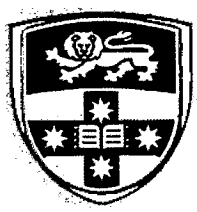
STRENGTH AND STIFFNESS IMPROVEMENT OF BIO-CEMENTED SYDNEY SAND

By

Youventharan DURAISAMY

B.Eng. (Hons) (Civil Engineering), M.Sc. (Geotechnical and Geological Engineering)

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy
School of Civil Engineering
The University of Sydney



THE UNIVERSITY OF SYDNEY

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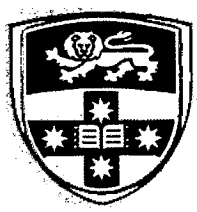

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ABSTRACT

This thesis explores the performance of small scale cemented soil columns produced using soil mixing with cement resulting from bacterially mediated reactions that precipitate calcium carbonate, a process often referred to as bio-cementation. Bio-cementation has received considerable research attention over the last decade as it has the potential to complement existing ground improvement techniques and mitigate environmental concerns with currently used materials. Previous research has concentrated on pumping and injection techniques because of concerns that bacteria will be unable to survive the stresses associated with industrial mixing processes, however it has been difficult to create uniform bio-cemented soil masses. In this thesis the ureolytic bacterium, *Bacillus Megaterium,* not previously reported in bio-cementation studies, has been investigated to determine its viability and efficiency as a microbe for mediating the calcite precipitation. It has been found that the highest hydrolysis rate is recorded when calcium concentrations are double the urea concentrations, and that significant amounts of calcite can be precipitated in a single mixing process. Unconfined compressive strength (UCS) tests and a series of triaxial tests have been conducted to quantify the effects of the bio-cementation on the mechanical response. Bender elements mounted in the triaxial cell have also been used to monitor the shear wave velocity during curing and shearing. The results of mechanical tests on the bio-cemented sand have been compared with tests on gypsum cemented and uncemented specimens. It has been found that bio-cementation by mixing produces homogeneous specimens with similar strengths and stiffnesses to the commonly used flushing or injection technique. To assess the performance of in-situ mixed, 38 mm diameter, bio-cemented sand columns a small scale in-situ mixing technique was used to create the model columns. Foundation tests have been performed at 1-g in a cylindrical tank with diameter of 600 mm. A significant improvement was observed in the response of foundations when placed on bio-cemented columns, and this was similar to the improvement from more conventional gypsum cements. These tests confirmed the feasibility of using an in-situ mixing technique with bio-cementation and provided valuable insight into the factors that must be considered in developing field applications.

This thesis also has demonstrated repair strategies and techniques to encourage healing and self-healing should damage occur in foundations. Results from tests performed to investigate the ability of biocement to repair cemented soil columns are reported.

BIBLIOGRAPHY AND REFERENCES

Abdulla, A.A. & Kiousis, P.D. (1997). Behavior of cemented sands-I. Testing. *International Journal for Numerical and Analytical Methods in Geomechanics*. 21(8), 533-547.

Achal, V., Mukherjee, A., Basu, P., & Reddy, M. (2009). Strain improvement of Sporosarcina pasteurii for enhanced urease and calcite production. *Journal of Industrial Microbiology & Biotechnology, 36*(7), 981-988.

Achal, V., & Pan, X. (2011). Characterization of Urease and Carbonic Anhydrase Producing Bacteria and Their Role in Calcite Precipitation. *Current Microbiology, 62*(3), 894-902.

Adams, M., & Collin, J. (1997). Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundations. *Journal of Geotechnical and Geoenvironmental Engineering, 123*(1), 66-72.

Airey, D. W. (1993). Triaxial Testing of Naturally Cemented Carbonate Soil. *Journal of Geotechnical Engineering, 119*(9), 1379-1398.

Airey, D., & Mohsin, A. (2013). Evaluation of shear wave velocity from bender elements using cross-correlation. *Geotechnical Testing Journal ASTM, 36*(4), 506-514.

Alexander, M. (1977). Introduction to soil microbiology, 2nd edition. John Wiley & Sons. New York: Cornell University.

Al-Tabbaa, A., Akinyugha, A., Unluer, C., Liska, M., & Yi, Y. (2013). Preliminary laboratory-scale model auger installation and testing of carbonated soil-MgO columns. *Geotechnical Testing Journal ASTM, 36*(3), 384-393.

Al-Tabbaa, A., & Ayotamuno, J. (1999). Laboratory-scale dry soil mixing of a sand A. Al-Tabbaa. *Dry Mix Methods for Deep Soil Stabilization*, 73.

Al-Tabbaa, A., & Harbottle, M. (2015). *Self-healing materials and structures for geotechnical and geo-environmental applications.* Paper presented at the Geotechnical Engineering for Infrastructure and Development-Proceedings of the XVI European Conference on Soil Mechanics and Geotechnical Engineering, ECSMGE 2015.

Al Thawadi, S.M. (2008). *High strength in-situ biocementation of soil by calcite precipitating locally isolated ureolytic bacteria.* Murdoch University, Australia. PhD Thesis: 264.

Al Thawadi, S.M., & Cord-Ruwisch, R. (2012). Calcium carbonate crystals formation by ureolytic bacteria isolated from Australian soil and sludge. *J. Adv. Sci. Eng. Res, 2*(1).

Al Qabany, S.M., Mortensen, B.M., Martinez, B.C., Soga, K., and Dejong, J.T. (2011). Microbial Carbonate Precipitation: Correlation of S-wave velocity with calcite precipitation. *ASCE Geo-Institute Annual Conference: Geo-Frontiers 2011*, Dallas, TX:3993-4001.

Al Qabany, A., & Soga, K. (2013). Effect of chemical treatment used in MICP on engineering properties of cemented soils. *Geotechnique, 63*(4), 331-339.

Ariyanti, D., Àbyor Handayani, N., & Hadiyanto, H. (2011). An Overview of Biocement Production from Microalgae. *International Journal of Science and Engineering, 2(2)*, 31-33.

Arunachalam, K.D., Sathyanarayanan, K.S., Darshan, B.S., & Rajagopal, R.B. (2010). Studies on the Characterisation of Biosealant properties of Bacillus sphaericus. *International Journal of Engineering, Science and Technology, 2*, 270-277.

Asghari, E., Toll, D.G., and Haeri, S.M. (2003). Triaxial behavior of a cemented gravelly sand, Tehran Alluvium. *Geotechnical and Geological Engineering*. 21(1),1-28.

Bachmeier, K.L., Williams, A.E., Warmington, J.R., & Bang, S.S. (2002). Urease activity in microbiologically-induced calcite precipitation. *Journal of Biotechnology, 93*(2), 171-181.

Bang, S.S., Lippert, J.J., Yerra, U., Mulukutla, S. and Ramakrishna, V. (2010). Microbial calcite, a bio-based smart nanomaterial in concrete remediation. *International Journal of Smart and Nano Materials*. 1(1), 28-39.

Bang, S.S., Galinat, J.K., and Ramakrishna, V. (2001). Calcite precipitation induced by polyurethane-immobilized bacillus pasteurii. *Enzyme and Microbial Technology*. 28(4), 404-409.

Bäuerlein, E. (2003). Biomineralization of Unicellular Organisms: An Unusual Membrane Biochemistry for the Production of Inorganic Nano-and Microstructures. *Angewandte Chemie International Edition, 42*(6), 614-641.

Barkouki, T., Martinez, B., Mortensen, B., Weathers, T., De Jong, J., Ginn, T., . . . Fujita, Y. (2011). Forward and Inverse Bio-Geochemical Modeling of Microbially Induced Calcite Precipitation in Half-Meter Column Experiments. *Transport in Porous Media*, 90(1), 23-39.

Black, J., Sivakumar, V., & McKinley, J. D. (2007). Performance of clay samples reinforced with vertical granular columns. *Canadian Geotechnical Journal, 44*(1), 89-95.

Bolton, M. (1986). The strength and dilatancy of sands. *Geotechnique, 36*(1), 65-78.

Boquet, E., Boronat, A., & Ramos-Cormenzana, A. (1973). Production of Calcite (Calcium Carbonate) Crystals by Soil Bacteria is a General Phenomenon. *Nature, 246*(5434), 527-529.

Bosch, R., Moore, E. R., García-Valdés, E., & Pieper, D. H. (1999). NahW, a novel, inducible salicylate hydroxylase involved in mineralization of naphthalene by Pseudomonas stutzeri AN10. *Journal of Bacteriology, 181*(8), 2315-2322.

Bouassida, M., & Hadhri, T. (1995). Extreme load of soils reinforced by columns: the case of an isolated column. *Soils and Foundations, 35*(1), 21-35.

Bouassida, M., & Porbaha, A. (2004). Ultimate bearing capacity of soft clays reinforced by a group of columns-application to a deep mixing technique. *Soils and Foundations, 44*(3), 91-101.

Braissant, O., Cailleau, G., Dupraz, C., & Verrecchia, E.P. (2003). Bacterially induced mineralization of calcium carbonate in terrestrial environments: the role of exopolysaccharides and amino acids. *Journal of Sedimentary Research, 73*(3), 485-490.

Bruce, D.A. (2000). An introduction to the deep soil mixing methods as used in geotechnical applications (No. FHWA-RD-99-138).

Brussaard, L. (1997). Biodiversity and Ecosystem Functioning in Soil. *Ambio.* 26(8), 563-570.

Bryant, R.S. (1991). MEOR screening criteria fit 27% of U.S. oil reservoirs. *Oil Gas Journal,* 89(15), 56-59.

Burbank, M.B., Weaver, T.J., Williams, B.C., & Crawford, R.L. (2012). Urease Activity of Ureolytic Bacteria Isolated from Six Soils in which Calcite was Precipitated by Indigenous Bacteria. *Geomicrobiology Journal, 29*(4), 389-395.

Buscot, F. & Varma, A. (2005). *Microorganisms in Soils: Roles in Genesis and Functions.* Germany: Springer.

Bills, P. M., & Lewis, D. (1975). A structural study of gallstones. *Gut, 16*(8), 630-637.

Carlson, B.M., & Faulkner, J.A. (1983). The regeneration of skeletal muscle fibers following injury: a review. *Medicine and science in sports and exercise, 15*(3), 187-198.

Castanier, S., Le Métayer-Levrel, G., & Perthuisot, J.P. (1999). Ca-carbonates precipitation and limestone genesis — the microbiogeologist point of view. *Sedimentary Geology, 126*(1), 9-23.

Cerato, A. B., & Lutenegger, A. J. (2007). Scale effects of shallow foundation bearing capacity on granular material. *Journal of Geotechnical and Geoenvironmental Engineering, 133*(10), 1192-1202.

Cheng, L., & Cord-Ruwisch, R. (2012). In situ soil cementation with ureolytic bacteria by surface percolation. *Ecological Engineering, 42*(0), 64-72.

Cheng, L., Cord-Ruwisch, R., & Shahin, M. A. (2013). Cementation of sand soil by microbially induced calcite precipitation at various degrees of saturation. *Canadian Geotechnical Journal, 50*(1), 81-90.

Cheng, L., Shahin, M., Cord-Ruwisch, R., Addis, M., Hartanto, T., & Elms, C. (2014). Soil stabilisation by Microbial-Induced Calcite Precipitation (MICP): Investigation into some physical and environmental aspects.

Chummar, A., & Vesic, A. (1973). Bearing capacity theory from experimental results. *Journal of Geotechnical and Geoenvironmental Engineering, 99*(sm7).

Clough, G.W., Rad, N.S., Bachus, R.C., & Sitar, N. (1981). Cemented sands under static loading. *Journal of the Geotechnical Engineering Division, 107*(6), 799-817.

Clough, G., Iwabuchi, J., Rad, N., & Kuppusamy, T. (1989). Influence of Cementation on Liquefaction of Sands. *Journal of Geotechnical Engineering, 115*(8), 1102-1117.

Consoli, N.C. (2009). Fundamental parameters for the stiffness and strength control of artificially cemented sand. *Journal of Geotechnical and Geoenvironmental Engineering*, 135(9), 1347.

Consoli, N.C., Rotta, G.V., and Prietto, P.M. (2000). The influence of curing under stress on the triaxial response of cemented soils. *Geotechnique,* 50(1), 99-106.

Consoli, N.C., Viana da Fonseca, A., Cruz, R.C., & Heineck, K.S. (2009). Fundamental parameters for the stiffness and strength control of artificially cemented sand. *Journal of Geotechnical and Geoenvironmental Engineering, 135*(9), 1347-1353.

Cooper, V.S., & Lenski, R.E. (2000). The population genetics of ecological specialization in evolving Escherichia coli populations. *Nature, 407*(6805), 736-739.

Cowell, L. (1985). *The effects of crop rotation history on nitogen and sulfur mineralization in Luvisolic soils.* (B.S.A. Degree), University of Saskatoon.

De Graef, B., De Windt, W., Dick, J., Verstraete, W., & De Belie, N. (2005). Cleaning of concrete fouled by lichens with the aid of Thiobacilli. *Materials and Structures, 38*(10), 875-882.

DeJong, J.T., Fritzges, M.B. and Nusslein, K. (2006). Microbially induced cementation to control sand response to undrained shear. *Journal of Geotechnical and Geoenvironmental Engineering,* 132(11), 1381-1392.

DeJong, J.T., Mortensen, B.M., Martinez, B.C. and Nelson, D.C. (2010). Bio-mediated soil improvement. *Ecological Engineering,* 36(2), 197-210.

DeJong, J.T., Soga, K., Banwart, S.A., Whalley, W.R., Ginn, T.R., Nelson, D.C., . . . Barkouki, T. (2010). Soil engineering in vivo: harnessing natural biogeochemical systems for sustainable, multi-functional engineering solutions. *Journal of the Royal Society Interface.*

DeJong, J.T., Soga, K., Kavazanjian, E., Burns, S., Paassen, L.A., Qabany, A.A., . . . Weaver, T. (2013). Biogeochemical processes and geotechnical applications: progress, opportunities and challenges. *Geotechnique, 63(4)*, 287-301.

De Muynck, W., Debrouwer, D., De Belie, N., & Verstraete, W. (2008). Bacterial carbonate precipitation improves the durability of cementitious materials. *Cement and Concrete Research, 38*(7), 1005-1014.

De Muynck, W., De Belie, N. Verstraete, W. (2010). Microbial carbonate precipitation in construction materials: A review. *Ecological Engineering,* 36(2), 118-136.

De Muynck, W., Verbeken, K., De Belie, N., & Verstraete, W. (2013). Influence of temperature on the effectiveness of a biogenic carbonate surface treatment for limestone conservation. *Applied Microbiology and Biotechnology, 97*(3), 1335-1347.

Dhami, N., Reddy, M.S., & Mukherjee, A. (2013). Bacillus megaterium mediated mineralization of calcium carbonate as biogenic surface treatment of green building materials. *World Journal of Microbiology and Biotechnology*, 29(12), 2397-2406.

Dick, J., De Windt, W., De Graef, B., Saveyn, H., Van der Meeren, P., De Belie, N., & Verstraete, W. (2006). Bio-deposition of a calcium carbonate layer on degraded limestone by Bacillus species. *Biodegradation., 17*(4), 357-367.

Dijkstra, J., Gaudin, C., & White, D. J. (2013). Comparison of failure modes below footings on carbonate and silica sands. *International Journal of Physical Modelling in Geotechnics, 13*(1), 1-12.

Dosier, G.K. (2014). *Methods for making construction material using enzyme producing bacteria: U.S. Patent No. 8,728,365*. Washington, DC: U.S. Patent and Trademark Office.

Douglas, S., & Beveridge, T.J. (1998). Mineral formation by bacteria in natural microbial communities. *FEMS microbiology ecology, 26*(2), 79-88.

Douglas, S. C., Schaefer, V. R., & Berg, R. R. (2012). Selection Assistance for the Evaluation of Geoconstruction Technologies for Transportation Applications. *Geotechnical and Geological Engineering, 30*(5), 1231-1247.

Dupraz, S., Parmentier, M., Ménez, B., & Guyot, F. (2009). Experimental and numerical modeling of bacterially induced pH increase and calcite precipitation in saline aquifers. *Chemical Geology, 265*(1), 44-53.

Duraisamy, Y., & Airey, D. (2015). Performance of biocemented Sydney sand using ex situ mixing technique. *The Journal of the Deep Foundations Institute, 9*(1), 48-56.

Duraisamy, Y., Airey, D., & Maggi, F. (2014). Urea hydrolysis rate of B. Megaterium for soil bio-cementation. *Proceedings of the 7th International Congress on Environmental Geotechnics*. Melbourne, Australia, 1143-1150.

Edvardsen, C. (1999). Water permeability and autogenous healing of cracks in concrete. *ACI Materials Journal, 96*(4).

Ehrlich, H.L. (1996). How microbes influence mineral growth and dissolution. *Chemical Geology, 132*(1), 5-9.

Ehrlich, H.L. (2002). Geomicrobiology, 4th Ed. Marcel Dekker, Inc., New York.

Ercole, C., Cacchio, P., Botta, A., Centi, V., & Lepidi, A. (2007). Bacterially induced mineralization of calcium carbonate: the role of exopolysaccharides and capsular polysaccharides. *Microscopy and Microanalysis., 13*(1), 42-50.

Farouk, A., & Shahien, M. M. (2013). Ground improvement using soil–cement columns: experimental investigation. *Alexandria Engineering Journal, 52*(4), 733-740.

Fernandez, A.L. and Santamarina, J.C. (2001). Effect of cementation on the small strain parameters of sand. *Canadian Geotechnical Journal.* 38(1), 191-199.

Ferris, C.F. (1996). Serotonin diminishes aggression by suppressing the activity of the vasopressin system. *Annals of the New York Academy of Sciences, 794*(1), 98-103.

Ferris, F.G., Phoenix, V., Fujita, Y., & Smith, R.W. (2004). Kinetics of calcite precipitation induced by ureolytic bacteria at 10 to 20°C in artificial groundwater. *Geochimica et Cosmochimica Acta, 68*(8), 1701-1710.

Fierer, N., Schimel, J.P., and Holdern P.A. (2003). Influence of drying rewetting frequency on soil bacterial community structure. *Microbial Ecology.* 45(1), 63-71.

Finlan, S., Quickfall, G., & Terzaghi, S. (2004). *Innovation in Slip and Settlement Remedials: The Soil Mixing Option.* Paper presented at the 9th Australia New Zealand Conference on Geomechanics, New Zealand.

Fortin, D., Ferris, F.G., and Beveridge, T.J. (1997). Surface mediated mineral development by bacteria. *Reviews in Minerology and Geochemistry*, 35(1), 391-428.

Fragaszy, R. J., Santamarina, J. C., Amekudzi, A., Assimaki, D., Bachus, R., Burns, S. E., . . . Tsouris, C. (2011). Sustainable development and energy geotechnology — Potential roles for geotechnical engineering. *KSCE Journal of Civil Engineering, 15*(4), 611-621.

Fritzges, M.B. (2005). *Biologically induced improvement of the response of sands*. Master thesis, University of Massachusetts, Amherst, MA,111.

Fujita, Y., Ferris, F.G., Lawson, R.D., Colwell, F.S., & Smith, R.W. (2000). Calcium carbonate precipitation by ureolytic subsurface bacteria. *Geomicrobiology Journal.* 17(4), 305-318.

Gerilla, G., Teknomo, K., & Hokao, K. (2007). An environmental assessment of wood and steel reinforced concrete housing construction. *Building and Environment, 42*(7), 2778-2784.

Ghosh, B., & Urban, M. W. (2009). Self-repairing oxetane-substituted chitosan polyurethane networks. *Science, 323*(5920), 1458-1460.

Gollapudi, U., Knutson, C., Bang, S., & Islam, M. (1995). A new method for controlling leaching through permeable channels. *Chemosphere, 30*(4), 695-705.

Guo, L., Huang, H., Gaston, D., & Redden, G. (2009). Modeling of calcite precipitation driven by bacteria-facilitated urea hydrolysis in a flow column using a fully coupled, fully implicit parallel reactive transport simulator. *AGU Fall Meeting Abstracts, 1*, 04.

Haeri, S.M., Hamidi, A., & Tabatabee, N. (2005). The effect of gypsum cementation on the mechanical behavior of gravelly sands. *Geotechnical Testing Journal ASTM.* 28(4), 380-390.

Hamdan, N., Kavazanjian, E., & Rittman, B.E. (2013). *Carbonate Cementation via Plant Derived Urease.* Paper presented at the 18th International Conference on Soil Mechanics and Geotechnical Engineering, France.

Hammes, F., Boon, N., De Villiers, J., Verstraete, W., Siciliano, S.D. (2003). Strain-specific ureolytic microbial calcium carbonate precipitation. *Applied and Environmental Microbiology.* 69(8), 4901-4909.

Hammes, F., & Verstraete, W. (2002). Key roles of pH and calcium metabolism in microbial carbonate precipitation. *Reviews in Environmental Science and Biotechnology*, 1(1), 3-7.

Hansen, L. M., & Solnick, J. V. (2001). Selection for Urease Activity during Helicobacter pylori Infection of Rhesus Macaques (Macaca mulatta). *Infection and Immunity, 69*(5), 3519-3522.

Harbottle, M. J., Lam, M.-T., Botusharova, S., & Gardner, D. R. (2014). Self-healing soil: Biomimetic engineering of geotechnical structures to respond to damage. *Proceedings of the 7th International Congress on Environmental Geotechnics*. Melbourne, Australia, 1121-1128.

Hardin, B. O., & Richart Jr, F. (1963). Elastic wave velocities in granular soils. *Journal of Soil Mechanics & Foundations Div, 89* (Proceeding Paper 3407).

Harkes, M.P., Paassen, L.A., Booster, J.L., Whiffin, V.S., & Loosdrecht, M.C.M. (2010). Fixation and distribution of bacterial activity in sand to induce carbonate precipitation for ground reinforcement. *Ecological Engineering, 36*(2), 112-117.

Huang, J. (1994). *The effects of density and cementation of soils.* PhD Thesis, University of Sydney.

Huang, J.T. & D.W. Airey (1998). Properties of artificially cemented carbonate sand. *Journal of Geotechnical and Geoenvironmental Engineering.* 124(6), 492-499.

Holtz, R.D. & Kovacs, W.D. (1981). An introduction to geotechnical engineering, NJ:Prentice Hall, Englewoods Cliffs, 733.

Hosoya, Y., Nasu, T., Hibi, Y., Ogino, T., Kohata, Y., & Makihara, Y. (1996). JGS TC Report: An evaluation of the strength of soils improved by DMM. *Grouting and Deep Mixing, Proceedings of IS-Tokyo, 96*, 14-17.

Inagaki, Y., Tsukamota, M., Hori, H., Sasaki , T., Soga, K., Al Qabany, A., & Hata, T. (2011). The influence of injection conditions and soil types on soil improvement by mircobial functions. *ASCE Geo-Institute Annual Conference: Geo-Frontiers 2011*, Dallas, TX:4021-4030.

IPCC. (2013). Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.

Ismail, M.A., Joer, H.A., Sim, W.H. & Randolph, M.F. (2002). Effect of cement type on shear behavior of cemented calcareous soil. *Journal of Geotechnical and Geoenvironmental Engineering*. 128(6), 520-529.

Ivanov, V. & Chu, J. (2008). Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. *Reviews in Environmental Science and Biotechnology*. 7(2), 139-153.

Joseph, C., Jefferson, A. D., Isaacs, B., Lark, R. J., & Gardner, D. R. (2010). Experimental investigation of adhesive-based self-healing of cementitious materials. *Magazine of Concrete Research, 62*(11), 831-843.

Jonkers, H. M. (2007). Self healing concrete: a biological approach. In *Self Healing Materials* (pp. 195-204): Springer Netherlands.

Jonkers, H.M., & Schlangen, E. (2007). *Crack repair by concrete-immobilized bacteria.* Paper presented at the Proceedings of the First International Conference on Self Healing Materials (pp. 18-20).

Jonkers, H. M., Thijssen, A., Muyzer, G., Copuroglu, O., & Schlangen, E. (2010). Application of bacteria as self-healing agent for the development of sustainable concrete. *Ecological Engineering, 36*(2), 230-235.

Juran, I., & Guermazi, A. (1988). Settlement Response of Soft Soils Reinforced by Compacted Sand Columns. *Journal of Geotechnical Engineering, 114*(8), 930-943.

Kaltwasser, H., Kramer, J., & Conger, W. (1972). Control of urease formation in certain aerobic bacteria. *Archive of Microbiology, 81*(2), 178-196.

Kamon, M. & Bergado, D.T. (1991). Ground Improvement Techniques. Paper presented at the 9th Asian Regional Conference on Soil Mechanics and Foundation. 2: 526-546.

Karatas, I. (2008). *Microbiological Improvement of the Physical Properties of Soils.* (Ph.D Degree Dissertation), Arizona State University, Arizona.

Karol, R.H. (2003). Chemical grouting and soil stabilization. New York, Marcel Dekker: 558.

Kasama, K., Zen, K., and Iwataki, K. (2006). Undrained shear strength of cement treated soils. *Soils and Foundations*. 46(2), 221-232.

Kildea, S., Ransbotyn, V., Khan, M. R., Fagan, B., Leonard, G., Mullins, E., & Doohan, F. M. (2008). Bacillus megaterium shows potential for the biocontrol of septoria tritici blotch of wheat. *Biological control, 47*(1), 37-45.

Kim, Y.Y., Schenk, A. S., Walsh, D., Kulak, A. N., Cespedes, O., & Meldrum, F. C. (2014). Bio-inspired formation of functional calcite/metal oxide nanoparticle composites. *Nanoscale, 6*(2), 852-859.

Kitazume, M., & Terashi, M. (2013). *The deep mixing method*: CRC Press.

Knudsen, K.L., Sowers, J.M., Witter, R.C., Wentworth, C.M., & Helley, E.J. (2000). Description of mapping of quaternary deposits and liquefaction susceptibility, nine-county San Francisco Bay Region, California. *Rep. No. United States Geologic Survey Open-File Report 00, 444.*

Kokusho, T. (1980). Cyclic triaxial test of dynamic soil properties for wide strain range. *Soils and Foundations, 20*(2), 45-60.

Kramer, S. L., & Mitchell, R. A. (2006). Ground motion intensity measures for liquefaction hazard evaluation. *Earthquake Spectra, 22*(2), 413-438.

Krumbein, W., & Cohen, Y. (1977). Primary production, mat formation and lithification: contribution of oxygenic and facultative anoxygenic cyanobacteria *Fossil Algae* (pp. 37-56): Springer Berlin Heidelberg.

Kucharski, E., Price, G., Li, H., & Joer, H. (1996). *Engineering properties of CIPS cemented calcareous sand.* Paper presented at the 30th International Geological Congress (pp. 92-97). Utrect, Netherlands.

Kucharski, E.S., Cord-Ruwisch, R., Whiffin, V., & Al-thawadi, S.M. (2012). Microbial biocementation. *U.S. Patent No. 8,182,604*. Washington, DC: U.S. Patent and Trademark Office.

Landa, V.R. (2007). *Microbial Activity in sediments: Effects on Soil Behavior.* (PhD Thesis), Georgia Institute of Technology.

Lee, M.-J., Choi, S.-K., & Lee, W. (2009). Shear Strength of Artificially Cemented Sands. *Marine Georesources and Geotechnology, 27*(3), 201-216.

Lee, S.G., & Calhoun, D.H. (1997). Urease from a potentially pathogenic coccoid isolate: purification, characterization, and comparison to other microbial ureases. *Infection and Immunity, 65*(10), 3991-3996.

Leonard, J. (1986). Increased rate of EOR brightens outlook. *Oil Gas Journal, 84*(15), 71-89.

Li, V.C., & Yang, E.H. (2007). Self healing in concrete materials. In *Self Healing Materials* (pp. 161-193): Springer.

Li, Y. (2014). *Mitigation of sand liquefaction using in situ production of biogas with biosealing.* (Doctoral dissertation), Iowa State University.

Lundgren, H. and Mortensen, K. (1953). Determination by the theory of plasticity of the bearing capacity of continuous footings on sand. Proceedings of 3rd International Conference on Soil Mechanics and Foundation Engineering, Zurich, Switzerland, Vol. 1, pp. 409-412.

MacLeod, F., Lappin-Scott, H., & Costerton, J. (1988). Plugging of a model rock system by using starved bacteria. *Applied and Environmental Microbiology, 54*(6), 1365-1372.

Madigan, M.T. & Martinko, J.M. (2003). Brock Biology of Microorganisms, 11th Ed. NJ: Prentice Hall, Upper Saddle River,992.

Malandraki, V., & Toll, D.G. (1996). The definition of yield for bonded materials. *Geotechnical and Geological Engineering, 14*(1), 67-82.

Martinez, B.C., & DeJong, J.T. (2009). *Bio-mediated soil improvement: load transfer mechanisms at the micro-and macro-scales.* Paper presented at the US–China Workshop on Ground Improvement Technologies, ASCE GSP.

Martinez, B.C., Dejong, J.T., Ginn, T.R., Montoya, B.M., Barkouki, T.H., Hunt, C., . . . Major, D. (2013). Experimental optimization of microbial-induced carbonate precipitation for soil improvement. *Journal of Geotechnical and Geoenvironmental Engineering, 139*(4), 587-598.

Martinez, B.C., T.H. Barkouki, DeJong, J.T. & Ginn, T.R. (2011). Upscaling of microbial induced calcite precipitation in 0.5m Columns: Experimental and Modeling Results, ASCE Geo-Institute Annual Conference: Geo-Frontiers 2011, Dallas, TX:4049-4059.

Matsuo, O., Shimazu, T., Goto, Y., Suzuki, Y., Okumura, R., & Kuwabara, M. (1996). *Deep mixing method as a liquefaction prevention measure.* Paper presented at the 2nd International Symposium on ground improvement geosystem, Tokyo.

Massarsch, K. (2005). *Deformation properties of stabilized soil columns.* Paper presented at the International Conference on Deep Mixing Best Practice and Recent Advances, Stockholm, Sweden.

Millo, C., Dupraz, S., Ader, M., Guyot, F., Thaler, C., Foy, E., & Ménez, B. (2012). Carbon isotope fractionation during calcium carbonate precipitation induced by ureolytic bacteria. *Geochimica et Cosmochimica Acta, 98*(0), 107-124.

Milligan, G.W.E., Fannin, R.J., Farrar, D.M., (1986). Model and full-scale tests of granular layers reinforced with a geogrid. In Proceedings of Third International Conference on Geotextiles, Vol. 1. Vienna, pp. 61–66.

Mitchell, A. C., & Ferris, F. G. (2005). The coprecipitation of Sr into calcite precipitates induced by bacterial ureolysis in artificial groundwater: Temperature and kinetic dependence. *Geochimica et Cosmochimica Acta, 69*(17), 4199-4210.

Mitchell, J. (1995). Reinforced Soil Structures with Poorly Draining Backfills Part II: Case Histories and Applications. *Geosynthetics International, 2*(1), 265-307.

Mitchell, J.K. (1993). Fundamentals of Soil Behavior. John Wiley and Sons, Inc.

Mitchell, J.K. & J.C. Santamarina (2005). Biological considerations in geotechnical engineering. *Journal of Geotechnical and Geoenvironmental Engineering.* 131(10), 1222-1233.

Mitchell, A.C., Dideriksen, K., Spangler, L.H., Cunningham, A.B., & Gerlach, R. (2010). Microbially Enhanced Carbon Capture and Storage by Mineral-Trapping and Solubility-Trapping. *Environmental Science & Technology, 44*(13), 5270-5276.

Mohsin, A.K.M. & D.W. Airey (2003). Automating G_{max} measurement in triaxial test. Paper presented at the *3rd International Symposium on the Deformation Characteristics of Geomaterials*, France.

Mohsin, A., & Airey, D. (2008). Using Gmax measurements to monitor degradation of an artificially cemented sand. *Deformational characteristics of geomaterials, 1*, 305-310.

Montoya, B.M., Dejong, J.T., & Boulanger, R.W. (2013). Dynamic response of liquefiable sand improved by microbial-induced calcite precipitation. *Geotechnique, 63*, 302-312.

Mora, E.P. (2007). Life cycle, sustainability and the transcendent quality of building materials. *Building and Environment, 42*(3), 1329-1334.

Mörsdorf, G., & Kaltwasser, H. (1989). Ammonium assimilation in Proteus vulgaris, Bacillus pasteurii, and Sporosarcina ureae. *Archives of Microbiology, 152*(2), 125-131.

Mortensen, B., Haber, M., DeJong, J., Caslake, L., & Nelson, D. (2011). Effects of environmental factors on microbial induced calcium carbonate precipitation. *Journal of Applied Microbiology, 111*(2), 338-349.

Mortensen, B.M. (2012). *Bio-mediated soil improvement and the effect of cementation on the behavior, improvement, and performance of sand.* (PhD Thesis), University of California, Davis.

Mortensen, B.M., Haber, M.J., DeJong, T.J., Caslake, L.F. & Nelson, D.C. (2011). Effects of environmental factors on microbial induced calcium carbonate precipitation. *Journal of Applied Microbiology.* 111(2), 338-349.

NEHRP, (2003). NEHRP Recommended provisions for seismic regulations for new buildings and other steel structures, Part 1: Provisions, Washington, D.C.

Nemati, M., Greene, E. A., & Voordouw, G. (2005). Permeability profile modification using bacterially formed calcium carbonate: comparison with enzymic option. *Process Biochemistry, 40*(2), 925-933.

Neville, A. (2002). Autogenous healing–a concrete miracle. *Concrete International, 24*(11), 76-82.

Ng, S. W., Lee, L. M., Tan, K. C., & Hii, L. S. (2013). Improvements in engineering properties of soils through microbial-induced calcite precipitation. *KSCE Journal of Civil Engineering, 17*(4), 718-728.

Novick, A. (1955). Growth of Bacteria. *Annual Review of Microbiology, 9*(1), 97-110.

Okwadha, G.D.O., & Li, J. (2010). Optimum conditions for microbial carbonate precipitation. *Chemosphere, 81*(9), 1143-1148.

Parks, S.L. (2009). *Kinetics of calcite precipitation by ureolytic bacteria under aerobic and anaerobic conditions.* (Doctoral Dissertation) Montana State University-Bozeman, College of Engineering.

Pentecost, A., & Bauld, J. (1988). Nucleation of calcite on the sheaths of cyanobacteria using a simple diffusion cell. *Geomicrobiology Journal, 6*(2), 129-135.

Periago, P. M., Conesa, R., Delgado, B., Fernández, P. S., & Palop, A. (2006). Bacillus megaterium Spore Germination and Growth Inhibition by a Treatment Combining Heat with Natural Antimicrobials. *Food Technology and Biotechnology, 44*(1), 17-23.

Popiel, C. O., Wojtkowiak, J., & Biernacka, B. (2001). Measurements of temperature distribution in ground. *Experimental Thermal and Fluid Science, 25*(5), 301-309.

Porbaha, A. (1998). State of the art in deep mixing technology: part I. Basic concepts and overview. *Proceedings of the ICE-Ground Improvement, 2*(2), 81-92.

Porbaha, A., Zen, K., & Kobayashi, M. (1999). Deep mixing technology for liquefaction mitigation. *Journal of infrastructure systems, 5*(1), 21-34.

Ramachandran, S.K., Ramakrishnan, V., & Bang, S.S. (2001). Remediation of concrete using microorganisms. ACI Material Journal. 98(1), 3-9.

Ramakrishna, V., Ramesh, K. P., & Bang, S.S. (2001). Bacterial concrete. In *Smart Materials and MEMS* (pp. 168-176). International Society for Optics and Photonics.

Ramakrishnan, V., Panchalan, R. K., & Bang, S. S. (2005). *Improvement of concrete durability by bacterial mineral precipitation.* Paper presented at the 11th International Conference on Fracture, Italy.

Ramanan, R., Kannan, K., Sivanesan, S. D., Mudliar, S., Kaur, S., Tripathi, A. K., & Chakrabarti, T. (2009). Bio-sequestration of carbon dioxide using carbonic anhydrase enzyme purified from Citrobacter freundii. *World Journal of Microbiology and Biotechnology, 25*(6), 981-987.

Rad, N.S. (1983). Static and dynamic behaviour of cemented sands. PhD Dissertation, Stanford University.

Redden, G., Fox, D., Zhang, C., Fujita, Y., Guo, L., & Huang, H. (2013). $CaCO_3$ precipitation, transport and sensing in porous media with in situ generation of reactants. *Environmental Science & Technology, 48*(1), 542-549.

Rebata-Landa, V., & Santamarina, J.C. (2006). Mechanical limits to microbial activity in deep sediments. *Geochemistry, Geophysics, Geosystems, 7*(11).

Reinhardt, H.W., & Jooss, M. (2003). Permeability and self-healing of cracked concrete as a function of temperature and crack width. *Cement and Concrete Research, 33*(7), 981-985.

Rivadeneyra, M.A., Delgado, G., Ramos-Cormenzana, A., & Delgado, R. (1998). Biomineralization of carbonates by Halomonas eurihalina in solid and liquid media with different salinities: crystal formation sequence. *Research in Microbiology, 149*(4), 277-287.

Rivadeneyra, M.A., Delgado, R., Quesada, E., & Ramos-Cormenzana, A. (1991). Precipitation of calcium carbonate by Deleya halophila in media containing NaCl as sole salt. *Current Microbiology, 22*(3), 185-190.

Roden, E.E., & Wetzel, R.G. (2002). Kinetics of microbial Fe (III) oxide reduction in freshwater wetland sediments. *Limnology and Oceanography, 47*(1), 198-211.

Rodríguez-Contreras, A., Koller, M., Miranda-de Sousa Dias, M., Calafell-Monfort, M., Braunegg, G., & Marqués-Calvo, M. S. (2013). High production of poly (3-hydroxybutyrate) from a wild Bacillus megaterium Bolivian strain. *Journal of Applied Microbiology, 114*(5), 1378-1387.

Rodriguez, O.G., & Hooton, R.D. (2003). Influence of cracks on chloride ingress into concrete. *ACI Materials Journal, 100*(2).

Rong, H., Qian, C.-x., & Li, L.-z. (2012). Influence of molding process on mechanical properties of sandstone cemented by microbe cement. *Construction and Building Materials, 28*(1), 238-243.

Rosenstein, I.J., Hamilton-Miller, J.M., & Brumfitt, W. (1981). Role of urease in the formation of infection stones: comparison of ureases from different sources. *Infection and Immunity, 32*(1), 32-37.

Sadek, S. & Saleh, M. (2007). The effect of carbonaceous fines on the cyclic resistance of poorly graded sand. *Journal of Geotechnical and Geological Engineering.* 25(2):257-264.

Sarda, D., Choonia, H., Sarode, D., & Lele, S. (2009). Biocalcification by Bacillus pasteurii urease: a novel application. *Journal of Industrial Biotechnology and Microbiology, 36*(8), 1111-1115.

Schaechter, M., Ingraham, J.L., & Neidhardt, F.C. (2006). *Microbe.* Washington, D.C.: ASM Press, American Society for Microbiology.

Seed, H.B., Idriss, I., & Arango, I. (1983). Evaluation of liquefaction potential using field performance data. *Journal of Geotechnical Engineering, 109*(3), 458-482.

Seeliger, H.P. (1956). Use of a urease test for the screening and identification of cryptococci. *Journal of Bacteriology, 72*(2), 127.

Siddharthan, R., & Suthahar, N. (2005). Simplified Seismic Response of DM Treated Sites. *Research Digest, National Deep Mixing (NDM) Research Program.*

Sitar, N., Clough, G.W., & Bachus, R.G. (1980). Behavior of weakly cemented soil slopes under static and seismic loading conditions. Prepared for the US Geological Survey Dept. of Interior Office of Eartquake Studies, Final Report, June.

SGI. (1986). The lime column method. Results from 10 years of research and practical use and future development (Vol. Report 31): Swedish Geotechnical Institute.

Shahraki, S., Zamorodian, A., Niazi, A., & O'Kelly, B. (2014). Improving sand with microbial-induced carbonated precipitation. *Proceedings of ICE-Ground Improvement, 168*(3), 217-230.

Sharma, R., Baxter, C. & Jander, M. (2011). Relationship between shear wave velocity and stresses at failure for weakly cemented sands during drained triaxial. *Soils and Foundations.*51(4), 761-771.

Shibata, T., & Taparaska, W. (1988). Evaluation of Liquefaction potential of soil using cone penetration tests. *Soils and Foundations.* 28(2), 49-60.

Shibuya, S., & Tanaka, H. (1996). Estimate of Elastic Shear Modulus in Holocene Soil Deposits. *Soils and Foundations, 36*(4), 45-55.

Shirakawa, M.A., Cincotto, M.A., Atencio, D., Gaylarde, C.C., & John, V.M. (2011). Effect of culture medium on biocalcification by Pseudomonas Putida, Lysinibacillus Sphaericus and Bacillus Subtilis. *Brazilian Journal of Microbiology, 42*, 499-507.

Simkiss, K. (1964). Phosphates as Crystal Poisons of Calcifications. *Biological Reviews, 39*(4), 487-504.

Slocombe, B. (2001). Deep compaction of problematic soils. *Problematic Soils*, 163-181.

Sneath, P.H.A. (1986). Nomenclature of Bacteria. *In Biological Nomenclature Today IUBS monograph Series, 2*, 38-48.

Standard, B. (2005). Eurocode 8: Design of structures for earthquake resistance.

Stabnikov, V., Jian, C., Ivanov, V., & Li, Y. (2013). Halotolerant, alkaliphilic urease-producing bacteria from different climate zones and their application for biocementation of sand. *World Journal of Microbiology and Biotechnology, 29*(8), 1453-1460.

Stocks-Fisher, S., Galinat, J.K., and Bang, S.S. (1999). Microbiological precipitation of $CaCO_3$. *Soil Biology and Biochemistry*, 31(11), 1563-1571.

Tanaka, H., Ohta, K., & Maruyama, T. (1991). *Performance of vertical drains of for soft and ununiform soils.* Paper presented at the Geo-Coast '91, Yokohama, Japan.

Tanaka, Y., Nakajima, Y., & Tsuboi, H. (1991). *Liquefaction control works.* Paper presented at the Symposium on Control of Soil Liquefaction, Japanese Society of Soil Mechanic and Foundation Engineering, Tokyo.

Terashi, M. (2002). *The state of practice in deep mixing methods.* Grouting and ground treatment, ASCE. 25-49.

Terzaghi, K. (1943). Theoretical Soil Mechanics. John Wiley and Sons, Inc., New York.

Tiano, P., Biagiotti, L., & Mastromei, G. (1999). Bacterial bio-mediated calcite precipitation for monumental stones conservation: methods of evaluation. *Journal of microbiological methods, 36*(1), 139-145.

Tobler, D.J., Cuthbert, M.O., Greswell, R.B., Riley, M.S., Renshaw, J.C., Handley-Sidhu, S., & Phoenix, V.R. (2011). Comparison of rates of ureolysis between Sporosarcina pasteurii and an indigenous groundwater community under conditions required to precipitate large volumes of calcite. *Geochimica et Cosmochimica Acta, 75*(11), 3290-3301.

Tobler, D.J., Maclachlan, E., & Phoenix, V.R. (2012). Microbially mediated plugging of porous media and the impact of differing injection strategies. *Ecological Engineering, 42*(0), 270-278.

Topolnicki, M. (2004). In situ soil mixing. *Ground Improvement, 2*, 331-428.

Tsuchida, H. (1970). Prediction and counter measure against the liquefaction in sand deposits (Abstract of the Seminar in the Port and Harbour Research Institute).

Tsukamoto, M., Inagaki, Y., Ishihara, M., & Sasaki, T. (2013). *Permeability and Mechanical Properties of Fine Sand Improved by Microbial Carbonate Precipitation.* Paper presented at the 22nd International Offshore and Polar Engineering Conference, Greece.

USEPA. (2009). Technical support document for endangerment and cause or contribute findings for greenhouse gases under Section 202(a) of the Clean Air Act.

Van Driessche, A. E. S., Benning, L. G., Rodriguez-Blanco, J. D., Ossorio, M., Bots, P., & García-Ruiz, J. M. (2012). The Role and Implications of Bassanite as a Stable Precursor Phase to Gypsum Precipitation. *Science, 336*(6077), 69-72.

Van Paassen, L.A. (2009). Biogrout: ground improvement by microbially induced carbonate precipitation. Department of Geotechnology. Delft, Delft University of Tecnhology. Ph.D Thesis.

Van Paassen, L.A. (2009). Microbes turning sand into sandstone, using waste as cement. *4th International Young Geotechnical Engineers Conference*. Alexandria, Egypt. 135-138.

Van Paassen, L.A., Ghose, R., Van Der Linden, T.J.M., Van Der Star, W.R.L. & Van Loosdrecht, M.C.M (2010). Quantifying biomediated ground improvement by ureolysis: large-scale biogrout experiment, Journal of Geotechnical and Geoenvironmental Engineering. 136(12), 1721-1728.

Van Paassen, L. A. (2011). *Bio-Mediated Ground Improvement: From Laboratory Experiment to Pilot Applications* (Vol. 397): ASCE.

Van Paassen, L. A., Harkes, M. P., Van Zwieten, G. A., Van der Zon, W. H., Van der Star, W. R. L., & Van Loosdrecht, M. C. M. (2009). *Scale up of BioGrout: a biological ground reinforcement method.* Paper presented at the 17th International Conference on Soil Mechanics & Geotechnical Engineering, Alexandria, Egypt.

Van Paassen, L., Harkes, M., Van Zwieten, G., Van der Zon, W., Van der Star, W., & Van Loosdrecht, M. (2009). *Scale up of BioGrout: a biological ground reinforcement method.* Paper presented at the Proceedings of the 17th international conference on soil mechanics and geotechnical engineering.

Van Paassen, L., Van Loosdrecht, M., Van den Eijnden, A., Mulder, A., Verwaal, W., Ngan-Tillard, D., . . . Bekendam, R. (2008). Reinforcement of calcarenite room and pillar mines by microbially induced carbonate precipitation. *Proceedings of EuroEngeo*, 1-6.

Van Tittelboom, K., De Belie, N., De Muynck, W., & Verstraete, W. (2010). Use of bacteria to repair cracks in concrete. *Cement and Concrete Research, 40*(1), 157-166.

Van Veen, J.A., Van Overbeek, L.S., & Van Elsas, J.D. (1997). Fate and activity of microorganisms introduced into soil. *Microbiology and Molecular Biology Reviews, 61*(2), 121-135.

Velpuri, N. V. P., Yu, X., Lee, H.-I., & Chang, W.-S. (2016). Influence Factors for Microbial-Induced Calcite Precipitation in Sands. *GEO*, 44.

Wagstaff (2006). [Personal Communication on wet mix technique to mitigate liquefaction].

Wanjari, S., Prabhu, C., Yadav, R., Satyanarayana, T., Labhsetwar, N., & Rayalu, S. (2011). Immobilization of carbonic anhydrase on chitosan beads for enhanced carbonation reaction. *Process Biochemistry, 46*(4), 1010-1018.

Warner, R.C. (1942). The kinetics of the hydrolysis of Urea and of Arginine. *Journal of Biological Chemistry, 142*(2), 705-723.

Warthmann, R., Van Lith, Y., Vasconcelos, C., McKenzie, J.A., & Karpoff, A.M. (2000). Bacterially induced dolomite precipitation in anoxic culture experiments. *Geology, 28*(12), 1091-1094.

Whiffin, V.S., (2004). Mirobial $CaCO_3$ precipitation for the production of biocement. Ph.D Dissertation , Murdoch University, Australia:154.

Whiffin, V.S., Van Paassen, L.A. & Harkes, M.P. (2007). Microbial carbonate precipitation as a soil improvement technique. *Geomicrobiology Journal,* 24(5), 417-423.

Whitman, W.B., Coleman, D.C., & Wiebe, W.J. (1998). Prokaryotes: The unseen majority. *Proceedings of the National Academy of Sciences, 95*(12), 6578-6583.

Worthen, D. (2009). Critical state framework and liquefaction of fine-grained soils. PhD Thesis, Washington State University.

Yadav, R., Labhsetwar, N., Kotwal, S., & Rayalu, S. (2011). Single enzyme nanoparticle for biomimetic CO2 sequestration. *Journal of Nanoparticle Research, 13*(1), 263-271.

Yoon, S., Kim, S., & Kim, J. (1994). Identification of inhibitory metabolites in high density culture of recombinant Bacillus megaterium PCK108. *Biotechnology Letters, 16*(10), 1011-1014.

Youd, T.L. (1992). Liquefaction, ground failure and consequent damage during 22 April 1991 Costa Rica Earthquake *Proc., NSF/UCR, U.S.-Costa Rica Workshop on the Costa Rica Earthquakes of 1990-1991, Effects on Soil and Structures*, EERI Pub. No. 93-A, EERI, Oakland, CA, 73-95.

Young, G.M., Amid, D., & Miller, V.L. (1996). A bifunctional urease enhances survival of pathogenic Yersinia enterocolitica and Morganella morganii at low pH. *Journal of Bacteriology, 178*(22), 6487-6495.

Zajic, J.E., & Spence, M.J. (1986). Properties of alkaliphilic halophiles. *Journal of Industrial Microbiology, 1*(3), 171-179.

Zamarreno, D.V., Inkpen, R., & May, E. (2009). Carbonate crystals precipitated by freshwater bacteria and their use as a limestone consolidant. *Applied and Environmental Microbiology, 75*(18), 5981-5990.