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The use of crushed aggregate to improve the performance of sand columns

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ABSTRACT: In recent years, land developers and engineers have been forced to consider land, previously dismissed due to poor founding conditions, as potential development sites in response to increasing urban populations and demand for services. The two most popular forms of addressing these poor founding conditions have been deep foundations or ground improvement techniques. Deep foundations focus on transferring the imposed loads of a structure onto suitable strata layers. Ground improvement techniques, on the other hand, improve the in-situ parameters of the soil and thus can be more cost-effective as well as more environmentally friendly. 26 bench scale tests were conducted where the stone aggregate diameter and concentration were varied. Results indicated that there is a marked improvement in the load-settlement behaviour of the column with the inclusion of the stone aggregate in the column material. An average increase of 6.4% in the bearing capacities was observed when increasing aggregate concentrations and an average 5.0% increase was observed when increasing the aggregate size. These results provide a positive indication that sand columns, strengthened with stone aggregate, and can be proven to be an efficient alternative to deep foundations in future developments in South Africa.

1 INTRODUCTION

The human population has grown at a rapid rate over the past several decades (United Nations Department of Economic & Social Concerns 2016), as has the need to provide housing and other basic services for the growing population, particularly in urban areas. Many of these urban areas are located within the vicinity of coastlines or other major bodies of water such as lakes, dams or rivers. Many of the portions of land within these urban areas with adequate founding conditions have either been developed, protected for conservation purposes or earmarked for alternative uses. As a result of this, land developers and engineers are forced to consider sites with substandard founding conditions as sites for potential developments.

According to Agis (2011), approximately 40 % of South Africa is covered under what can be described as “poor soil conditions” (Sobhee-Beetul 2012). Classified as “Class 22” soils, these soils are characterised as having “imperfect drainage, high swell / shrinkage potential, plastic and sticky”. These conditions often mean that engineers can design buildings with shallow foundations which are relatively inexpensive, easy to design and construct, as well as capable of transferring the structural load to the ground. Sites with good founding conditions typically have the following characteristics (Jones & Davies 1985):

- High bearing capacities
- High shear strength characteristics
- Low compressibility

However, sites with poor ground conditions often force engineers to adapt the design of foundations to ensure the building’s stability. The two primary methods of dealing with these poor conditions are deep foundations and ground improvement techniques (Hughes & Withers 1974, Som & Das 2006, Craig 2012). Deep foundations often consist of concrete or steel piles which transfer the structural load through poor strata layers to lower, stiffer strata layers via friction and end bearing.

Ground techniques, on the other hand, offer an alternative to deep foundations and focus on improving the shear strength properties of the marginal strata layers and are often more economical and environmentally friendly than deep foundations. Ground improvement techniques improve soil conditions by either decreasing the pore water pressure and the void ratio of the soil or adding a stronger material / strengthening agent to the soil (Nicholson 2015, Stapelfeldt 2012).

There are numerous ground improvement techniques available to engineers today and it is the responsibility of the engineer to choose the most appropriate one. Some of them are:

- Inclusions
- Vibration
- Dewatering
- Chemical additions

Aggregate columns, also referred to as granular piles, are a simple pre-bored hole in the ground, filled with a coarse, stiff material such as sand or stone (Ambily & Ghandi 2007). This technique improves the load-bearing capacity, reduces settlement, increases the rate of consolidation and mitigates liquefaction (Isaac & Madhavan 2009).

Stone columns have become popular methods for ground improvement in Europe and have been extensively used since the 1950s; however, they remained largely unused in the USA until 1972 (Barksdale & Bachus 1983). In modern days, stone columns can be made up to 15 m long, 0.5 m in diameter, and support loads of up to 300 kN each (Hughes & Withers 1974).

Aggregate columns have also proved to be one of the most versatile methods available today due to their ease of installation and relatively small impact on the environment (Barksdale & Bachus 1983)

2 OBJECTIVES OF THE STUDY

The primary objective of this paper was to determine the effect of the inclusion of aggregate on the strength and settlement characteristics of bench-scale sand columns, specifically, the pressure required to deflect the column a predetermined distance. To achieve this aim, the following parameters of the columns were varied:

- Aggregate concentration
- Aggregate size
- Moisture content

Variables such as column length, column diameter and the base and column materials were kept constant throughout this investigation.

3 METHODOLOGY

The three primary materials used during this investigation were Durbanville Clay, Cape Flats Sand and crushed stone aggregate.

The Durbanville and Cape Flats materials were first oven-dried for 24 hours before being air-cooled. The clay was then mixed in 5 kg batches using a Tyrone industrial mixer with the appropriate volume of water to ensure consistent moisture content at either Liquid Limit (LL) or Optimum Moisture Content (OMC).

Each test specimen was prepared in a 550 mm high, 326 mm diameter cylindrical, stainless steel tank with a wall thickness of 13 mm. The inner walls of the tank were coated in a thin layer of oil to prevent adhesion before the clay was placed in 50 mm layers until a height of 400 mm was attained. Each layer was compacted using a 290 mm diameter wooden board and a 2 kg square base rammer which was dropped 12 times from a height of 180 mm.

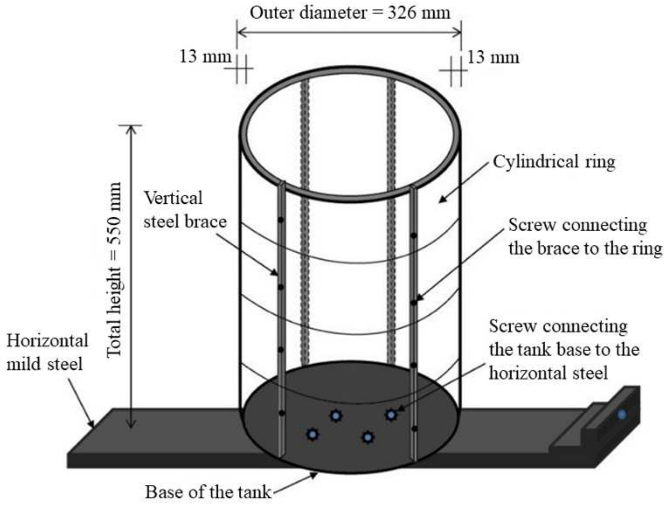

Figure 1. Diagram of the cylindrical tank (Ruben 2014)

Once the clay had been placed within the tank and compacted, a steel cylindrical auger, with an internal diameter of 100 mm, was then inserted into the centre of the compacted clay and the clay within the central cylinder was augered out. The steel cylinder was then extracted an initial 35 mm and the first layer of the column was poured into the auger and compacted. Afterwards, the cylinder was extracted 50 mm for each column layer until the desired height was reached.

Once the test specimen was adequately prepared, the tank was placed within the loading bay of the Zwick machine. A hollow steel cylinder was subsequently placed on the centre of the 200 mm loading plate and the Zwick machine was lowered manually until the loading plate was in contact with the steel cylinder. A software package called TestXpert was used to record the pressure and the correlating displacement measurements during testing, as well as plot the relationship between the two variables.

Figure 2. Test specimen at LL, with the loading plate and cylinder, prior to testing

Once the specimen was in place and the Zwick loading plate was in contact with the steel cylinder, the TestXpert software was opened up on the personal computer attached to the Zwick machine. A thorough check of all the testing characteristics were correct was the performed and the force measured by the machine was manually set to zero.

Table 1. Identification sequence & description

Identification symbol	Description
M1	Details a test done using Durbanville Clay at Liquid Limit
M2	Details a test done using Durbanville Clay at Optimum Moisture Content
S	Details a test done with a sand column installed
A1	Details a test done with 6mm aggregate
A2	Details a test done with 9mm aggregate
A3	Details a test done with 13mm aggregate
C1	Details a test done with a sand column containing a 20% concentration of aggregate by mass
C2	Details a test done with a sand column containing a 30% concentration of aggregate by mass
C3	Details a test done with a sand column containing a 40% concentration of aggregate by mass

4 RESULTS

4.1 *Effective moisture content*

Moisture content was found to influence the overall shape of the graph, as seen in Figure 3. At LL and OMC, both graphs begin with a relatively steep gradient before tapering off. However, at LL, the gradient continues to taper off. At OMC, the graphs all exhibit an increase in gradient after 10 mm deflection, the gradients begin to flatten out. The initial tapering off was attributed to the initial settlement of the column material, since the pressure applied would have resulted in a reduction of air voids. However, the continued tapering of the gradients at LL and the steepening of the gradients at OMC were attributed to the moisture content. The clay at LL was found to have less lateral bearing capacity than at OMC. After initial settlement, the column material either bulged outwards (at LL) or took up the vertical load applied (at OMC).

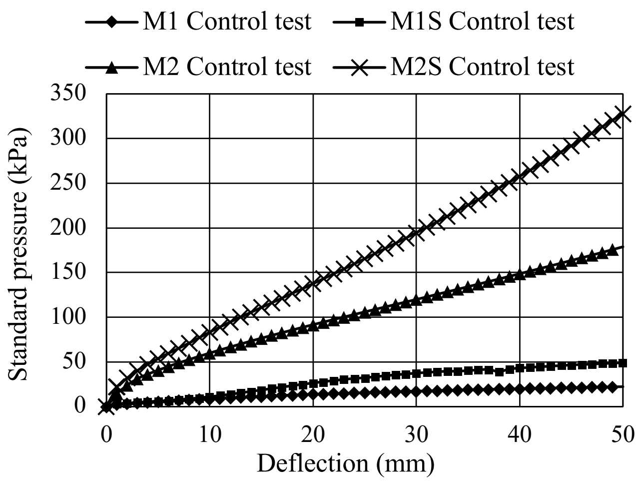

Figure 3. Effect of moisture content

4.2 *Effect of aggregate concentration*

Figures 4 to 9 show the relationship between the concentration of aggregate within a sand column and the load-settlement behaviour. The graphs exhibit a small degree of improvement as the aggregate concentration increases over all three aggregate sizes. An increase in the aggregate concentration resulted in an average increase of 6.4 % in the load bearing capacity of the columns with a standard deviation of 3.1 %. The maximum and minimum observed increases were 13.2 % and 2.7 % respectively.

All graphs presented in figures 4 to 9 have some discrepancy in the initial load-settlement behaviour. Some graphs displayed higher initial load bearing capacities yet went on to have a smaller final load bearing capacity. This behaviour was attributed to the imperfections in the columns, such as small clusters of aggregate that may have provided an initial increased load bearing capacity. However, for this investigation, only the final load bearing capacity was examined.

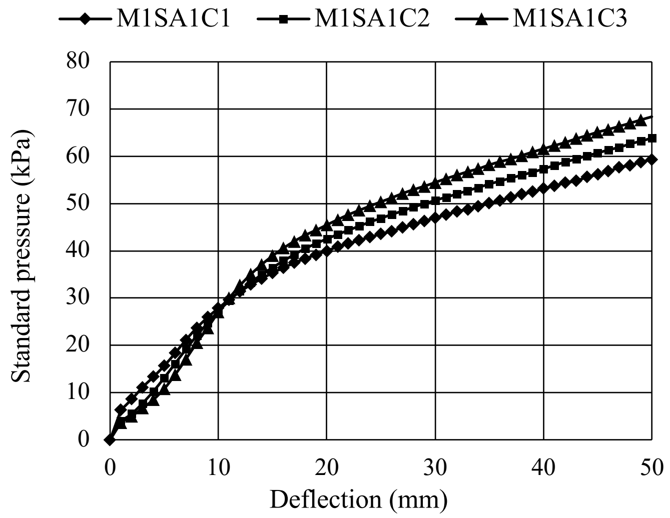

Figure 4. Load-settlement response for sand columns containing 6mm aggregate at LL

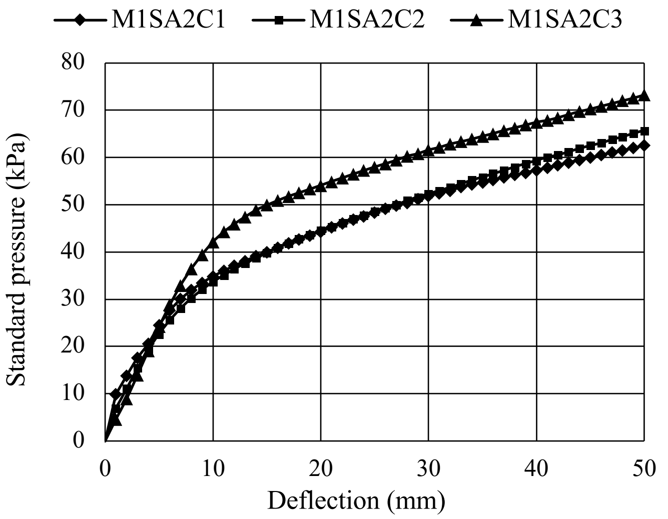

Figure 5. Load-settlement response for sand columns containing 9mm aggregate at LL

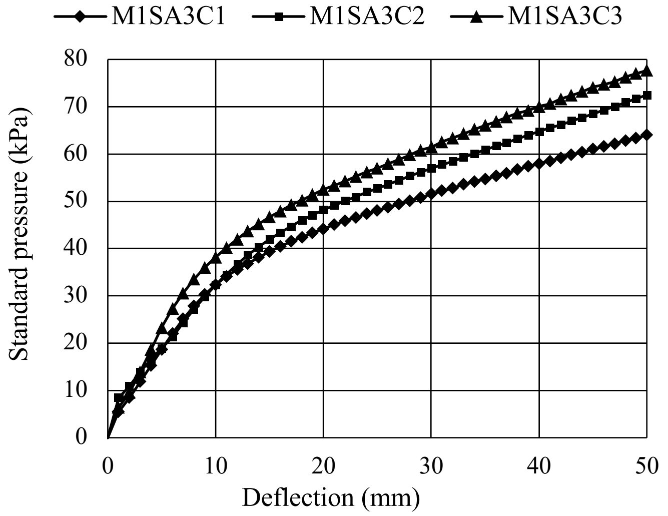

Figure 6. Load-settlement response for sand columns containing 13mm aggregate at LL

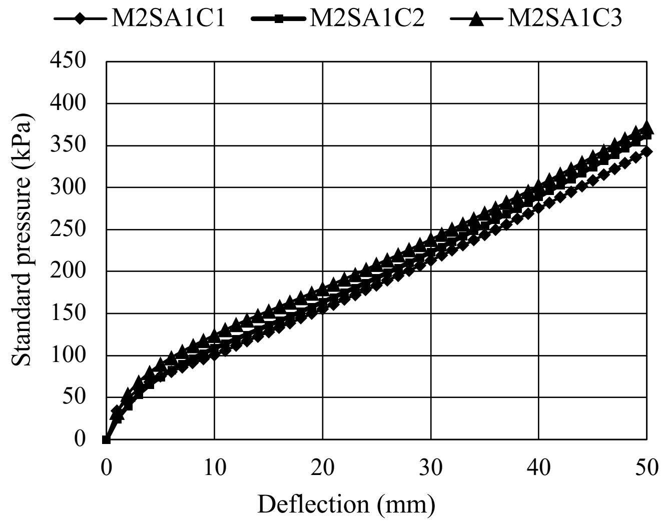

Figure 7. Load-settlement response of sand columns containing 6mm aggregate at OMC

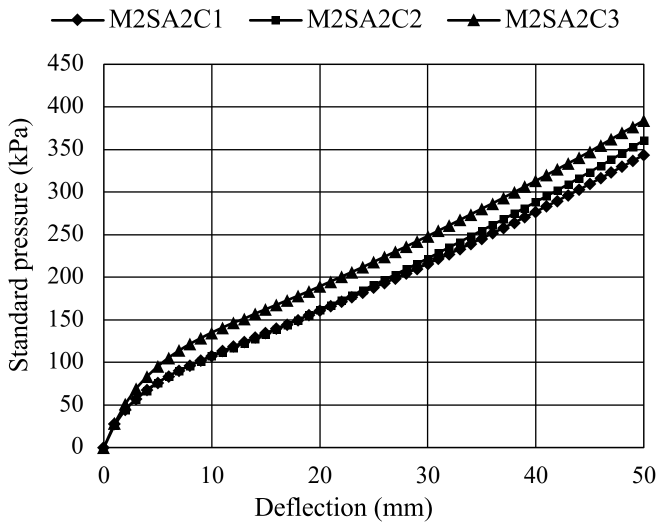

Figure 8. Load-settlement response of sand columns containing 9mm aggregate at OMC

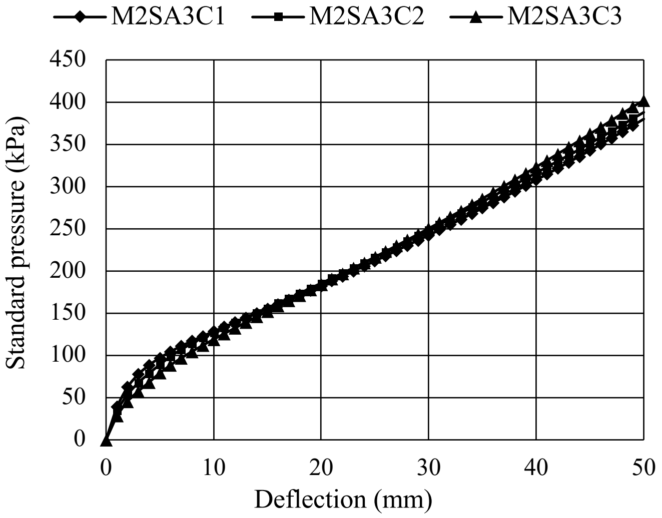

Figure 9. Load-settlement response of sand columns containing 13mm aggregate at OMC

4.3 *Effect of aggregate size*

Figures 10 to 15 show the relationship between the size of aggregate with a sand column and the load-settlement behaviour. The graphs exhibit a small degree of improvement in the load bearing capacity with every increase in aggregate size over all three concentrations. The average increase in the load bearing capacity was 5.0 % with a standard deviation of 3.4 %. The maximum and minimum increases were 10.2 % and 0.2 % respectively.

Increasing the aggregate size produced increases in the load bearing capacity in all cases, except for the M2SA2C2 and M2SA2C3 columns, where a decrease of 0.7 % was observed. Given the overall trend observed as well as literature reviewed, this was considered an anomaly.

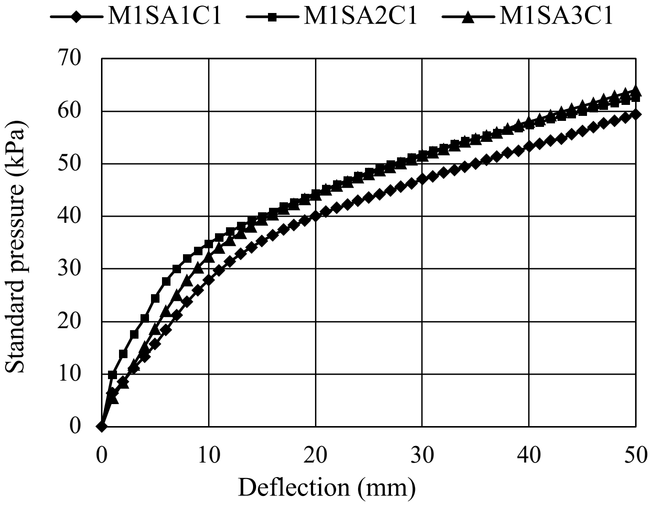

Figure 10. Load-settlement response of sand columns containing 20% aggregate at LL

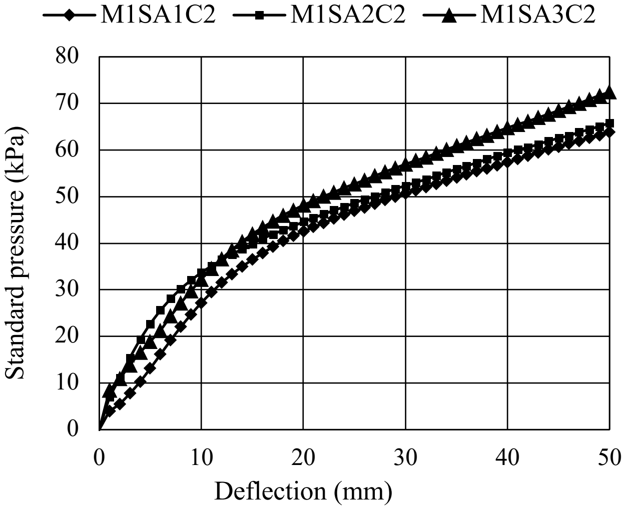

Figure 11. Load-settlement response of sand columns containing 30% aggregate at LL

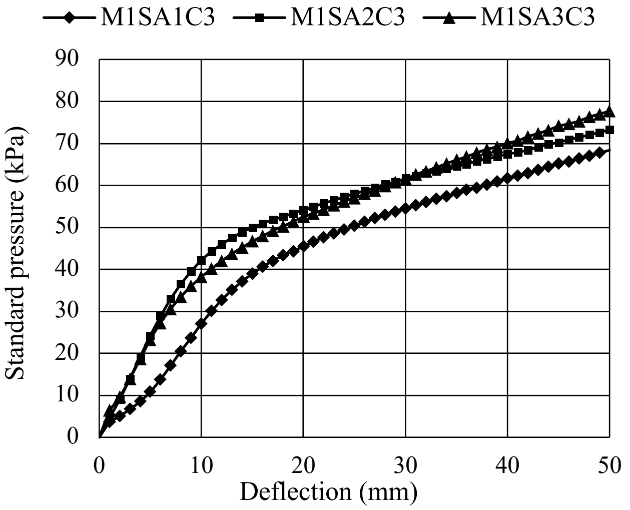

Figure 12. Load-settlement response of sand columns containing 40% aggregate at LL

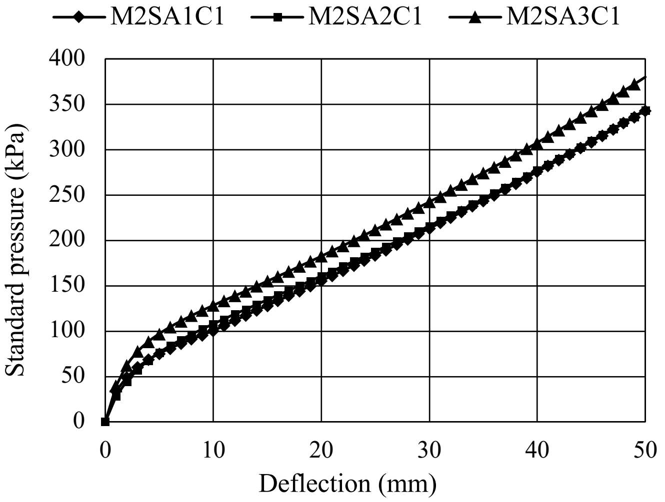

Figure 13. Load-settlement response of sand columns containing 20% aggregate at OMC

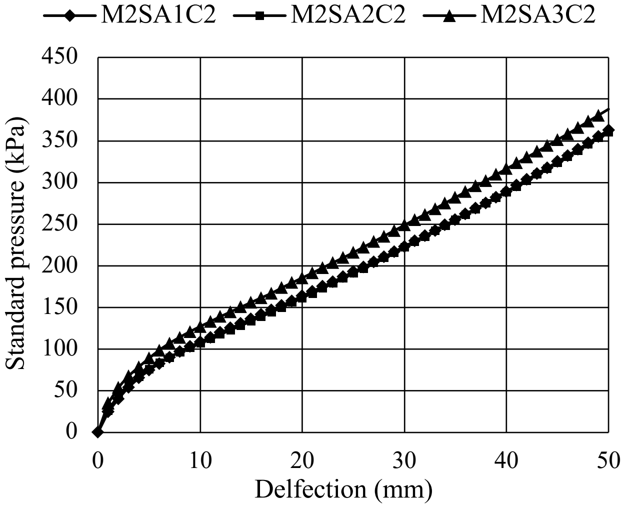

Figure 14. Load-settlement response of sand columns containing 30% aggregate at OMC

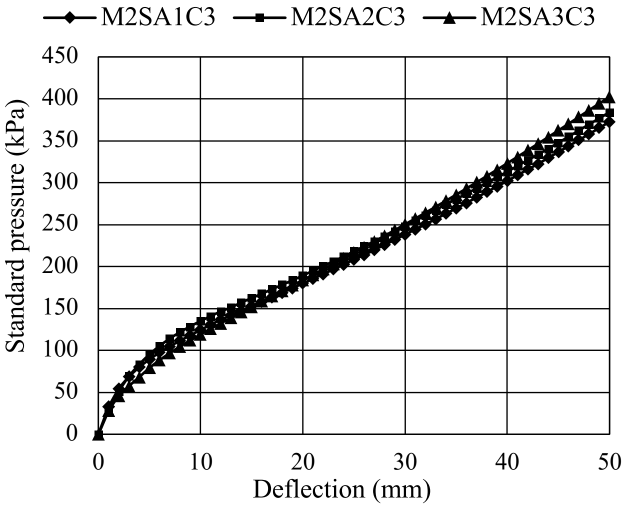

Figure 15. Load-settlement response of sand columns containing 40% aggregate at OMC

5 CONCLUSIONS & RECOMMENDATIONS

The aim of this investigation was to investigate the effect of crushed aggregate inclusions in sand columns set in a typical South African clay. A total of 26 experiments were conducted, including two repeatability tests and two control tests for both moisture contents, with varying aggregate concentrations and sizes included in the sand columns.

5.1 *Conclusions*

The following conclusions were drawn from this study:

5.1.1 *Effect of aggregate concentration*

The load bearing capacity of the sand column was improved as the ratio of crushed aggregate to sand within the column increased. A mean increase of 6.4% was observed in the final load bearing capacities of the columns. A comparison of all the final bearing capacities also yielded a standard deviation of 3.4%.

5.1.2 *Effect of aggregate size*

The load bearing capacity of the test specimen increased as the size of the aggregate included within the column increased. An overall increase of 5.0% was observed in the final load bearing capacities, with a standard deviation of 3.1%.

5.2 *Recommendations*

Based on the results obtained in this investigation, as well as if further bench-scale models produce positive results, full scale models of the columns, varying other parameters such as column width, column diameter, column spacing, and the materials used in the columns, can be installed and tested. This would help engineers gain a more accurate understanding of their behaviour and failure mechanisms

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