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An Experimental Study On The Performance Of 3d Geogrid Reinforced Sand Under Repeated Loading

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Abstract

Objectives: *To study the effect of spacing between reinforced layers, numbers of geogrid layers with / without vertical confinement, rigidity and height of confinement were studied.*

Methodology: *The application of geosynthetics to enhance the strength characteristics of the soil is beneficial technique under static and repeated loads. In the present investigation a series of laboratory tests were conducted to study the improvement of soil resistance under repeated loading. 2D Geogrid (plain geogrid 2-dimensional) and 3D geogrid (geogrid with vertical confinement) is used to enhance the load-settlement behavior of the model footing of square shape resting over sand.*

Findings: *The results are presented in terms of Settlement Ratio (SR) and Cyclic Resistance Ratio (CRR). 3D geogrid reinforced sand bed with optimum reinforcement condition the CRR value increased to 500 time compared with unreinforced sand bed at 40mm settlement of the footing and SR value decreases to 0.03 times compared with unreinforced sand bed at same settlement level. The performance of model footing resting over 3D geogrid reinforced sand bed was improved when compared with unreinforced sand bed, which confirms the improvement resulting in increasing the load carrying capacity against repeated loading and also decreases the footing settlement on repeated loading. The experimental results demonstrated that the provision of 3D reinforcement element is effective in improving the performance of footing resting on them.*

Keywords: *S/B ratio; U/B ratio; Repeated loading; Rigid vertical confinement; Semi-rigid vertical confinement; Flexible vertical confinement.*

INTRODUCTION

Soil reinforcement and soil confinement are the two different methods in the stabilization of cohesionless soil. In the last two decade soil confinement and reinforcement technique has been used for stabilization of cohesionless soil in various construction projects all over the world. In soil reinforcement technique, different geosynthetic material has been used to solve various geotechnical problems but no one has been studied on effect of combining reinforcement and confinement technique as a single unit to improve the load carrying capacity of cohesionless soil. In this technique geogrid has been used as reinforcement material and PVC pipes has been used as confinement material to the cohesionless soil. This combination of geogrid and PVC pipes is called as 3D geogrid. In the previous study geogrid (2D) has been used as reinforcement material to cohesionless soil (sand) to study load-settlement behaviour of footing resting on sand beds, the studied parameters such depth of first layer reinforcement, spacing between the number of reinforcement layers and relative density of soil [3] This paper presents the experimental results of model tests conducted in laboratory on square footing resting on geogrid with PVC pipes (3D) reinforced sand beds subjected to repeated loading. Researchers across the globe have studied the characteristics of geosynthetics which are reinforced for shallow foundations [4]. The density of soil below foundation mainly affects the stability and bearing capacity of foundation [1], the placement of geogrid reinforcement at the optimum depth below the footing [2], effective length of reinforcement, optimum number of layers of reinforcement [7]. The performance of 2-dimensional geogrid reinforced sand under cyclic loading, a series of model tests were conducted and evaluated at 0.3B as the optimum spacing between the reinforcement layer and 0.3B as the optimum depth for the first layer of reinforcement to the surface level of sand [6].

To study the performance of footing on 3D geogrid as both reinforcement and confinement material to soil (Sand) under repeated loading, the objectives of this research work is to bring out the effectiveness of the provision of 3D element in improving the performance of footings when subjected to repeated loads and also to study the effect of various parameters such as depth of first layer of reinforcement, spacing of reinforcement, number of reinforcement layers, rigidity and height of vertical confinement on the performance of footings.

MATERIAL PROPERTIES

Table 1: Properties of sand

Properties	**Test Result**
Specific gravity (G)	2.62
Particle size distribution	
Silt and Clay size, %	0.2
Sand size, %	98.8
Gravel size, %	0.0
Uniformity coefficient (Cu)	2.89
Coefficient of Curvature (Cc)	0.96
Dry Density, (kN/m^3) @ 36 %relative density	15.4

Table 2: Properties of other materials used

Parameters	**Values**
Geogrid	
Thickness of joint (mm)	5
Thickness at Rib (mm)	2.4
Geogrid size (diameter in mm)	480
Structure	Hexagonal aperture Bi oriented, mesh type
Tensile strength (kPa)	7.74
Aperture size at Junction (mm)	26.1
Vertical confinement	
Density (g/cm^3)	1.4
Inner diameter of pipe (mm)	18.8
Thickness of pipe (mm)	2.6
Modulus of Elasticity for Rigid PVC pipe (MPa)	1480
Modulus of Elasticity for Semi-Rigid pipe (MPa)	1020
Modulus of Elasticity for Flexible pipe (MPa)	550
Model footing	
Material	Mild Steel
Size of footing	100mm x 100mm
Shape of footing	Square
Thickness of footing (mm)	4

Model tank	
Material	Mild Steel
Internal height of tank (mm)	390
Internal diameter of tank (mm)	500
Thickness of tank (mm)	3.5

TEST METHOD

A. Preparation of unreinforced and 2D and 3D geogrid reinforced sand bed

Unreinforced sand bed was prepared by vibratory compaction of sand in three layers up to height of tank 360mm by sand raining technique. The reinforced sand bed was prepared by insertion of 2D and 3D geogrid at particular depth and spacing in sand layer with regard to the base of footing, 5mm gap was maintained between the wall surface of the tank and 2D and 3D geogrid reinforcement to reduce the wall friction. The footing was located centrally on the top surface of the prepared sand bed in model tank, the internal diameter of model tank is 5 times the size of footing to avoid confinement effect from the model tank.

B. Repeated Load Test Procedure

Model tests were conducted in the laboratory using Automated Dynamic Test Apparatus (ADTA), for applying repeated load on model footing. The prepared sand sample was placed in ADTA machine for applying repeated load of magnitude 300 kPa, frequency of 2Hz and sinusoidal wave type. Movicon-9.1 software was used in the system, to control ADTA machine. The surface displacements were measured in terms of settlement using linear variable differential transformer (LVDT's) which is placed orthogonal to each other. The LVDT's and load cell was assembled with the control unit, where conversion from analog to the digital takes place and stored in data acquisition system.

In the present investigation all the experiments are conducted with repeated loads characterized as Amplitude = 300 kPa and Frequency f = 2 Hz

C. 2D geogrid and 3D geogrid system

Fig. 1 (a) Presents the 2D geogrid system, Fig. 1 (b) presents the 3D geogrid system and Fig. 2 Shows the sectional elevation of geogrid with PVC pipes and Fig. 3 shows the PVC pipes used. Geogrid act as both reinforcement and confinement to the soil in lateral direction and PVC pipes provide confinement to soil was provided in both lateral and vertical directions. The PVC pipes are placed perpendicular to the geogrid layer thus combining the geogrid and PVC pipes to make 3D geogrid system.

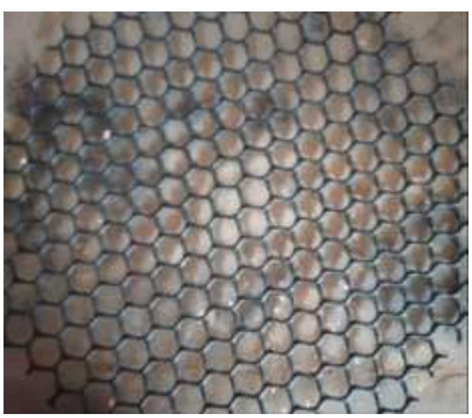

Fig. 1 (a) Top view of Geogrid (2D geogrid)

Fig. 1 (b) Top view of Geogrid with PVC pipes (3D geogrid)

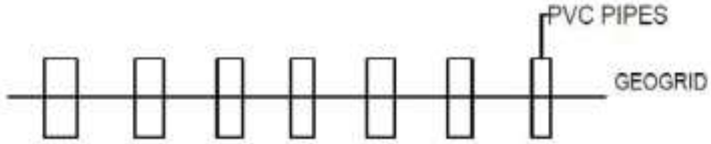

Fig. 2. Sectional elevation of Geogrid with vertical confinement

Fig. 3 (a). Rigid PVC pipes **Fig. 3 (b).** Semi-Rigid pipes **Fig. 3 (c).** Flexible pipes

RESULTS AND DISCUSSION

In the present study, investigations are made to determine the performance of model square footing rested on 3D geogrid reinforced sand beds subjected to repeated loading. The parameters varied in the experiments include, (i) Depth of first layer of reinforcement (U) (ii) Spacing of reinforcement (S) (iii) Numbers of reinforcement layers (N) and (iv) Height of vertical confinement (H=2cm and H=4 cm) in (3D geogrid) (iv) Rigidity of vertical confinement (Rigid, Semi-rigid and Flexible) in (3D geogrid). The relative density of sand is maintained at 36 % for all the tests.

A. Effect of reinforcement configuration for 3D geogrid with 2cm height of Rigid vertical confinement

a) Effect of U/B ratio

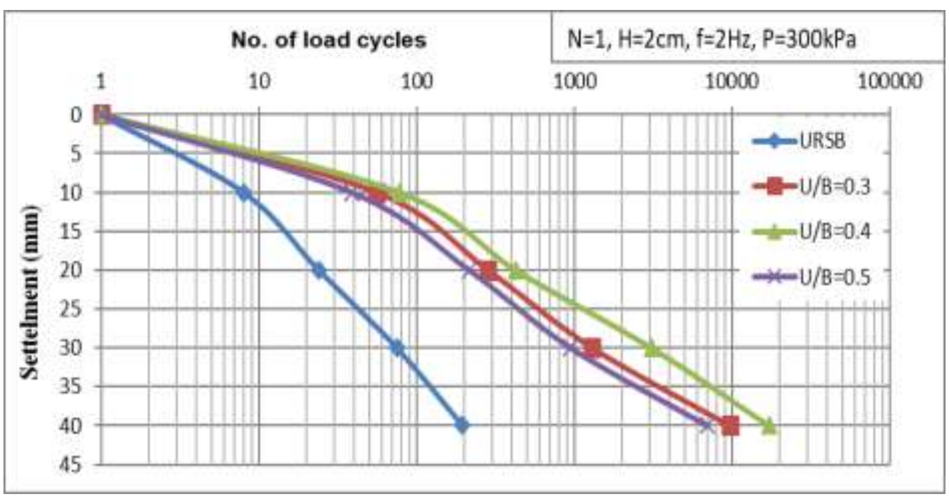

Fig. 4. Effect of depth of single layer 3D reinforced sand bed on settlement of footing under repeated load

Fig. 4 shows the repeated load performance of footing placed on single layer 3D reinforcement sand bed (N=1) for the U/B ratio 0.3, 0.4 and 0.5. The number of load cycle taken by the footing to reach 40mm settlement for U/B ratio 0.3, 0.4 and 0.5 is 7730, 13446 and 5575 respectively. For U/B ratio 0.4, yields highest number of load cycles, therefore it is consider as an optimum condition and kept constant for the rest of the experiments.

b) Effect of S/B ratio

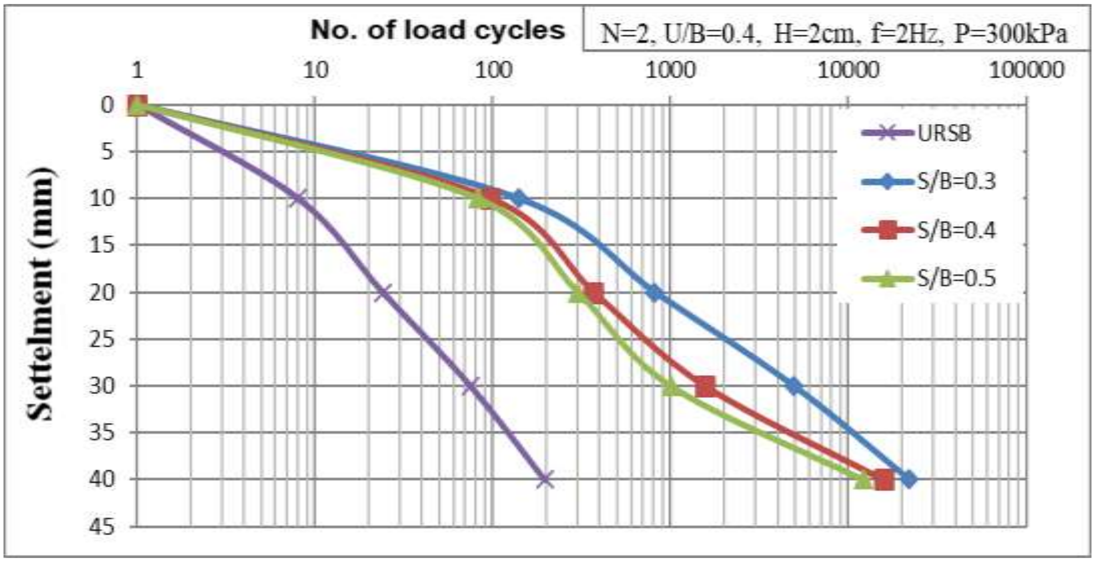

Fig. 5. Effect of two layer 3D reinforced sand bed under repeated load with U/B=0.4

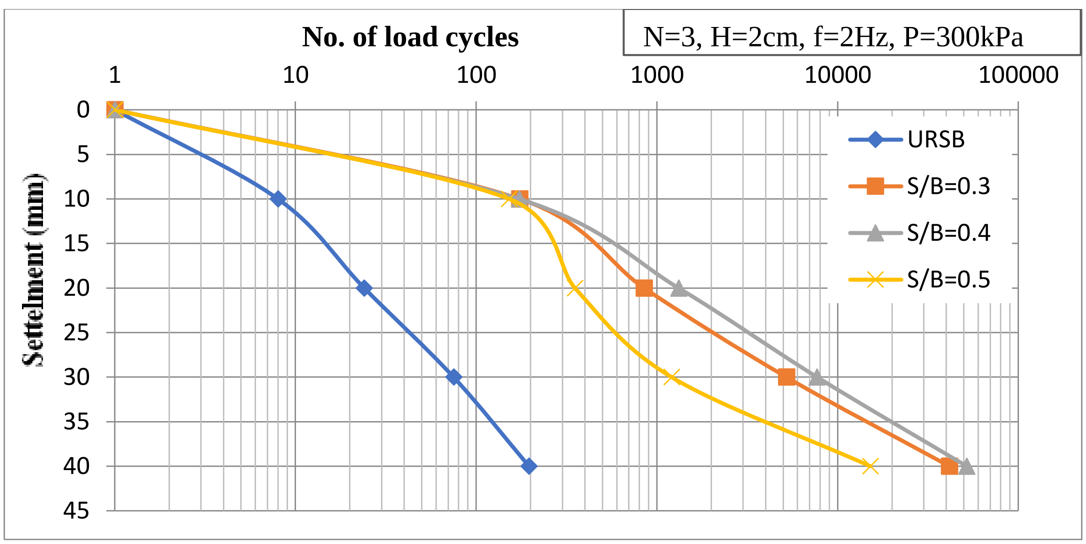

Fig. 6. Effect of spacing of reinforcement for three layers 3D reinforced sand bed under repeated load with U/B=0.4

Fig. 5 shows the performance of footing resting on two layers 3D geogrid reinforced sand bed for the S/B ratio 0.3, 0.4, and 0.5. The number of load cycle considered for 40mm settlement for S/B ratio 0.3, 0.4 and 0.5 is 28135, 34867 and 18913 respectively. Fig. 6 shows the performance of footing resting on three layers 3D reinforcement sand bed for S/B ratio 0.3, 0.4, and 0.5. The number of load cycle taken for 40mm settlement for S/B ratio 0.3, 0.4 and 0.5 are 33078, 45216 and 33315. From the Fig. 5 and 6, for S/B ratio 0.3 shows the highest number of load cycles taken compared with S/B ratio 0.4 and 0.5. Hence, S/B ratio 0.3 was considered as an optimum condition.

c) Effect of Number of reinforced layers (N)

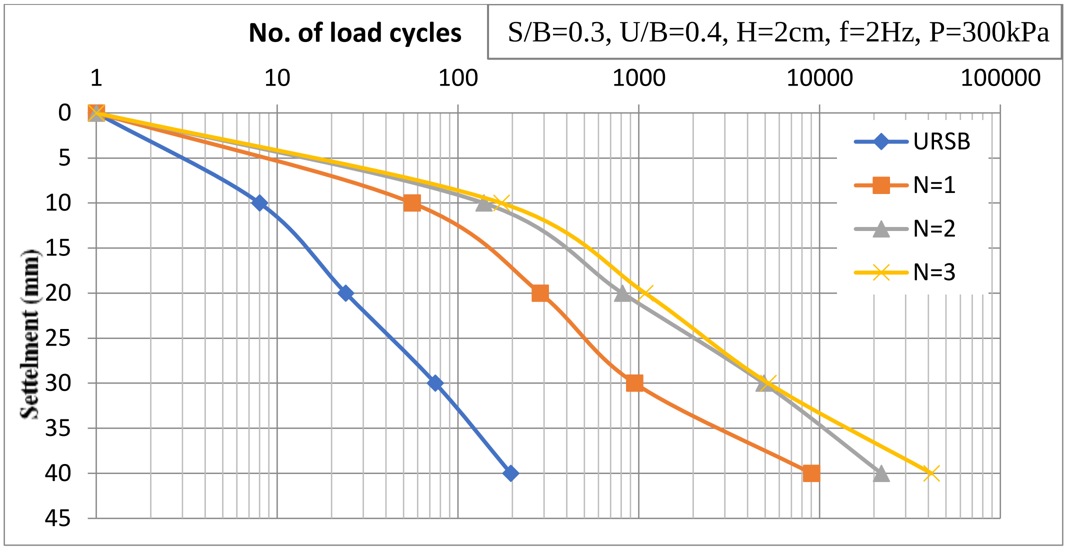

Fig. 7. Effect of number of reinforcement layers for 3D reinforced sand bed under repeated load with S/B=0.3 and U/B=0.4

Fig. 7 shows the performance of footing resting on 3D geogrid reinforced sand bed for N = 1, 2 and 3 by keeping optimum U/B ratio 0.4 and S/B ratio 0.3 as constant. The number of load cycle taken for 40mm settlement for N= 1, 2 and 3 is 17232, 33315 and 45216 respectively. Further with increase in the reinforcement layer beyond 3 there is no more effective, therefore the number of reinforcement layers restricted to 3. With the increase in number of 3D geogrid reinforcement layers which intern's increases friction between soil and geogrid, also provides lateral and vertical confinement to the soil therefore the number of load cycles taken from the footing increases.

B. Effect of reinforcement configuration of 3D geogrid with 4cm height Rigid vertical confinement.

a) Effect of U/B ratio

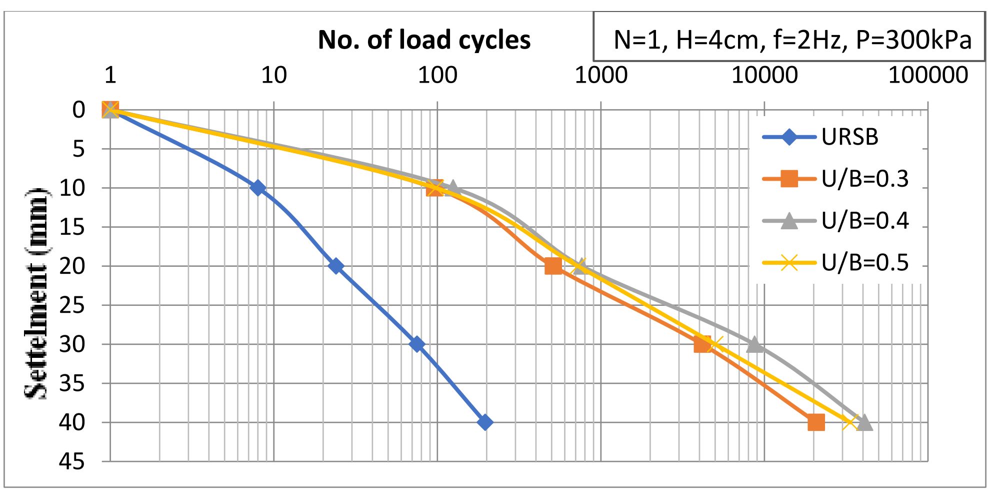

Fig. 8. Effect of depth of single layer 3D reinforced sand bed on settlement of footing under repeated load

Fig. 8 shows the performance of footing placed on single layer 3D reinforced sand bed for the U/B ratio 0.3, 0.4 and 0.5. The number of load cycle taken for 40mm settlement for U/B ratio 0.3, 0.4 and 0.5 are 20791, 41032 and 33520 respectively. Here for U/B ratio 0.4 shows the highest number of load cycles, hence it was considered as an optimum condition and kept constant for the rest of the experiments.

b) Effect of spacing between the reinforced layers

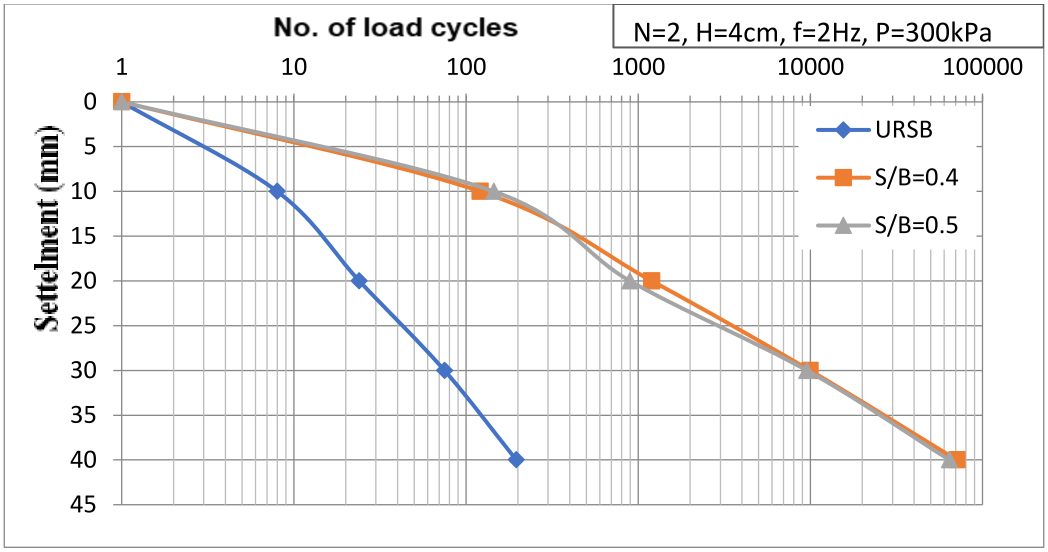

Fig. 9. Effect of two layer 3D reinforced sand bed under repeated load, U/B = 0.4

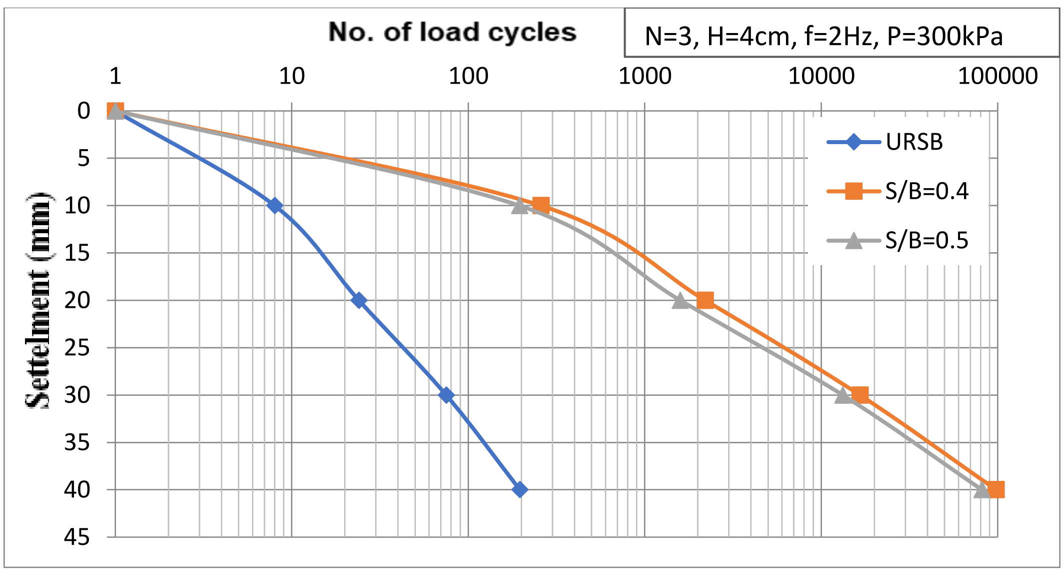

Fig. 10. Effect of three layer 3D reinforced sand bed under repeated load with U/B=0.4

Fig. 9 shows the performance of two layers (N=2) 3D reinforcement sand bed for the S/B ratio 0.4 and 0.5. The number of load cycle taken for 40mm settlement for S/B ratio 0.4 and 0.5 are 70991 and 64354 respectively. Fig. 10 shows the performance of three layers (N=3) 3D reinforcement sand bed for the S/B ratio 0.4 and 0.5. The number of load cycle taken for 40mm settlement for S/B ratio 0.4 and 0.5 are 98010 and 81444 respectively. From the Fig. 9 and 10 for S/B ratio 0.4, shows the highest number of load cycles taken compared to S/B ratio 0.3. From this it can be concluded that irrespective of numbers of reinforcement layers, lesser the spacing between reinforcement layers higher will the load resistance capacity and the optimum spacing between the 3D geogrid reinforcement layers is 0.4B.

C. Effect of reinforcement configuration for 3D geogrid with 2cm height of Semi-rigid vertical confinement

a) Effect of number of layers of reinforcement (N)

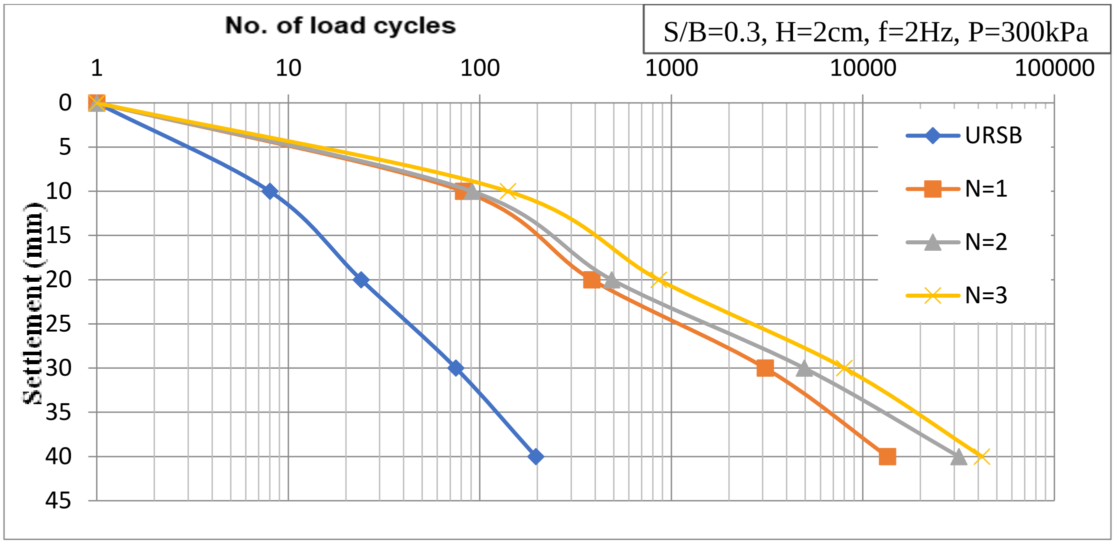

Fig. 11. Effect of number of reinforcement layers for the footing on 3D reinforced sand bed under repeated load with S/B = 0.3 and U/B = 0.4

Fig. 11 shows the performance of 3D Geogrid (semi-rigid vertical confinement) reinforced sand bed for N = 1, 2 and 3 by keeping optimum U/B ratio 0.4 and S/B 0.3 as constant. The number of load cycle taken for 40mm settlement for N= 1, 2 and 3 are 13446, 31707 and 41820 respectively. Further with increase in the reinforcement layer beyond 3 there is no more effective, therefore the number of reinforcement layers restricted to 3. With the increase in number of 3D geogrid reinforcement layers which intern's increases friction between soil and geogrid, also provides lateral and vertical confinement to the soil therefore the number of load cycles taken from the footing increases.

D. Effect of reinforcement configuration of 3D geogrid with 4cm height of Semi-rigid vertical confinement

a) Effect of number of layers of reinforcement (N)

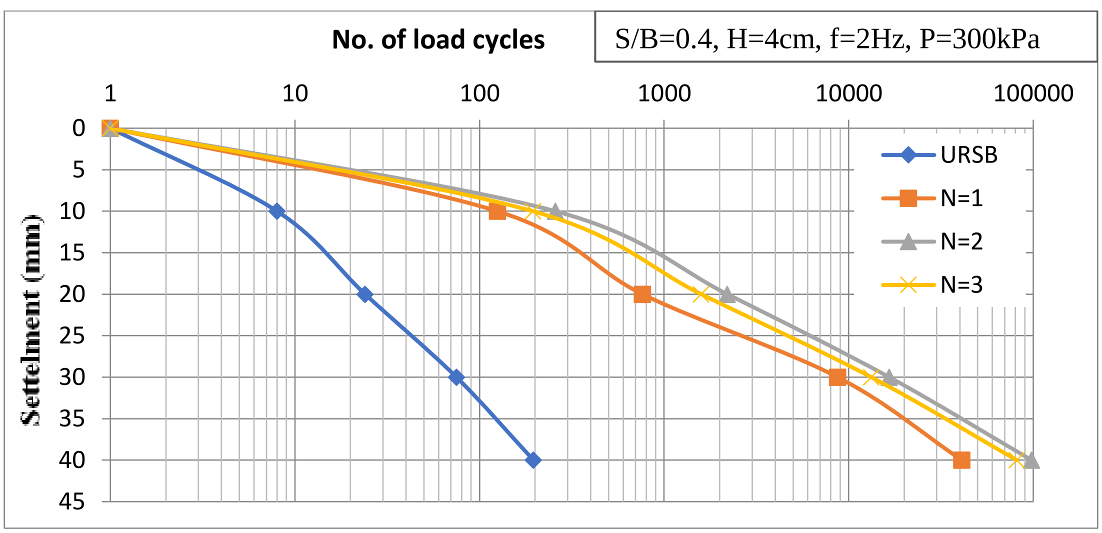

Fig. 12. Effect of 3D reinforced sand bed under repeated load with S/B = 0.4 and U/B = 0.4

Fig. 12 shows the performance of 3D Geogrid (semi-rigid vertical confinement) reinforced sand bed for N = 1, 2 and 3 by keeping optimum U/B ratio 0.4 and S/B 0.4 as constant. The number of load cycle taken for 40mm settlement for N= 1, 2 and 3 are 36299, 65829 and 95245 respectively. Further with increase in the reinforcement layer beyond 3 there is no more effective, therefore the number of reinforcement layers restricted to 3. With the increase in number of 3D geogrid reinforcement layers which intern's increases friction between soil and geogrid, also provides lateral and vertical confinement to the soil therefore the number of load cycles taken from the footing increases.

E. Effect of reinforcement configuration of 3D geogrid with 2cm height of Flexible vertical confinement

a) Effect of number of layers of reinforcement

Fig. 13 shows the performance of 3D Geogrid (flexible vertical confinement) reinforced sand bed for N = 1, 2 and 3 by keeping optimum U/B ratio 0.4 and S/B 0.3 as constant. The number of load cycle taken for 40mm settlement for N= 1, 2 and 3 are 12121, 21969 and 39398 respectively. With the increase in number of 3D geogrid reinforcement layers which intern's increases friction between soil and geogrid, also provides lateral and vertical confinement to the soil therefore the number of load cycles taken from the footing increases.

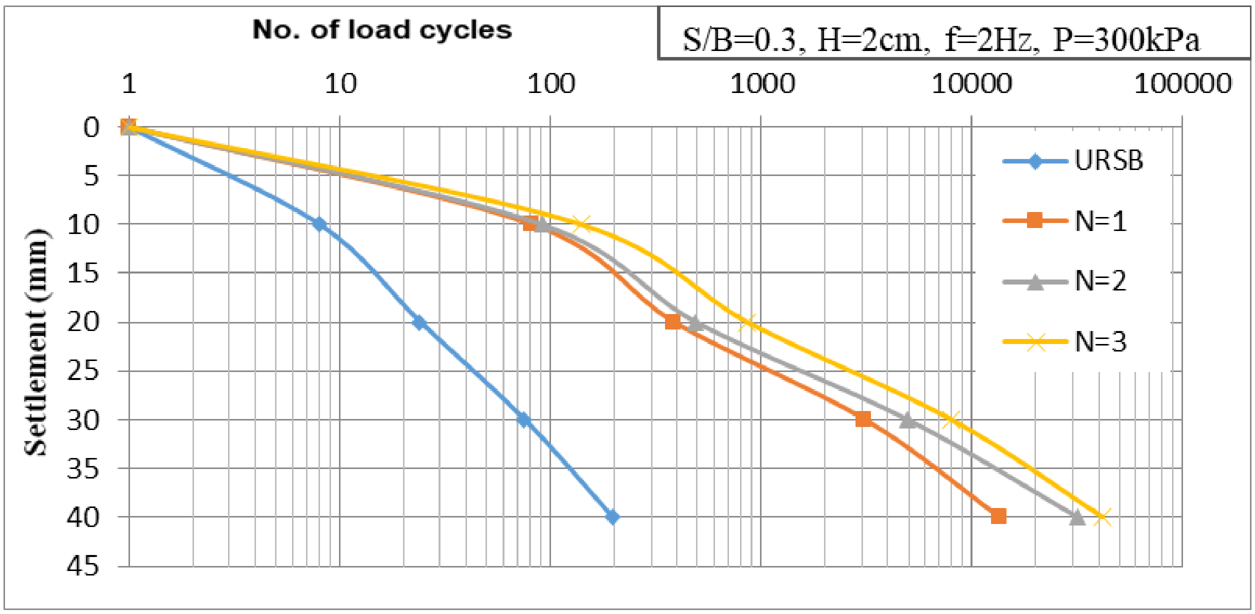

Fig. 13. Effect of number of reinforcement layers for the footing on 3D reinforced sand bed under repeated load with S/B = 0.3 and U/B = 0.4

F. Effect of reinforcement configuration of 3D geogrid with 4cm height of Flexible vertical confinement

a) Effect of number of layers of reinforcement

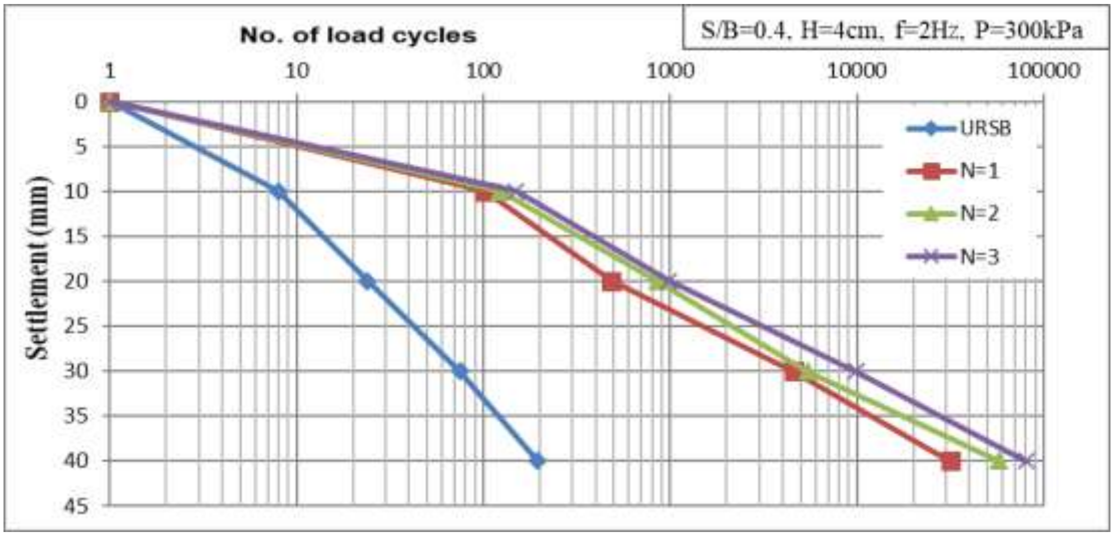

Fig. 14. Effect of 3D reinforced sand bed under repeated load with S/B = 0.4 and U/B = 0.4

Fig. 14 shows the performance of 3D Geogrid (flexible vertical confinement) reinforced sand bed for N = 1, 2and 3 by keeping optimum U/B ratio 0.4 and S/B 0.4 as constant. The number of load cycle taken for 40mm settlement for N= 1, 2and 3 are 31568, 57774 and 80229 respectively. With the increase in number of 3D geogrid reinforcement layers which intern's increases friction between soil and geogrid, also provides lateral and vertical confinement to the soil therefore the number of load cycles taken from the footing increases.

G. Comparison of results

To bring out the effect of inclusion of geogrid (2D) and geogrid with vertical confinement (3D) comparison of results are made for optimum reinforcement condition both in 2D geogrid and 3D geogrid reinforced sand beds. Fig 15 indicates that the number of load cycles resisted by surface footing resting on 3D geogrid with rigid vertical confinement of H=2cm reinforced sand beds is 45,216 cycles, whereas for 3D geogrid with semi-rigid vertical confinement of H=2cm reinforced sand beds is 41,820 cycles. Similarly for 3D geogrid with flexible vertical confinement of H=2cm reinforced sand beds the number of load cycles resisted is 39,398 cycles. The number of load cycles for the surface footing resting on 2D geogrid reinforced sand bed (optimum reinforcement condition) is 36,704 cycles for 40mm settlement and for unreinforced sand bed it is 196 cycles at 40mm settlement [2].

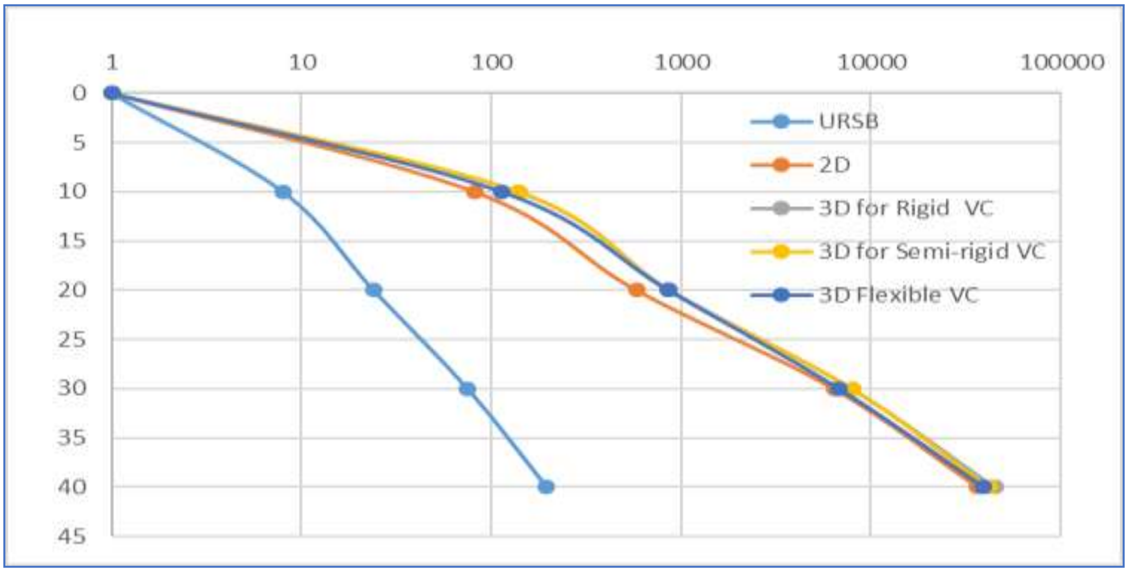

Fig. 15. Comparison of performance of square footing resting on unreinforced, 2D geogrid, and 3D geogrid with vertical confinement of H=2cm reinforced sand beds.

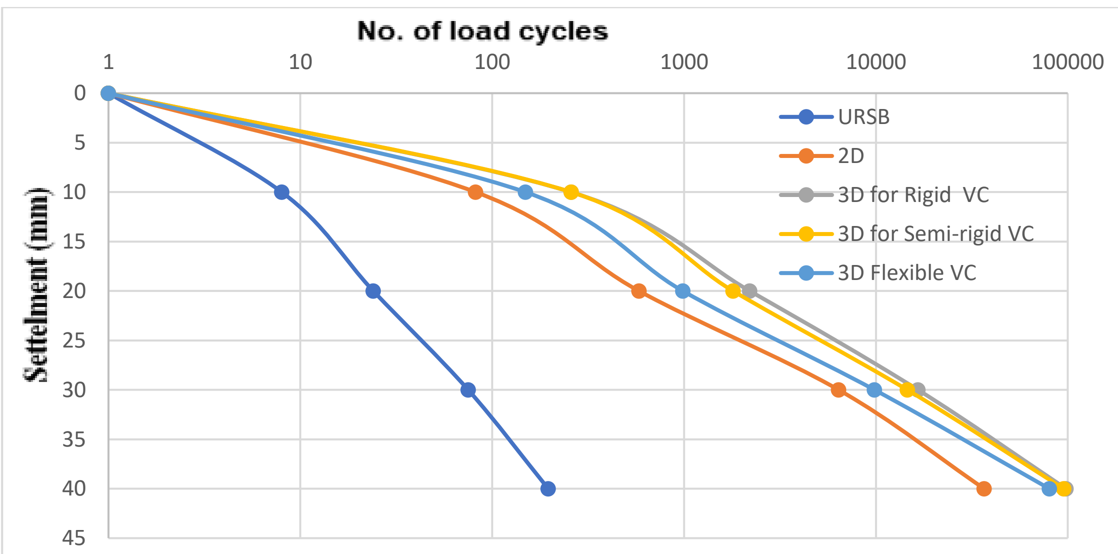

Fig. 16. Comparison of performance of square footing resting on unreinforced, 2D geogrid, and 3D geogrid with vertical confinement of H=4cm reinforced sand beds.

Fig 16 indicates that the number of load cycles resisted by surface footing resting on 3D geogrid with rigid vertical confinement of H=4cm reinforced sand beds is 98,010 cycles, whereas for 3D geogrid with semi-rigid vertical confinement of H=4cm reinforced sand beds is 95245 cycles. Similarly for 3D geogrid with flexible vertical confinement of H=4cm reinforced sand beds the number of load cycles resisted is 80,229 cycles.

This observation clearly demonstrates that the footing resting on 3D geogrid reinforced sand beds, the inclusion of rigid PVC pipes as a vertical confinement in 3D geogrid is more effective in taking more number of load cycles compared to the cases where semi-rigid and flexible PVC pipes are used as vertical confinement. Further with increase in the height of vertical confinement efficiency in resisting the number of load cycles is increased for all the three types of reinforcements.

a. Cyclic Resistance Ratio (CRR)

The effect of height of PVC pipes in 3D reinforcement is verified by cyclic resistance ratio. It is the ratio of the number of loading cycles resisted by the reinforced sand beds to the number of loading cycles resisted by the unreinforced sand beds at same settlement levels.

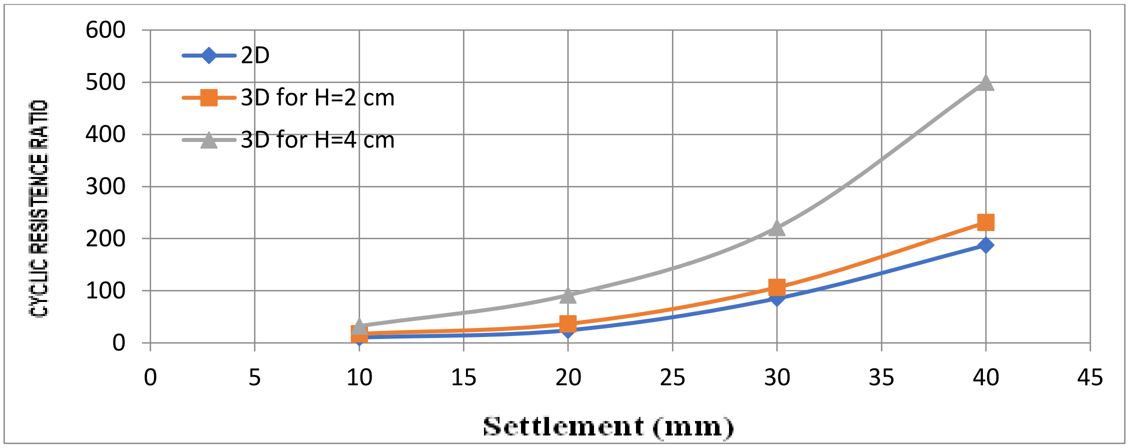

Fig. 17. Comparison of CRR for square footing resting on unreinforced, 2D geogrid, and 3D geogrid reinforced sand beds.

To bring out the effect of inclusion of geogrid (2D) and geogrid with vertical confinement (3D) comparison of results are made for optimum reinforcement condition both in 2D geogrid and 3D geogrid reinforced sand beds. Fig. 17 shows that CRR for 2D geogrid reinforced sand beds is quite lower as compared to 3D geogrid irrespective height of vertical confinement, this clearly show that, inclusion of 3D reinforcement significantly improves the Cyclic Resistance Ratio of sand beds compared to 2D reinforced sand beds. Further, in 3D geogrid reinforced sand beds, increase in the height of PVC pipes in vertical direction further improves the confining action of sand particles, which in turn improves the CRR.

b. Settlement Ratio

The effect of height of PVC pipes in 3D reinforcement is further verified by the settlement aspect ratio in terms of settlement ratio (SR). It is defined as the ratio of settlement of reinforced sand bed after N number of cycles to the settlement of unreinforced sand beds at identical number of cycles N.

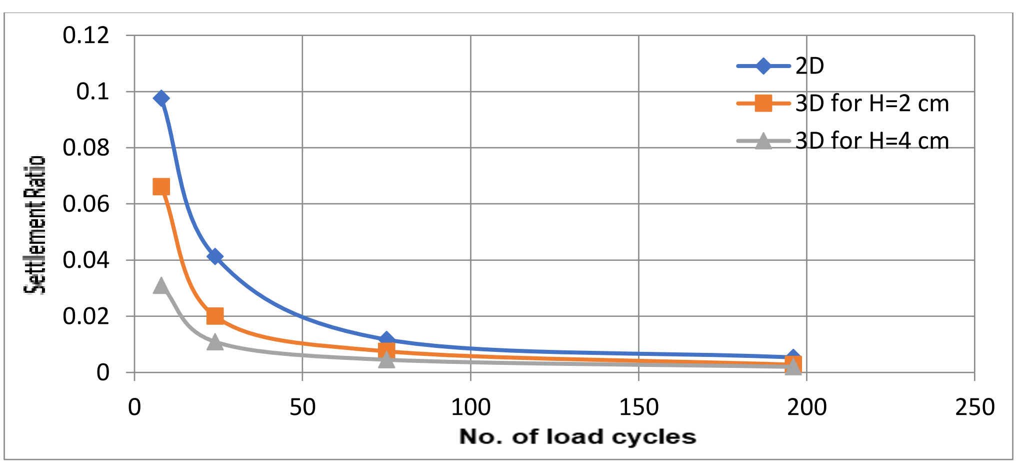

Fig 18. Comparison of SR for square footing resting on 2D geogrid, and 3D geogrid reinforced sand beds.

Fig. 18 presents the variation of Settlement Ratio with number of load cycles, SR is for three layers of 2D reinforced sand bed with reinforcement spacing 0.3B. SR for 2D geogrid reinforced sand beds is higher as compared to 3D geogrid irrespective of height of vertical confinement, this clearly shows that, inclusion of 3D reinforcement significantly reduces the Settlement Ratio of sand beds compared to 2D reinforced sand beds. Further, in 3D geogrid reinforced sand beds, increase in the height of PVC pipes in vertical direction further improves the confining action of sand particles, which in turn decreases settlement of footing.

CONCLUSIONS

1) In general, 3D geogrid reinforced sand beds have shown better performance compared with unreinforced sand bed irrespective of number of reinforcement layers and spacing between the reinforcement under repeated loads.
2) Based on the vertical confinement of 3D geogrid reinforced sand provided
   a) For H=2cm in 3D geogrid; U/B=0.4, N=3 and S/B=0.3
   b) For H=4cm in 3D geogrid; U/B=0.4, N=3 and S/B=0.4

   Exhibited better results compared to the other reinforcement configuration.
3) In 3D geogrid reinforced sand bed, increase in the height of vertical confinement (H=4cm), the SR decreases and CRR value increases compared with vertical confinement (H=2cm).
4) In 3D geogrid reinforced sand bed, the performance of 3D geogrid with rigid vertical confinement perform better compared with semi-rigid and flexible vertical confinement.
5) In 3D geogrid reinforced sand bed with optimum reinforcement condition the CRR value increased to 500 time compared with unreinforced sand bed at 40mm settlement of the footing and SR value decreases to 0.03 times compare with unreinforced sand bed at same settlement level.

The performance of square model footing resting over 3D geogrid reinforced sand bed was improved when compared with unreinforced sand bed, which confirms the improvement resulting in increasing the load carrying capacity against repeated loading and also decreases the footing settlement on repeated loading.

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