

SYSTEM FOR COMPACTING A SEDIMENT BED CONTAINING WATER AND METHOD THEREOF

CROSS-REFERENCE TO RELATED APPLICATION

- 5 **[0001]** This application claims the benefit of priority of US Provisional Application No. 61/974,622, filed 3 April 2014, the contents of which being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

- 10 **[0002]** The present invention generally relates to a system for compacting a sediment bed containing water and a method thereof, and more particularly, for compacting loose or soft sediment bed in-situ and underwater.

BACKGROUND

- 15 **[0003]** In-situ soil strengthening has conventionally been carried out in several ways, such as vacuum suction if the soil mass is above water, installing prefabricated vertical drains (PVD), or consolidation by using surcharge/overburden. If the bed is located tens of metres underwater, and in more favourable conditions, sand column may be applicable. An alternative would be to dredge the seabed to remove the soft soil, which may prove
20 costly and not viable most of the time. However, if the source material has been disturbed or loosened, and they are to be placed on the seabed underwater, the conventional methods described above would not be suitable. Except for good quality landfill material such as sand, depositing loose silty, muddy or lower quality sediment on the seabed would result in the formation of a layer of soft and unstable sediment deposit with very
25 high water content, and the deposit would be prone to be transported en mass by flow and waves. This layer would not be able to support overburden and heavy loads, such as construction machineries on it. In general, the soft layer would take many years to consolidate and many more years before the reclaimed area becomes useable.

- 30 **[0004]** In fact, such deposit is most undesirable in engineering applications. The ground could be liquefied easily under the slightest ground movement such as earthquake, and would not be able to support any load as the ground could collapse like a quicksand.

[0005] Soil strengthening or consolidation essentially refers to the process through which the sediment would be compacted. Soil consolidation has been employed in many construction and land reclamation projects to compact the soil. Removal of pore water (dewatering) for compacting the soil may be accelerated by using sand pipes or PVD, and sometimes using vacuum suction. These conventional processes are possible where the consolidation process is initiated from dry surfaces, i.e., above water. However, the same process cannot be implemented underwater as the water removed from soil pores would be replaced by surrounding water. As a result, the soil matrix may not collapse and soil consolidation may thus not take place. Due to this problem, it is conventionally not suitable or appropriate to dewater soil underwater, and soil underwater is typically compacted by introducing sand in an attempt to replace the pore water in the soil matrix, hence making the soil gain density and more compact.

[0006] A need therefore exists to provide a system for compacting a sediment bed containing water and a method thereof, which seek to overcome, or at least ameliorate, one or more of the deficiencies of the conventional art mentioned above, and in particular, for compacting loose or soft sediment bed in-situ and underwater. It is against this background that the present invention has been developed.

SUMMARY

[0007] According to a first aspect of the present invention, there is provided a system for compacting a sediment bed containing water, the system comprising:

- a surface member configured to rest on a surface of the sediment bed;
- a plurality of hollow elongated members affixed to a bottom side of the surface member and configured for penetrating into the sediment bed;

- one or more vibration devices disposed on the surface member, the vibration device is configured to induce vibration of the surface member and the plurality of hollow elongated members; and

- one or more extractors coupled to the plurality of hollow elongated members for extracting water from the sediment bed through the plurality of hollow elongated members.

[0008] Preferably, the surface member is made of a slab of hard material.

[0009] Preferably, the hard material is concrete.

[0010] Preferably, each of the plurality of hollow elongated members comprises a porous section configured for allowing water from the sediment bed to enter.

[0011] Preferably, each of the plurality of hollow elongated members has a
5 cylindrical cross-section and is rigid.

[0012] Preferably, the vibration device, by inducing vibration of the surface member and the one or more hollow elongated members, is operable to compact the sediment bed under the surface member and stimulate the removal of water from the sediment bed into the plurality of hollow elongated members.

10 [0013] Preferably, the vibration device is a pneumatic vibration device.

[0014] Preferably, the extractor is configured to extract water from the plurality of hollow elongated members through suction.

[0015] Preferably, the extractor is an ejector pump.

[0016] Preferably, the extractor and the vibration device are configured to operate
15 simultaneously so as to remove water from the sediment bed and compact the sediment bed under the surface member simultaneously.

[0017] Preferably, the sediment bed is underwater.

[0018] According to a second aspect of the present invention, there is provided a method of compacting a sediment bed containing water, the method comprising:

20 lowering a surface member on a surface of the sediment bed and
penetrating a plurality of hollow elongated members affixed to a bottom side of the surface member into the sediment bed;

 inducing vibration of the surface member and the plurality of hollow
elongated members using one or more vibration devices disposed on the surface
25 member; and

 extracting water from the sediment bed through the plurality of hollow
elongated members using one or more extractors coupled to the plurality of
hollow elongated members.

[0019] Preferably, the surface member is made of a slab of hard material.

30 [0020] Preferably, the hard material is concrete.

[0021] Preferably, each of the plurality of hollow elongated members comprises a porous section configured for allowing water from the sediment bed to enter.

[0022] Preferably, each of the plurality of hollow elongated members has a cylindrical cross-section and is rigid.

5 [0023] Preferably, said inducing vibration is operable to compact the sediment bed under the surface member and stimulate the removal of water from the sediment bed into the plurality of hollow elongated members.

[0024] Preferably, the vibration device is a pneumatic vibration device.

10 [0025] Preferably, said extracting water comprises extracting water from the plurality of hollow elongated members through suction.

[0026] Preferably, the extractor is an ejector pump.

[0027] Preferably, said inducing vibration and said extracting water are performed simultaneously so as to remove water from the sediment bed and compact the sediment bed under the surface member simultaneously.

15 [0028] According to a third aspect of the present invention, there is provided a method of producing a system for compacting a sediment bed containing water, the method comprising:

providing a surface member configured to rest on a surface of the sediment bed;

20 affixing a plurality of hollow elongated members to a bottom side of the surface member, the plurality of hollow elongated members configured for penetrating into the sediment bed;

25 disposing one or more vibration devices on the surface member, the vibration device configured to induce vibration of the surface member and the plurality of hollow elongated members; and

coupling one or more extractors to the plurality of hollow elongated members for extracting water from the sediment bed through the plurality of hollow elongated members.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Embodiments of the present invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

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FIG. 1 depicts a schematic drawing of a system for compacting a sediment bed containing water according to an embodiment of the present invention;

FIG. 2 depicts a schematic drawing of a hollow elongated member having a plurality of porous sections according to an embodiment of the present invention;

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FIG. 3 depicts a broad overview of a method of compacting a sediment bed containing water corresponding to the system as illustrated in FIG. 1;

FIG. 4 depicts a broad overview of a method of producing a system for compacting a sediment bed containing water according to an embodiment of the present invention; and

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FIG. 5 depicts a schematic drawing of an exemplary implementation of the system as shown in FIG. 1 to compact a loose or soft sediment bed in-situ and underwater.

DETAILED DESCRIPTION

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[0030] Embodiments of the present invention provide a system (assembly) for compacting (consolidating) a sediment bed containing water and a method thereof, and more particularly, for compacting loose or soft sediment bed in-situ and underwater. For example, the hydraulics and geotechnical method may be used for preparing seabed for large scale bed preparation for various purposes such as dumping or land reclamation in deep or shallow water. The method may be applied to improve the condition of existing sediment bed such as soft mud and loose silty deposits, including sediment bed whereby loose and soft ash or lower quality soft soil have been used as fill materials. By way of examples only, the method could be used for drainage of swampy areas, wetlands or bogs. The ground/foundation thus prepared/treated has been found to be sufficiently strong, such as to support overburdens and construction machineries for further land reclamation and foundation work.

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[0031] According to embodiments of the present invention, it is recognized that for soft deposit to be useable, the ground has to be strengthened, the water content of the deposit has to be reduced, and the discrete soil particles have to be compacted through reduction of pore spaces. In short, the deposit has to be compressed, compacted to reduce pore spaces, and dispel the pore waters in the process. The process/treatment should be such that re-entrainment of water into the soil pores is avoided or at least substantially minimized.

[0032] FIG. 1 depicts a schematic drawing of a system 100 for compacting a sediment bed containing water, e.g., loose or soft sediment bed underwater, according to an embodiment of the present invention. The system 100 comprises a surface member (platform) 106 configured to rest on a surface of the sediment bed, and a plurality of hollow elongated members 110 affixed to a bottom side 112 of the surface member 106 and configured for penetrating into the sediment bed. The system 100 further comprises one or more vibration devices 116 disposed on the surface member 106, the vibration device 116 being configured to induce vibration of the surface member 106 and the plurality of hollow elongated members 110, and one or more extractors 118 coupled to the plurality of hollow elongated members 110 (coupling mechanism not shown for simplicity) for extracting water from the sediment bed through the plurality of hollow elongate members 110.

[0033] In particular, according to a preferred embodiment, the extractor 118 and the vibration device 116 is configured to operate simultaneously (concurrently) so as to remove water from (dewater) the sediment bed and compact the sediment bed under the surface member simultaneously (concurrently). This advantageously addresses the problems associated with the conventional methods discussed in the background preventing them from dewatering a sediment bed underwater to compact the sediment bed. In particular, by inducing vibration (thus compacting the sediment bed) while removing the displaced soil pore water (e.g., through ejector-suction), the soil will settle and will not rebound. The surface member 106 is thus able to move vertically downward in tandem with the settlement until a desired degree of compaction is achieved. That is, through vibration and soil pore water removal simultaneously, the sediment bed below the surface member can be much more effectively compacted as the pore water is

generally prevented from re-entering the underlying sediment bed (i.e., compaction occurs due to the vibration which collapses the pore spaces, thus does not leave sufficient pore spaces for the pore water to re-enter). This advantageously enables the compaction of loose or soft sediment under underwater and significantly strengthens the sediment bed processed/treated, thus allowing the processed/treated sediment bed to support overburden and construction machineries for example.

[0034] In various embodiments, the surface member 106 is made of a slab of hard material such as a concrete slab. Concrete slab has the advantage of having high density, mass and strength which will remain intact even after a prolong period of vibration. The mass of the concrete slab also aids to exert a vertical load to press on and compact the underlying sediment bed. For example, the concrete slab may have steel reinforcement for added strength. As shown in FIG. 1, the surface member 106 preferably has a planar or flat base portion 130, and a periphery wall portion 132 extending upwards in an oblique manner. It was found that a vertical periphery wall portion would result in the surface member 106 progressively sinking into the soil, resulting in the heaving of soil at the edge of the surface member 106. Configuring the periphery wall portion 132 to extend upwards in an oblique manner has been found to still achieve soil compaction but with reduced degree of heave. Preferably, the angle of inclination (from a plane of the surface member 106) is about 45° to 75°, and for example, 60°. The base portion 130 is configured to rest on the sediment bed and the periphery wall portion 132 is configured to block or prevent the surrounding sediment from flowing onto the surface member 106 as the surface member 106 descends during compaction. Therefore, the height of the periphery wall portion 132 is configured to have a height sufficient to block the surrounding sediment from flowing onto the surface member 106 during compaction. That is, the height of the periphery wall portion 132 is configured based on the intended or expected amount (in depth/height) the sediment bed under the surface member 106 will lower when compacted, and should be more than such an intended or expected amount.

[0035] For example, the surface member 106 may be referred to as a top cap-slab. Furthermore, as the surface member 106 is made of a slab of hard material, its mass also serves to provide a vertical load (downward gravitational force) or pressure on the

underlying sediment bed, thereby compacting the sediment bed as the sediment bed is being vibrated or shaken. In an embodiment, additional weights may be disposed on the surface member 106 to provide more downward gravitational force for compacting the underlying sediment bed. For example only and without limitation, the mass of the surface member 106 may be in the range of about 2.5 to 3 t/m² (tons per square meter).

[0036] In various embodiments, each of the plurality of hollow elongated members 110 comprises one or more porous sections or segments 210 configured for allowing water from the sediment bed to enter into the hollow elongated member 110 as shown in FIG. 2. In particular, the porous sections 210 are perforated and covered with a filter material to allow water to flow into the hollow elongated member 110 while blocking/excluding larger sediment particles. As examples, the porous section 210 may be made of a wire mesh or covered with geotextiles that is capable of filtering out particles larger than, for example, about 0.2mm. In various embodiments, the size of the pores may be in the range of about 100μm to about 300μm in diameter. Preferably, the elongated member 110 has a cylindrical cross-section and is rigid. This allows the elongated member 110 to penetrate into the sediment bed as the surface member 106 is lowered onto the loose sediment bed to be compacted. For example, the elongated member 110 may be a well casing made of steel or stainless steel.

[0037] Accordingly, with the system as shown in FIG. 1, the vibration device 116, by inducing vibration of the surface member 106 and the hollow elongated members 110, is operable to compact the sediment bed under the surface member 106 and stimulate the removal of water from the sediment bed into the hollow elongated members 110. At the same time, the water collected in the elongated members 110 is extracted, for example, through suction by an ejector pump. Therefore, during operation, the vibration member 116 and the extractor 118 operate simultaneously so as to remove water from the sediment bed and compact the sediment bed under the surface member simultaneously. As a result, the sediment bed below the surface member can be much more effectively compacted as the pore water is generally prevented from re-entering the underlying sediment bed. This significantly strengthens the sediment bed processed and thus enables the sediment bed to support overburden and construction machineries for example.

[0038] In various embodiments, the vibration device 116 may be configured to vibrate at a magnitude/intensity and frequency in the range of about 2Hz to about 60Hz. It will be appreciated to a person skilled in the art that the frequency of the vibration can be adjusted as appropriate. For example, the vibration device 116 may be a pneumatic vibration block.

[0039] FIG. 3 depicts a broad overview of a method 300 of compacting a sediment bed containing water corresponding to the system 100 as illustrated in FIG. 1. The method 300 comprises a step 302 of lowering a surface member 106 on a surface of the sediment bed and penetrating a plurality of hollow elongated members 110 affixed to a bottom side 112 of the surface member 106 into the sediment bed, a step 304 of inducing vibration of the surface member 106 and the plurality of hollow elongated members 110 using one or more vibration devices 116 disposed on the surface member 106, and a step 306 of extracting water from the sediment bed through the plurality of hollow elongated members 110 using one or more extractors 118 coupled to the plurality of hollow elongated members 110. In a preferred embodiment, the step 304 of inducing vibration and the step 306 of extracting water are performed simultaneously (concurrently) so as to remove water from the sediment bed and compact the sediment bed under the surface member 106 simultaneously (concurrently). As mentioned above, this enables the underlying sediment bed to be compacted much more effectively, thus significantly strengthens the underlying sediment bed for various purposes.

[0040] FIG. 4 depicts a broad overview of a method 400 of producing a system 100 for compacting a sediment bed containing water. The method 400 comprises a step 402 of providing a surface member 106 configured to rest on a surface of the sediment bed, a step 404 of affixing a plurality of hollow elongated members 110 to a bottom side 112 of the surface member 106, the plurality of hollow elongated members 110 configured for penetrating into the sediment bed, a step 406 of disposing one or more vibration devices 116 on the surface member 106, the vibration device 116 configured to induce vibration of the surface member 106 and the plurality of hollow elongated members 110, and a step 408 of coupling one or more extractors 118 to the plurality of hollow elongated members 110 for extracting water from the sediment bed through the plurality of hollow elongated members 110.

[0041] Hereinafter, the present invention will be described more fully with reference to FIG. 5, in which an exemplary embodiment of the invention is shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiment set forth herein. Rather, the exemplary embodiment
5 is provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, lengths and sizes of layers and regions may be exaggerated for clarity.

[0042] FIG. 5 depicts a schematic drawing of an exemplary implementation of the system 100 according to an example embodiment of the present invention. In this
10 example embodiment, the system 100 is lowered into a loose or soft sediment bed 510 underwater, which requires compacting for various purposes.

[0043] In the example embodiment, the system 100 comprises a top cap-slab 106 (surface / platform member), a number of pneumatic vibration blocks 116 (vibration device), and rigid suction legs 110 (hollow elongated members). It will be appreciated to
15 a person skilled in the art that the number and length of the suction legs 110 can be varied as appropriate such as based on the area of the underlying sediment bed required to be compacted. By way of example only, the top cap 106 may have a square cross-section, having a dimension of about 2 to 5 m x 2 to 5 m, and the suction legs 110 may each be a hollow cylinder of about 1.5 m to 2.0 m in length and 75 mm to 150 mm in diameter.
20 Configuring the top cap 106 to have a square cross-section advantageously makes it easier to cover an entire target area in a series / an array of grid patterns. However, it will be appreciated to a person skilled in the art that the top cap 106 may have other shapes as appropriate, such as rectangular or circular. The suction legs 110 also function as a well casing through which water may be drawn and removed from the sediment using an
25 ejector pump 118.

[0044] For example, the system 100 may be lowered into the sediment bed 510 at a quay side or from a floating platform or a vessel. As the system (assembly) 100 is lowered onto the loose sediment bed 510, by nature of the softness of the soil sediment bed 510, the system 100 will sit or rest on the sediment bed 510 with the suction legs 110
30 penetrated into the sediment bed 510 as shown in FIG. 5.

[0045] Thereafter, the vibration block 116 attached to the top slab 106 is actuated to provide vibrating / shaking action that would stimulate and dispel soil water from the pores while compacting the loose sediment under the weight of the slab 106. The slab 106 would thus sit and descend with the compacted soil. In an embodiment, additional weights (not shown) may be disposed on the slab 106 so as to provide further gravitational downforce for further compacting the loose sediment. In addition, at the same time, the ejector pump 118 is operated such that the dispelled soil water is removed from the suction legs 110 with porous cylindrical surfaces (e.g., wire mesh sections 210). For example, suction may be achieved using an ejector pumping system 118 based on hydraulic (Bernoullie) principle.

[0046] In a preferred embodiment, the system 100 is raised and lowered multiple times to achieve a higher degree of compaction. After achieving the required compaction, the system (assembly) 100 is then raised and lowered onto an adjacent section of the sediment bed 510 requiring compaction.

[0047] Therefore, embodiments of the present invention advantageously overcome various limitations of conventional methods and successfully achieve compaction, removal of pore water and consolidation underwater. Advantageously, the consolidated soil mass will generally not re-entrain water into the pores after compaction and thus enables the compaction of loose sediment with high water content underwater such as nearshore having a depth of water, e.g., between 15-50m or from a floating platform or a vessel.

[0048] Accordingly, it can be appreciated that the system 100 advantageously functions as both a vibrator (compactor) and a pore-water ejector. In particular, the vibrating motion of the system 100 leads to compaction of the soil particles and dispel pore water from the soil. The pore water is removed from the loose sediment using, for example, the ejector pumps 118 connected to the suction legs 110. The sediment bed/deposit treated in this manner has been found to form good foundation suitable for various purposes such as to support overburden and construction machineries.

[0049] Furthermore, the method and system according to embodiments of the present invention make it possible to use less favourable sediment as land fill material since they can be effectively compacted and strengthened as described hereinbefore. In addition, the

method and system advantageously cause little disturbance and entrainment of sediment into the water column, and hence reducing total suspended sediment in the water. In particular, one of the main environmental impacts of underwater soil work is the entrainment of bed sediment into the water column, causing increased turbidity, and smoldering of neighbouring habitats such as coral. However, compaction according to embodiments of the present invention does not involve dredging or displacement of soil through rapid penetration of the system / device into the sediment bed.

[0050] While embodiments of the invention have been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

What is claimed is:

- 5 1. A system for compacting a sediment bed containing water, the system comprising:
 - a surface member configured to rest on a surface of the sediment bed;
 - a plurality of hollow elongated members affixed to a bottom side of the surface member and configured for penetrating into the sediment bed;
 - 10 one or more vibration devices disposed on the surface member, the vibration device is configured to induce vibration of the surface member and the plurality of hollow elongated members; and
 - one or more extractors coupled to the plurality of hollow elongated members for extracting water from the sediment bed through the plurality of
 - 15 hollow elongated members.
2. The system according to claim 1, wherein the surface member is made of a slab of hard material.
- 20 3. The system according to claim 2, wherein the hard material is concrete.
4. The system according to any one of claims 1 to 3, wherein each of the plurality of hollow elongated members comprises a porous section configured for allowing water from the sediment bed to enter.
- 25 5. The system according any one of claims 1 to 4, wherein each of the plurality of hollow elongated members has a cylindrical cross-section and is rigid.
6. The system according to any one of claims 1 to 5, wherein the vibration device, by inducing vibration of the surface member and the one or more hollow
- 30 elongated members, is operable to compact the sediment bed under the surface

member and stimulate the removal of water from the sediment bed into the plurality of hollow elongated members.

5 7. The system according to any one of claims 1 to 6, wherein the vibration device is a pneumatic vibration device.

10 8. The system according to any one of claims 1 to 7, wherein the extractor is configured to extract water from the plurality of hollow elongated members through suction.

9. The system according to claim 8, wherein the extractor is an ejector pump.

15 10. The system according to any one of claims 1 to 9, wherein the extractor and the vibration device are configured to operate simultaneously so as to remove water from the sediment bed and compact the sediment bed under the surface member simultaneously.

20 11. The system according to any one of claims 1 to 10, wherein the sediment bed is underwater.

25 12. A method of compacting a sediment bed containing water, the method comprising:
lowering a surface member on a surface of the sediment bed and penetrating a plurality of hollow elongated members affixed to a bottom side of the surface member into the sediment bed;
inducing vibration of the surface member and the plurality of hollow elongated members using one or more vibration devices disposed on the surface member; and
30 extracting water from the sediment bed through the plurality of hollow elongated members using one or more extractors coupled to the plurality of hollow elongated members.

13. The method according to claim 12, wherein the surface member is made of a slab of hard material.

5 14. The method according to claim 13, wherein the hard material is concrete.

15. The method according to any one of claims 12 to 14, wherein each of the plurality of hollow elongated members comprises a porous section configured for allowing water from the sediment bed to enter.

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16. The method according any one of claims 12 to 15, wherein each of the plurality of hollow elongated members has a cylindrical cross-section and is rigid.

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17. The method according to any one of claims 12 to 16, wherein said inducing vibration is operable to compact the sediment bed under the surface member and stimulate the removal of water from the sediment bed into the plurality of hollow elongated members.

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18. The method according to any one of claims 12 to 17, wherein the vibration device is a pneumatic vibration device.

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19. The method according to any one of claims 12 to 18, wherein said extracting water comprises extracting water from the plurality of hollow elongated members through suction.

20. The method according to claim 19, wherein the extractor is an ejector pump.

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21. The method according to any one of claims 12 to 20, wherein said inducing vibration and said extracting water are performed simultaneously so as to remove water from the sediment bed and compact the sediment bed under the surface member simultaneously.

22. A method of producing a system for compacting a sediment bed containing water, the method comprising:

5 providing a surface member configured to rest on a surface of the sediment bed;

affixing a plurality of hollow elongated members to a bottom side of the surface member, the plurality of hollow elongated members configured for penetrating into the sediment bed;

10 disposing one or more vibration devices on the surface member, the vibration device configured to induce vibration of the surface member and the plurality of hollow elongated members; and

coupling one or more extractors to the plurality of hollow elongated members for extracting water from the sediment bed through the plurality of hollow elongated members.

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