INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

The paper was published in the proceedings of the 9th Australia New Zealand Conference on Geomechanics and was edited by Geoffrey Farquhar, Philip Kelsey, John Marsh and Debbie Fellows. The conference was held in Auckland, New Zealand, 8 – 11 February 2004.

Geomechanical Performance of Salt Formation for Nuclear Waste Repository in Thailand

Kittitep Fuenkajorn
Ph.D.,P.E., Associate Professor, Geological Engineering,
Suranaree University of Technology, Thailand
Kitcha Klayvimut
B.E., Research Assistant, Geological Engineering,
Suranaree University of Technology, Thailand

Summary: A series of laboratory testing and numerical modeling has been performed to assess the geomechanical performance of rock salt formation in the northeast of Thailand for the nuclear waste repository. The characterization, cyclic loading, and uniaxial and triaxial creep tests have been performed on the salt specimens under isothermal conditions. Finite element analyses use the laboratory-calibrated properties to assist in the design of the repository dimensions. The results indicate that the repository should invoke the long-wall pillar concept and should be located at about 500 metres depth. The repository rooms are 4 m wide, 4 m high and 50 m long, separated by 16 m wide abutment pillar. The width for the barrier and protective pillars is 50 metres. Under these design parameters, the predicted room convergence is about 15 cm, and the surface subsidence is about 20 cm through 500 years of isolation.

INTRODUCTION

The increasing amount of nuclear wastes in Thailand has called for a permanent solution to dispose of or isolate these harmful materials from the biosphere. The low level wastes, collected from the hospitals, laboratories, and the Office of Atomic Energy for Peace (OAEP), may require the isolation period as long as 500 years, or at least until the radionuclide reaches an acceptable level. A common solution to this problem that has been practiced internationally is to dispose such wastes into the geologic media (National Research Council, 1989; United States Department of Energy, 1995; Langer, 1999). The method invokes the characteristics of the host rock and the properties of engineering barriers to ensure the long-term isolation (Langer, 1998). In the U.S. and Germany, rock salt has long been one of the prime candidates, primarily due to its mechanical stability, low permeability, healing capability, and availability. Extensive research on rock salt has been carried out in the North America and Europe for the past 30 years. Much effort has been aimed at determining the mechanical, thermo-mechanical, chemical and hydrological properties and behavior of the rock (Hardy, 1982; Wallner, 1984; Habib and Berest, 1993). Even though extensive rock salt formations in the northern part of Thailand exist, the necessary information regarding their mechanical performance and hydrological integrity is not available.

The objective of the present research is to assess experimentally and numerically the mechanical performance of the salt formations for use as nuclear waste repository in Thailand. The work serves as a mission of the OAEP in an attempt at minimizing the environmental impact from the wastes by isolating them permanently from the biosphere. The research effort primarily involves compilation of available data on the salt sequences, mechanical laboratory testing, and computer simulations for the preliminary design.

ROCK SALT FORMATION IN THAILAND

The rock salt studied in this research is from the Cretaceous Maha Sarakham Formation. The Formation is preserved within two basins: the northern Sakon Nakhon basin and the southern Khorat basin (Utha-aroon et al., 1995). These basins underlie much of the Khorat Plateau in the northeast of Thailand, and are separated by the highlands of the Phu Phan Range (Figure 1). The complete Maha Sarakham Formation is composed of three salt beds: Lower, Middle and Upper salt members. Each member is overlain by a clastic sediment unit: Lower, Middle and Upper Clastic members (Warren, 1999). The sequence may be incomplete in some areas due to the processes of subsequent erosion, salt flowage and dissolutional loss. The maximum thickness remains unknown, but it could exceed one kilometer. However, for most of the area, the average thickness is about 250 m.

MECHANICAL LABORATORY TESTING

Series of laboratory experiments have been carried out on salt core specimens obtained from three sites in the Khorat and Sakon Nakhon basins. Figure 1 shows the three locations from which the drilled cores have been

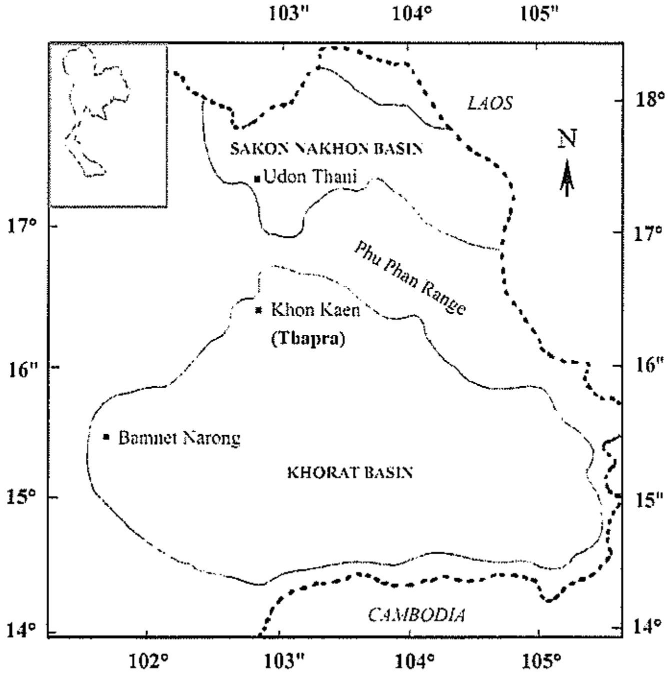

Figure 1. Locations where the salt cores are obtained from both Khorat and Sakon Nakhon basins in the northeast of Thailand. (Modified from Japan International Cooperation Agency, 1981)

obtained. They are from the depths ranging between 210 and 400 metres. The experiments can be divided into three main groups: basic characterization tests, creep tests, and cyclic loading tests. The salt core specimens have a nominal diameter of 60 mm. They are cut and polished to obtain specific dimensions for each test. The sample preparation and test procedures follow the relevant ASTM standard practices (i.e., ASTM D2664, D2938, D3967, D4405, D4543, and D5731), as much as practical.

The basic characterization tests include uniaxial and triaxial compressive strength testing, Brazilian tensile strength testing and point load index testing. Table 1 shows the test results. The triaxial test results are obtained for the confining pressures ranging from of 3.4 MPa to 6.9 MPa. The salts have the internal friction angle of 49 degrees and the cohesion of 8 MPa. The compressive strengths from the three sites available are relatively high as compared with those from other sources in the United States, Canada and Germany. This is probably due to the significant amount of inclusions (e.g., anhydrite, sulfates, carbonates, and iron oxides).

Table 1. Summary of Characterization Test Results.

Locations		**Uniaxial Compressive Strength (MPa)**	**Brazilian Tensile Strength (MPa)**	**Point Load Strength Index (MPa)**
Bamnet Narong District Chaiyaphom Province (Khorat basin)		28.8 ± 4.0	1.4± 0.4	N/A
Thapra District Khonkaen Province (Khorat basin)		29.0 ± 2.7	1.6± 0.3	N/A
Muang District Udon Thani Province (Sakon Nakhon basin)	Middle salt	26.3 ± 7.7	1.7± 0.4	0.8 ± 0.3
	Lower salt	31.1 ± 6.7	1.6± 0.4	0.6 ± 0.04

The uniaxial cyclic loading tests determine the true elastic modulus of the salt. The salt core specimens are subject to the cycles of uniaxial loading until failure. The maximum axial stress is varied among specimens from 16 MPa to 29 MPa while the minimum stress is maintained constant at 0.1 MPa. For each specimen the elastic modulus is calculated from the series of unloading curves for all loading cycles. For all stress levels, the elastic modulus tends to decrease as the number of cycles increases, and remains constant after about 50 to 100 cycles. The calculated elastic modulus values range from 20 GPa to 30 GPa.

A series of short- and long-term uniaxial and triaxial creep tests determine the time-dependent behavior of the salt under isothermal condition. The short-term results calibrate the visco-elastic parameters, and the long-term results calibrate the visco-plastic coefficient of the salt. For the uniaxial testing, the applied constant axial stresses vary from 10 to 30 MPa for the short-term testing, and from 4.1 to 14 MPa for the long-term testing. The triaxial creep testing has the constant axial stresses varying from 16.6 to 21.1 MPa, while the confining pressures are maintained at 3.4 and 6.9 MPa (Figure 2).

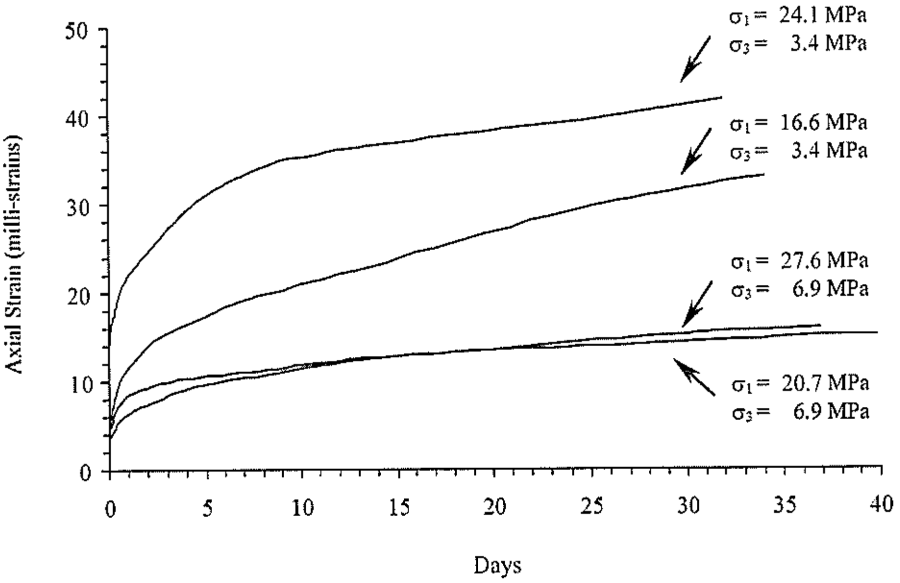

Figure Results of the long-term triaxial creep testing. The confining pressures (σ_3) = 3.4 and 6.9 MPa. The axial stresses (σ_1) vary from 16.6 MPa to 27.6 MPa.

COMPUTER SIMULATIONS

The laboratory test results have been used to determine the property parameters in the constitutive equation proposed by Serata and Fuenkajorn (1992). It is capable of describing the elastic, visco-elastic, visco-plastic, strain-softening, and strain-hardening behavior of the salt. It has been incorporated into a finite element program called GEO (Figure 3). The key property parameters obtained from the regression analysis on the salt data tested here are given in Table 2. High intrinsic variability of the properties has been observed. This is probably due to the non-uniform distribution of the inclusions within the salt specimens. The effect of the inclusions on the salt properties has also been observed elsewhere (Hansen et al., 1987).

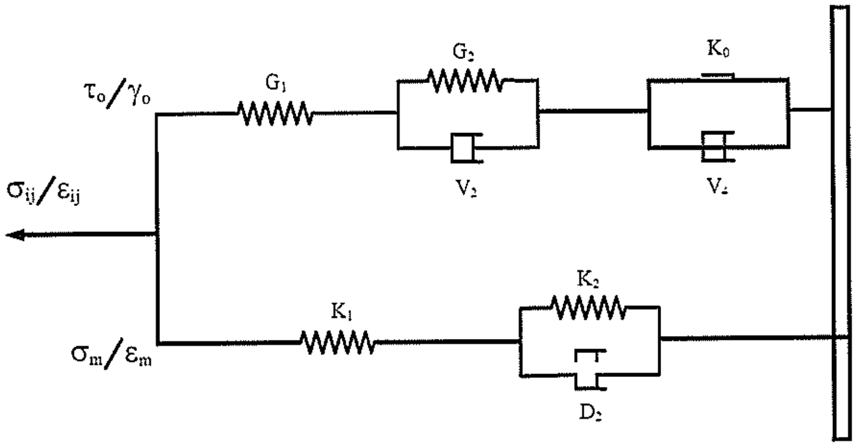

Table 2. Summary of Key Property Parameters Calibrated from the Experimental Results,

Key Properties	Symbols	Units	Ranges	Average	Test Types
Shear Modulus	G_1	GPa	8.7 - 9.0	8.8	Cyclic Loading
Retarded Shear Modulus	G_2	GPa	0.2 - 2.1	1.1	Uniaxial Creep (Short-term)
Elastoviscosity	V_2	GPa·day	0.1 - 17.0	9.1	Uniaxial Creep (Short-term)
Plastoviscosity	V_4	GPa·day	2.4 - 93.1	33.6	Uniaxial & Triaxial Creep
Ultimate Bulk Modulus	K_1	GPa	40.6 - 42.0	41.1	Cyclic Loading
Retarded Bulk Modulus	K_2	GPa	0.9 - 9.8	4.9	Uniaxial Creep (Short-term)
Critical Octahedral Shear Strain	γ_c	10^{-3}	2	2	Cyclic Loading

The analysis assumes the low temperature condition (low-level nuclear wastes). The key design requirements are 1) the mechanical stability during the emplacement period of 50 years, 2) the containment integrity for the repository during the isolation period of 500 years, and 3) minimization of the movement of the surrounding rock formations. To meet these requirements, the long-wall pillar concept is proposed. The repository rooms are arranged in a parallel pattern, connecting with a main entry. The height of the repository room is defined to be 4 metres to satisfy the available equipment. Three series of the finite element modeling have been performed to determine the appropriate depth of the repository horizon, the maximum room width, and the optimum pillar width. The functional requirements for these design components include 1) maintaining the mechanical stability of the salt roof and floor to allow safe and effective operation, 2) achieving controllable surface subsidence through the emplacement and isolation periods, and 3) minimizing the repository area while being capable of handling the amount of the wastes through the next 50 years.

The first series of computer modeling simulates the vertical cross-sections of the repository at 502 metres depth, having the room widths varying from 4, 6 to 8 metres to determine their effect on the opening stability. For the second series, six pillar widths have been simulated to determine the optimum pillar width, i.e. 4, 8, 12, 16, 20 and 36 metres. Figures 4 and 5 show the simulation results in form of the vertical closure and surface subsidence through the next 50 and 500 years, respectively. The results suggest that the room width of 4 meter induces the least magnitude of room closure. Increasing the pillar width beyond 16 metres does not significantly reduce the closure and the subsidence. Using the room width of 4 metres and pillar width of 16 metres, the last series of modeling assesses the impact of the repository depth. Based on the geology of the actual sites, three depths are simulated, i.e. 502, 603 and 817 metres. The results indicate that the repository horizon should be at 500 metres depth. Beyond this depth excessive closure and failure of salt roof and floor may occur (Figures 4 and 5).

CONCLUSIONS

The objective of this research is to assess the geomechanical performance of rock salt in the Maha Sarakham Formation in the northeast of Thailand for nuclear waste repository. The effort involves mechanical laboratory testing and numerical modeling. The mechanical characterization, cyclic loading, and uniaxial and triaxial creep tests have been performed on the salt core specimens under isothermal conditions. Finite element analyses use the laboratory-calibrated properties to assist in the design of the repository dimensions and layout under a variety of loading and boundary conditions. The results indicate that repository horizon should invoke the long-wall pillar concept and should be located at about 500 metres depth. The repository rooms are 4 m wide, 4 m high and 50 m long, separated by 16 m wide pillar. The minimum width for the barrier and protective pillars is 400 metres. Under these design parameters, the predicted room convergence is about 15 cm before backfill installation, and the surface subsidence is about 20 cm through the next 500 years of isolation.

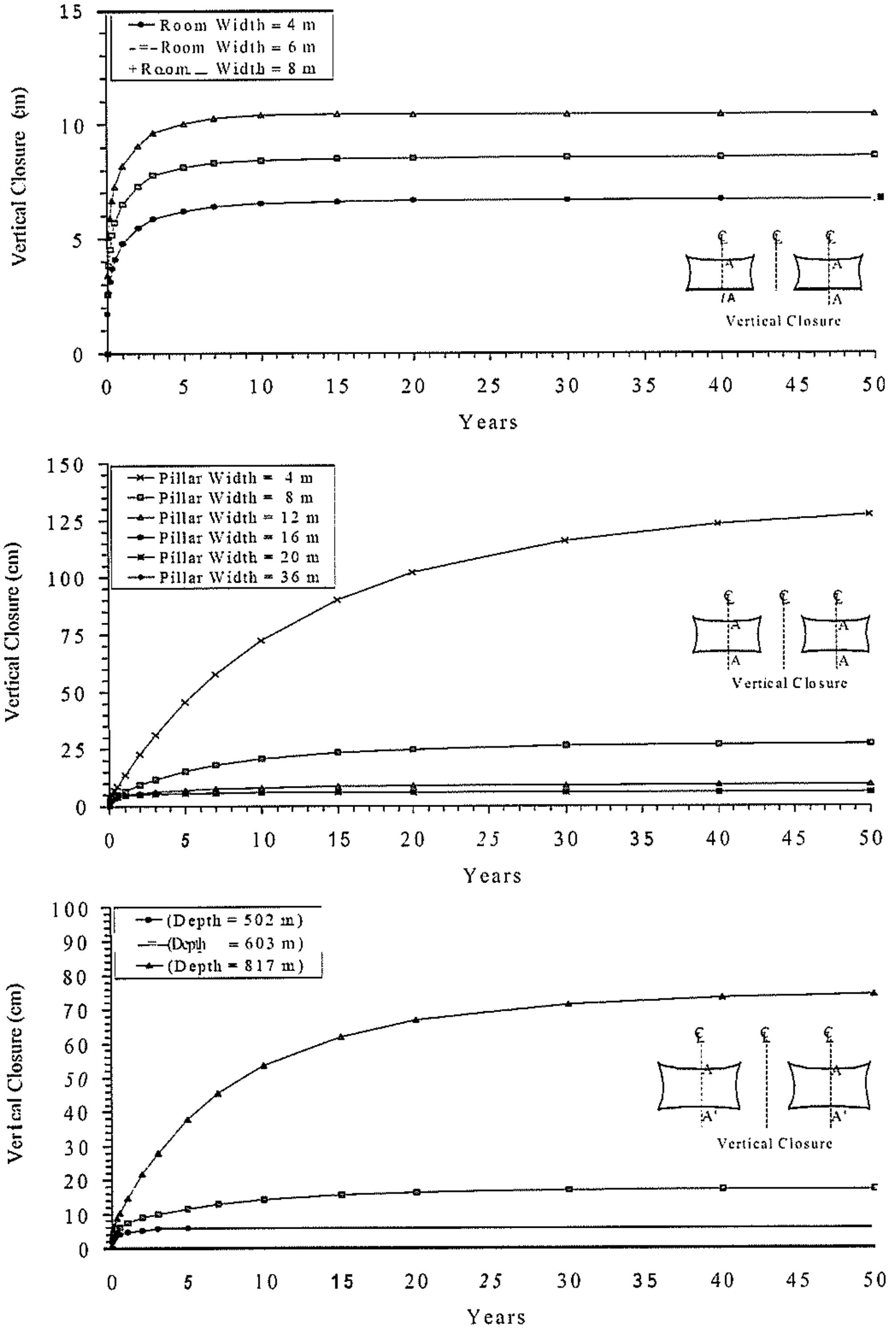

Figure 4. Predicted vertical closure of repository rooms for various room-pillar dimensions (top and middle) and depths (bottom). The top and middle plots resulted from the simulation at 502 m depth.

ACKNOWLEDGEMENTS

The present research has been co-funded by the Thailand Research Fund (TRF) and the Office of Atomic Energy for Peace (OAEP). Permission to publish this paper is gratefully acknowledged. The opinion given in this paper does not necessarily reflect the opinion of TRF and OAEP. We would like to thank Mr. Keith Crosby, Vice President of the Asia Pacific Potash Corporation, Ltd. who has provided salt cores for testing.

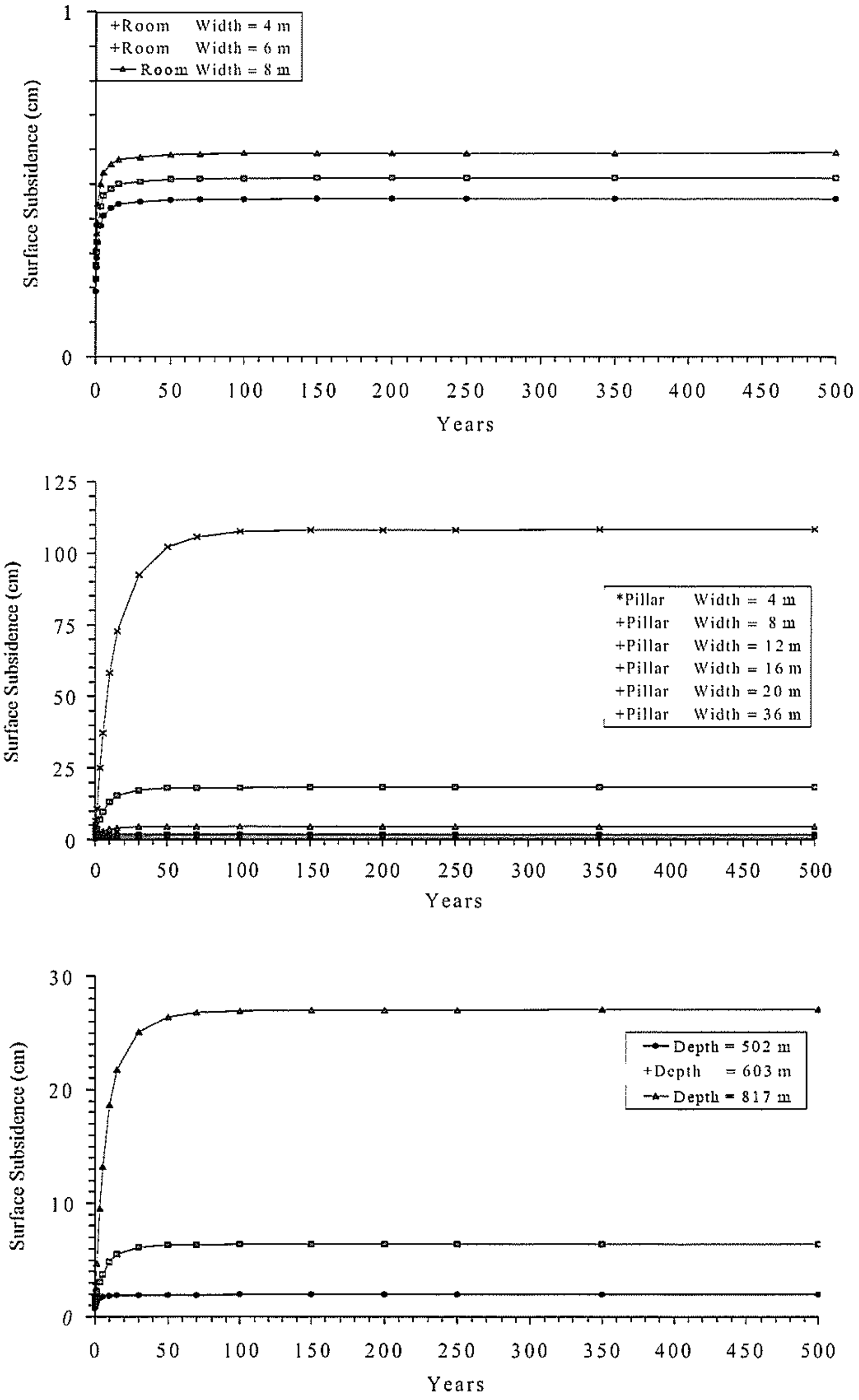

Figure 5. Predicted surface subsidence of repository rooms for various room-pillar dimensions (top and middle) and depths (bottom). The top and middle plots resulted from the simulation at 502 m depth.

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