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Subject: A Note Comparing Patented Porous Displacement Piles versus Stone Columns, Rammed Aggregate Piers, Concrete and Steel piles and Drilled Shafts

I have prepared a note comparing Patented Porous Displacement Piles versus Stone Columns, Rammed Aggregate Piers, Concrete and Steel Piles and Drilled Shafts. Please review the note. I request my LINKEDIN friends to please include patented porous displacement piles as a viable ground modification technique for deep densification of soils and for replacement of concrete and steel piles and drilled shafts to save significantly in the costs of foundations for state or federally funded projects or private projects by developers and design-build projects. My US patent No. US 10,844,568 can be downloaded in PDF from the IP center of my website [www.sar6inc.com](http://www.sar6inc.com/), for details about the porous displacement piles.

    Stone Columns are installed using a high amplitude, very heavy vibratory probe either using bottom feed for the stones, without drilling a hole, or excavating a hole by high velocity jets of water and pouring stones from top of hole, during excavation or after excavating the hole, and then afterwards using vibratory probe to densify stone fill and adjoining in-situ soil. Stone Columns by bottom feed method without drilling a hole provide much higher quality stone columns and densifies the in-situ sandy soil significantly but does not densify in-situ clayey and silty soils. The installation of stone columns with bottom feed is very slow. Therefore, ground modification contractors prefer the drilling method, in which case, pre-drilling the hole first reduces the strength of the in-situ soil. Afterwards, using very high amplitude vibration and feeding stones from the top of the hole, in-situ sandy soils are densified, but this process also does not densify in-situ silty and clayey soils or rather reduces their strength by remolding clays by water and vibration. However, this technique provides a sort of reinforcement to share and support the foundation loads.

     While installing stone columns in cohesive soils comprising either clayey soils, or silty soils, or fine sand with more than 35 percent fines, vibrating the stones for achieving compaction, the fine particles of the in-situ soils flow into large voids of stone matrix of stone columns, making stone mix like a silty or clayey stone mix. Therefore, the stone initially a porous material becomes semi-impervious to impervious material. The excess pore-water pressures developed if any, cannot dissipate through the stone columns consisting of silty or clayey stone mix.  If no dissipation of excess pore-water pressures occurs, then no densification of clays, silts or sand with more than 35% fines shall occur, because excess pore-water did not squeeze out its matrix.

    The open aggregates or stones are used in stone columns or rammed aggregate piers. In all cases of rammed aggregate piers, first a hole is drilled into the ground to the design depth and then aggregate is poured from the top of the hole, in layers and each layer of aggregate is rammed by drops of a heavy weight. In the process of repeated ramming of the aggregates, at a

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very fast rate, the surrounding in-situ soil consisting of either the wet clayey soils, the silty soils or the sand with more than 35% fines, flows in the open matrix of the aggregate, making it as a clayey and silty aggregate, and thus, changing it from a porous material to the semi-impervious or impervious material.  The excess pore-water pressures, generated if any, during installation of the rammed aggregate piers cannot be dissipated through semi-impervious or impervious rammed aggregate piers neither during the installation nor after installation or when the load is applied by the structure constructed over it. If no dissipation of excess pore-water pressures occurs, then no densification of clays, silts or sand with more than 35% fines shall occur, because pore-water did not squeeze out its matrix.

    The best way to verify that the very soft, soft, medium stiff or very stiff in-situ clayey, silty soils have been densified or not densified, is to do SPT, CPT or PMT, in the in-situ soil around the stone columns or rammed aggregate piers, first before and then after the installation of stone column or rammed aggregate piers. One will find that the Cone tip resistance, SPT blow count number and moisture content of in-situ cohesive soils around stone columns and rammed aggregate Piers is the same whether before or after their installations.  Stone columns, vibro-floatation, vibro-replacement, and rammed aggregate piers will densify the in-situ sandy soils, but these methods are not as efficient as the method of porous displacement piles. Porous displacement piles can densify in-situ sandy soils from very loose, loose, medium dense and dense sands to very dense sand by selecting suitable grid spacing in a grid pattern. The sandy soils are pre-compacted in layers in a pipe section with removable end plate above the ground to the selected relative density generally greater than 70 percent to up to about 95 percent and then driving the said pile into ground to a design depth. After which the pipe section is pulled out of ground leaving the pre-compacted sand column in the ground. In this process, no soil is drilled out and on the contrary, sandy soil to densify in-situ soil is inserted into ground without creating heave of the ground at the ground surface.

Similarly, porous displacement piles can also densify cohesive soils consisting very soft, soft, medium stiff, stiff, very stiff clayey or silty soils or sand with more than 35% fines to very stiff to hard cohesive soils, by selecting a suitable grid spacing in a grid pattern and selecting relative density of pre-compacted sandy columns generally greater than 70 percent to up to 95 percent. The gradation of pre-compacted sandy column’s sandy soil is selected based on Terzaghi’s filter design criteria to provide free-flow of pressurized pore-water and to dissipate excess pore-water pressure through the porous displacement piles, while preventing migration of fine particles of the in-situ soil.

   Because of the very high load bearing capacity of the porous displacement piles, the porous displacement piles can effectively eliminate or replace steel or concrete piles and drilled shafts, making huge savings in cost of foundation and of a project by about up to 40 to more than 50%. Because the clays are prestressed after dissipation of excess pore-water pressures, the possibility of any settlement or excess pore-water pressures to occur under the loaded footing is very small, and if any develop shall quickly dissipate, during construction and all before the completion of construction. In such cases, there is no possibility of down-drag to occur, when porous displacement piles are used to densify in-situ soils.

   Very soft clays have undrained shear strength of equal or less than 0.25 tons per sq ft and cannot support spread footings. If it is specified that very soft to soft clays be densified to either medium-stiff clay with undrained strength greater than 0.5 to up to 1.0 tons per sq ft or greater, then spacing of the porous displacement piles and the relative density of the porous displacement piles (PDP), containing sandy soils, shall be appropriated selected/designed to densify and achieve undrained shear strength of in-situ clays to either greater than 0.5 to up to or greater than 1.0 tons per sq ft.

Soft to medium stiff clays have undrained shear strength of 0.5 to 1.0 tons per sq ft and it can provide allowable bearing capacity only of either 1.0 or 2.0 tons per square only but with significant settlement. If it is specified that such cohesive soils be densified to undrained strength of 2 tons per sq ft or greater, then the grid spacing of the porous displacement piles and the relative density of the porous displacement piles (PDP), containing sandy soils, shall be appropriately selected/designed to densify and achieve undrained shear strength of in-situ clays to 2 tons per sq ft or greater than 2 tons per sq ft. Because porous displacement piles prestress clays, the settlement of densified clays under load shall be very small. Table 1 shows the initial undrained strength, initial allowable capacity and achieved undrained shear strength and achieved allowable bearing capacity with insignificant settlement under load, after densification by the porous displacement piles.

Table 1: Improvement of consistency, undrained shear strength, and bearing capacity of Clays.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Consistency of Clays | Initial undrained shear strength (Us) of in-situ clays to be densified (tons/sq ft) | Target Consistency of densified in-situ clay after densification by PDP | Target undrained shear strength of in-situ clays after densification by PDP (tons/sq ft) | Allowable Bearing Capacity(qa) of un-densified in-situ clays without PDP installation (tons/sq ft) | Allowable Bearing Capacity of densified in-situ clays with PDP (tons/sq ft) |
| Very Soft | Su<=0.25 | Medium stiff | Su = 0.5 | qa =0.45 | qa >1.5 |
| Very Soft | Su=>0.25 | Medium stiff to stiff | Su = 1.0 | qa => 0.45 | qa >3.0 |
| Soft | Su =0.5 | Medium stiff to stiff | Su => 1.5 | qa = 0.95 | qa >3.0 |
| Medium Stiff | Su =1.0 | Stiff to very stiff | Su = 2.0 | qa =1.9 | qa >5.0 |
| Stiff | Su = 1.5 | Very Stiff to hard | Su = 3.0 | qa = 2.8 | qa >7.0 |
| Stiff | Su = 2.0 | Very stiff to hard | Su = 4.0 | qa = 3.8 | qa >9.0 |
| Very stiff | Su = 2 to 3 tsf | Hard | Su = 4 to 5 tsf | qa = 3.8-5.7 | Qa>7.6-9.5 |

  \*Using Ng = 5.7 for square footing, and Factor of Safety = 3.0, Allowable Bearing Capacity = Ng \*Su/FS.

   Table 2 shows the improvement of relative density and allowable bearing capacity of sandy soils after installation of the porous displacement piles.

Table 2: Improvement of relative density, angle of friction angle and bearing capacity of sands.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Classification of sandy soils | Initial friction angle (degrees)/relative density | Target classification of sandy soils after densification by PDP | Target friction angle/relative density after densification by PDP | Allowable Bearing Capacity(qa) of un-densified in-situ sandy soils without PDP installation (tons/sq ft) | Allowable Bearing Capacity of densified in-situ sandy soils with PDP (tons/sq ft) |
| Very Loose | Less than 28 | Medium dense | 32/55% | qa = 0.5 | qa >1.5 |
| Very Loose | Less than 28 | Medium Dense | 34/65% | qa = 0.45 | qa >2.0 |
| Loose | Less than 31 | Dense | 34/65% | qa = 1 | qa >3.0 |
| Medium dense | 32 to 33 | Dense | 36/75% | qa = 1.5 | qa >5.0 |
| Medium Dense | 33 to 35 | Dense | 38/80% | qa = 2 | qa >7.0 |
| Dense | 36 to 37 | Very Dense | 40/85% | qa = 3 | qa >9.0 |
| Dense | 38 | Very Dense | 45/95% | qa = 4 | qa >9.0 |

    The total settlement after deep densification by porous displacement piles (PDP) shall be about less than ¼” to ½”.

    It is well known that the cost of sandy soil is much less than stone or aggregate. For installation of porous displacement, no special equipment like that required for Stone columns, vibro-floatation, vibro-replacement, and rammed aggregate piers, is required. Because the porous displacement piles densify all types of in-situ soils, wider grid spacing can be used compared to those required for Stone columns, vibro-floatation, vibro-replacement, and rammed aggregate piers. The compressive strength and load carrying capacity of the porous displacement piles is much higher than those of Stone columns, vibro-floatation, vibro-replacement, and rammed aggregate piers, because densified in-situ soils surround the porous displacement piles after their installation, while the un-densified in-situ cohesive soils remain surrounded around the stone columns and rammed aggregate piers.  The cost of the porous displacement shall be much less than the costs of the stone columns, vibro-floatation, vibro-replacement, and rammed aggregate piers.

    When subsurface soils consist of several layers of sandy soil layers and also clayey soil layers to deep depths the porous displacement shall densify all these types of layers to adequate density in order to provide very high allowable capacity based on the grid spacing and relative density of pre-compacted sandy soils of the porous displacement piles. **One will wonder then why we need these high-cost structural elements such as concrete and steel piles and drilled shafts, to support foundations of the structures, when porous displacement piles can reduce the cost of foundations by up to 40 to 50%, by replacing piles and drilled shafts for deep foundations in most subsurface soil conditions.**

OTHER INDUSTRIAL APPLICATIONS

    The porous displacement piles can also densify the tailings of a tailing reservoir if the tailings have reached such a stage that when piezocone penetration test soundings are performed in the tailings, some penetration pore-water pressures greater than the hydrostatic pressures are recorded in these soundings. Generally, tailings reach to this stage near the upstream of tailing dykes/dams. By installing porous displacement piles in tailings upstream of the tailing dykes/dams, the safety factor for the stability of tailings dams/dykes shall be increased significantly. Generally, tailing dams/dykes are standing at a factor of safety very close to one, but after installation of porous displacement piles in tailings upstream of dykes or in upstream face of tailings dams/dykes, the factor of safety will be significantly greater than one, and possibility of any failure of tailing dams/dykes will be forever eliminated.

    In several states, oil tanks of capacity of 1 million gallons or more have been/are being supported on reinforced concrete mat, few feet below ground surface. The diameter of such reinforced concrete mat is generally greater than 75 feet because the diameter of these oil tanks is generally 75 feet or greater. Because the stress distribution zone shall extend about 3.75 times the radius of the reinforced concrete mat, the total settlement is likely to be much greater than about 2”-5” or greater even in good subsurface soil conditions. The installation of the porous displacement piles prior to construction of the concrete mat in its footprint area shall reduce the total settlement by about quarter or more of the above values. Those oil tanks or any other structure when experiencing continued settlement or have already experienced significant settlement so as to damage or bend the external piping and their connections, the installation of porous displacement on a batter from outside the footprint of the concrete mat to penetrate in the ground under the mat shall densify the subsurface in-situ soils, and shall therefore, reduce settlement and raise the oil tanks and if any tilt on any side, then that also can be corrected.

    The concrete and steel piles decay due to chemical reactions from the waste or by corrosion, (as the case may be) but replacing them by the porous displacement piles, all these problems will automatically get solved.

     The installation technique is briefly explained as below:

1.      First fill sandy soil in layers and compact each layer to relative density equal or greater than 70% in a pipe pile with a removable end plate,

2.      the compacted sandy soil shall meet the filter design criteria to prevent migration of fine particles of the in-situ Clays, silts and very fine sands and also to provide free flow of pressurized pore-water through inside it,

3.      then drive a hollow pipe pile to a selected depth below the ground surface,

4.      drive the displacement pipe pile with removable end plate and filled with compacted sandy soil, as described-above through inside the hollow pipe pile,

5.      the displacement pipe pile is driven through inside the hollow pipe pile to limit any heave of the in-situ soil at the ground surface,

6.      after the said displacement pipe pile has been driven to a design depth, a heavy weight is inserted inside the displacement pipe pile on top of the compacted sandy soil,

7.      the displacement pipe pile with removable end plate is pulled out of the ground leaving the removable end plate at the bottom of the design depth and also leaving a column of compacted sandy soil in the ground from the ground surface to up to the design depth,

8.      the heavy weight inside the displacement pipe pile prevents any necking to form in the compacted column of sandy soil during withdrawal of the pipe pile and also pushes the sandy soil in the space previously occupied by the pipe pile,

9.      in this process the column of compacted sandy soil left in the ground behaves as a porous displacement pile, which develops very high excess pore-water pressures, in the range of 50 to 200 psi, which are dissipated by flow of pressurized pore-water through inside the porous displacement piles.

10.  This procedure is repeated to form columns of compacted sandy soil at adjoining locations in a designed grid pattern, to rapidly consolidate and densify under and around the footprint of footings.

Further details can be read by downloading the US patent No. 10844568 or my several other US patents from the IP center of my website, [www.sar6inc.com](http://www.sar6inc.com/).  Please call me or email me if you have any questions.

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