”) over the container (F) while the sand is sprinkled in. At the top of the assembly is a feeder (G) which provides a continuous flow of sand; infra-red emitters and receivers, set along two horizontal lines (levels) inside the hopper, control the shutters of the feeder to regulate the appropriate sand volume (controlled between the fixed minimum and maximum levels) as the sand is being deposited. Position sensors, set along the rail, activate the proper shutter.

When necessary, a vertical bucket elevator supplies sand from the storage silo’s opening up to the feeder.

In order to avoid any undesirable potential energy influences caused by the continuous variation of sand volume inside the hopper, two laminae sloped at an angle of ±45 degrees were inserted one under the other to intersect the sand flow just above the bottom opening.

All couplings in the SSA were shielded in order to prevent excessive wear due to the dusty environment created by the pouring of the sand. Similar precautions led to the choice of groove wheels and steel–wire cables for tractions, in preference to chains and sprockets.

Electronic circuits control the SSA to ensure a constant height of fall during sand sprinkling, to prevent the hopper from becoming empty and to reverse the frame’s horizontal movement once it reaches the outer edges of the container.

To empty the apparatus after use is a simple process; it is only necessary to turn the upper opening of the bucket–elevator toward the silo. The sand comes out from the sluice gate (see “H” in Fig. 1) and is immediately returned to storage.

The SSA has proved to be a reliable machine, and it requires only one person to operate it.

By choosing the appropriate settings on the sand release opening width, the drop height controller (i.e. the touch sensor described above) and the translation velocity, the SSA can produce a sand bed characterized by an uniform relative density anywhere. The value of relative density, influenced by the above
three settings, lies within a range spanning from 25% to 70%.

CALIBRATION TESTS

By establishing three parameters, with adjustments permitted, preliminary analyses were carried out in order to check the spreader's performance.

The results obtained can be shown by plotting $D_r$ against the height-of-fall $H$ (Fig. 2), against the opening width $O_w$ (Fig. 3) and against the translation velocity $T_v$ (Fig. 4).

The sand used was a medium-fine laboratory sand (uniformity coefficient $C_u=1.67$—specific gravity of sand particles $G_s=2.63$ gr/cc—$D_{50}=0.26$ mm).

In each test for each of the separate groups, the two remaining parameters were kept constant in order to investigate the effect of one single parameter on $D_r$.

From a qualitative point of view, the height-of-fall influence on the resulting relative density of the sample, reaching an asymptotic behavior in the proximity of 140–150 cm., shows a trend similar to a theoretical analysis of terminal velocity (Vaid, 1984). It was observed that increasing the opening width leads to lower relative density values, thus showing that interference phenomena among sand grains during free-falling and at the time of impact produces a loss of kinetic energy.

The effect of translation velocity leads to the preceding conclusion. In fact, with increased velocities, the resulting direction vector of a single grain’s velocity is shifted from the vertical; the outcome is that the sheet of free-falling sand reaches the surface spreading in the same direction as translation and results in smaller mass at the time of impact, with less granular interference.

It can be stated that denser beds are obtained by:

- increasing height-of-fall
- reducing opening width
- increasing translation velocity

Further experiments led to the calibration of the SSA using a considerably slower translation velocity.

In fact, operating at higher speeds, it follows that:

- after every reversal stop the uniformly ac-
celerated motion generates longer zones characterized by variable relative density close to the caisson’s edges
—there is a higher degree of stress on the SSA’s joints and structure, thus producing more frequent fatigue failures
—the sand grains’ trajectories have a longer horizontal component: consequently the free-falling sand strikes structural models (e.g., model piles) set over the sand bed surface and bounces randomly, causing unacceptable disturbance in the soil-foundation interaction zone itself.

—the sheet of sand is very likely to be randomly affected by air motion during free-fall, producing alterations inside the sand bed (especially operating at high values of height-of-fall).

For these reasons it was decided to carry out the complete calibration running the SSA at a translation velocity of 4 cm/sec. The soil used in this final phase is a natural sand which comes from the river Ticino; it is a uniform (Cu=2.1) coarse sand (D50=1.18 mm) with a specific gravity of sand particles Gs=2.64 g/cc, and its physical characteristics are as shown in Fig. 5; the reported values for \( \gamma_{\text{max}} \), \( \gamma_{\text{min}} \) have been determined by minimum and maximum void ratio measurements from laboratory samples at the densest and loosest states according to Terzaghi (1967). Ticino sand has already been thoroughly classified and tested both for strength and for deformability parameters by Baldi et al. [Feb. 1986~Mar. 1986]; thus it can be adopted as a reference sand.

A total of 40 tests were carried out combining \( O_w \) and \( H \) parameters; each time the sand was deposited, several values of relative density were experimentally evaluated by the following technique:

1. a steel cylinder (100 mm high, 152 mm inner diameter) with a sharp lower edge was pushed into the sand bed starting from the free surface, by means of a very slow-running electric motor in order to minimize disturbance effects.
2. using a small pipe connected to a vacuum pump, the first stratum of sand (about 20 mm high) was extracted from the cylinder for the purpose of leveling the inner sand surface.
3. when the measure of the inner sand surface height from the upper edge of the cylinder was taken, a second stratum (about 50 mm high) of sand was collected into a glass container inserted along the vacuum line.
4. by weighing the collected sand and measuring the inner actual sand level,
<table>
<thead>
<tr>
<th>Opening Width [mm]</th>
<th>Height of Fall [cm]</th>
<th>110</th>
<th>90</th>
<th>60</th>
<th>40</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td>71.5 (0.50)</td>
<td>71.1 (1.81)</td>
<td>71.5 (2.35)</td>
<td>72.0 (2.00)</td>
<td>70.0 (2.16)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>71.3 (2.43)</td>
<td>69.5 (1.85)</td>
<td>66.7 (1.05)</td>
<td>64.4 (1.21)</td>
<td>58.3 (0.90)</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>70.2 (1.85)</td>
<td>66.5 (0.15)</td>
<td>52.3 (0.46)</td>
<td>51.9 (1.60)</td>
<td>43.6 (0.74)</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>64.6 (2.14)</td>
<td>67.2 (2.78)</td>
<td>53.1 (2.46)</td>
<td>47.9 (1.08)</td>
<td>34.3 (1.70)</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>58.3 (0.94)</td>
<td>52.4 (2.45)</td>
<td>46.8 (1.25)</td>
<td>38.6 (1.01)</td>
<td>31.1 (2.10)</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>51.3 (1.16)</td>
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<td>38.5 (0.75)</td>
<td>35.4 (0.25)</td>
<td>27.0 (0.94)</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>42.2 (1.25)</td>
<td>37.2 (0.97)</td>
<td>30.5 (0.71)</td>
<td>31.5 (2.55)</td>
<td>25.3 (1.65)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>33.3 (2.15)</td>
<td>30.5 (2.00)</td>
<td>25.7 (0.15)</td>
<td>26.7 (0.83)</td>
<td>23.8 (2.11)</td>
</tr>
</tbody>
</table>

Fig. 6. Calibration graph for ticino sand

By means of a multiple non-linear regression analysis on such data, it was possible to obtain $D_r$ as a function of $H$ and $O_w$. The interpolated relationship, with a multiple correlation coefficient equal to 0.9951 and a standard error $S=1.60$ is:

$$D_r=169.19-1.369\cdot H+2.257\cdot 10^{-5}\cdot H^2$$

$$-43.97\cdot O_w+0.655\cdot O_w\cdot H$$

$$-1.061\cdot 10^{-8}\cdot O_w\cdot H^2+4.024\cdot O_w^2$$

$$-6.477\cdot 10^{-9}\cdot O_w^3\cdot H+4.425\cdot 10^{-3}\cdot O_w^2\cdot H^2$$

$$-0.107\cdot O_w^8+1.252\cdot 10^{-3}\cdot O_w^3\cdot H$$

$$+4.988\cdot 10^{-6}\cdot O_w^3\cdot H^2$$

Back-tests confirmed that by computing $D_r$ using Eq. (3), the maximum differences from measured $D_r$ values lie within a range equal to:

$$\pm 3\% = \pm 4.8\%$$

This is considered to be a reasonable error margin.

It is quite a time-consuming process to choose $O_w$ and $H$ adjustments by solving eq. (3) at the required $D_r$ value. Consequently, for practical laboratory use, the surface representing the relationship (3) was plotted using contour lines as shown in Fig. 6, where each line shows the combinations of $O_w$ and $H$ required to accomplish a sand bed at a specific relative density.

The smoothness and effectiveness of function (3) make it possible to carry out reliable linear interpolations on the calibration graph in Fig. 6.

**CONCLUSIONS**

From a theoretical point of view, the SSA could be used to reproduce much larger sand beds, bearing in mind that any mechanical problem that might arise in relation to size would have to be dealt with. It should be pointed out that variations in $D_r$ along the depth can be achieved in order to simulate a real site; what is more, the sand gradation can be changed in order to reproduce stratification in the bed itself.

Finally, it can be stated that given the three
adjusting parameters $T_v$, $O_w$ and $H$, the SSA's versatility allows the use of a wide range of sands.

The SSA described in this paper cannot be claimed to be a unique means of preparing sand beds, but it, or any analogous equivalent, is certainly an essential item of equipment for experimental Soil Mechanics and Foundation Engineering modelling in the laboratory.

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REFERENCES


