The Use of ANSS as a stabilizer for fine grained swelling soils

1. General

Distress of flexible pavement due to volume change of the subgrade is a major problem of economic concern. Variations in water content in the subgrade induce differential deformations which result in cracking of the pavement leading to a reduction in life expectancy of the pavement and/or higher maintenance costs. Swelling soils are common all over the globe, and the economic consequences of damages caused by swelling soils to pavement structures are huge. The design and construction of pavements on subgrade materials with inferior characteristics such as low strength, high potential for volume change, high water content and poor workability is not trivial. Improvement of the subgrade properties could involve a combination of the following solutions: replacement of the problematic soils, installation of impermeable membranes to guard against changes in moisture content do not occur or the use of stabilizers either chemical, cement based, lime based, fly ash, polymer or the common liquid based stabilizers. Stabilization of the subgrade material will allow for the design of a thinner overall pavement or alternatively extended life and reduction in required maintenance.

AnyWay’s Natural Soil Stabilizer-ANSS, is a cement based stabilizer supplied in powder form composed of natural materials. When mixed with subgrade soils an exothermic hydration process ensues due to the exchange of ions between the stabilizer and the in-situ materials. Voids in the subgrade soil are partially filled with crystalline reaction products, creating a mechanical bond between the subgrade particles. The chemical reaction continues over time, resulting in increased CBR and UCS values. The consistency limits (LL, PL) of the stabilized soil are improved (reduction in LL and PL), especially in the cases of highly plastic clays and silts. The hydration process results in a stabilized soil which exhibits greater shear strength, stiffness and bearing capacity.

2. Objectives of the Study

The overall objective of the proposed study is to document the effects of ANSS on the behavior and performance of fine grained subgrade soils of high swell potential. To date there is a lack of documented evidence as to the ability of ANSS to inhibit volume change due to variations in water content. Furthermore, there is only limited data on the effects of swelling on the strength and deformation properties of materials stabilized with ANSS.

The concept chosen for this investigation is based on the following benchmarks:

(a) A set of laboratory consolidation/swell tests aimed to investigate the effect of stabilizer content on the vertical volume change of a swelling clay as a function of initial water content, ANSS content and vertical pressure.

(b) Evaluation of a swell coefficient (α_{ω}) of the stabilized clay as a function of the ANSS content and the change in water content. The swell coefficient is defined as the ratio between the vertical strain in response to the change in water content. The swell coefficient is an indicator of the potential activity of the stabilized clay.

(c) Measurements of Resilient modulus and the development permanent deformations will be used in order to gage the combined effects of volumetric strain (swelling) and changes in water content on the mechanical response of the stabilized material. Measurement of the above parameters is important in the design of flexible pavement structures. Modern mechanistic-empirical design procedures make use of rational quantitative parameters in describing material response to traffic loads. Both parameters (Resilient Modulus and Permanent Deformation) are integral in the design procedures suggested in the AASHTO design Guide (NCHRP 1-37A).

The current report deals with the performance of the first two benchmarks, the third will be dealt with in detail over the second stage of the research.

3. Test Program

This part of the research is aimed at quantifying the affect of ANSS content on the swelling properties of a clayey soil of high swell potential. The test program included a set of experiments with the objective to examine the vertical swell of stabilized and non stabilized specimens as a function of initial water content, applied vertical pressure and ANSS content. A second phase of experiments was to evaluate the rate of vertical swell in response to a change in water content as a function of the initial water content and ANSS content.

3.1 Soil characterization

The soil examined in the current research was sampled from Ramat David Air Force base in the Yisrael Valley in northern of Israel. Based on the results of indicative tests, this soil is classified as CH according to the USCS classification system and as A-7-6 according to the AASHTO classification system. The consistency limits are as follows: Liquid Limit, LL = 77%, Plastic Limit, PL = 28% and Plastic Index = 49%. The specific gravity (Gs) is 2.72 and the free swell, FS is 150%. The above properties indicates that the soil has a high swelling potential.

3.2 Consolidation/Swell Tests

The aim of measuring the vertical swell under an applied vertical surcharge is to examine the change of the vertical dimension of the specimen (swelling percentage) as a function of time, as the clay specimen is allowed to absorb an unlimited amount of water. The apparatus used in this research is a standard rigid ring consolidometer. The specimen is laterally restrained and can absorb water freely through two porous stones placed at the upper and lower boundaries of the specimen. The change in height of the specimen is monitored during the entire test. The swelling percentage is expressed as follows:

$$S_v = \frac{\Delta h}{h_0} * 100 \quad \% \tag{3.1}$$

When:-

S_v - Vertical Swell (%)

Δh- the change of the specimen height

h_0 - the initial specimen height

Two methods were used in monitoring the change of the specimen vertical deformation:-

(a) Measurement of the vertical deformation with a Linear Variable Differential Transducer-LVDT, that is capable to resolve a deflection of the order of 0.5 μm.

(b) Measurement of the vertical deformation using a digital deflectometer with a resolution of 1 μm.

The data was recorded and saved using a special program written in LabView (National Instruments).

The tests were performed under different vertical pressures of 1, 10, 30 and 50 kPa. The pressures were chosen to simulate realistic overburden pressures. The specimens were prepared with different combinations of initial conditions, namely; nominal water content and ANSS content. Table 3.1 summarizes the different experimental factors considered in the tests.

<u>Table 3.1</u>: Experimental Factors in measuring vertical deformation

ANSS Content (%)				Nominal Water content ω_{nom} (%)
6	4	2	0	
X	X	X	X	26
X	X	X	X	28
X	X	X	X	30

- Specimens were prepared at the chosen water contents to simulate the range of water contents that are expected to be encountered in processing the clay in the field, PL±2%.

- It should be noted, that even under controlled laboratory conditions preparation of a uniform/identical set of test specimens is an impossible task.
- After the curing period the water content of the specimen is slightly lower than the water content immediately after compaction.
- ANSS content was set as a percent by dry weight of the natural soil.
- All specimens ere cured over a period of 7 days.

3.3 Rate of Swell Tests

Determination of the swell coefficient was accomplished by measuring the change in vertical strain per water content change as the specimen wets up. The tests were performed under a vertical pressure of 1 kPa. The tests were performed in a standard rigid ring consolidometer. Upon reaching a desired percent swell the specimen was quickly removed from the consolidometer ring and the water content measured. The resulting water content is the average water content since water absorbed into the specimen is not uniform from all sides.

The experimental factors are the same as those presented in Table 3.1. Each test in test program includes 4 test points. The points range from 0% swell to maximum swell value, with two intermediate points.

The swell rate is defined as the slope between the swell percentage with no load and the change in water content (from the beginning of the test to the point were the test was stopped):

$$\varepsilon_v = \alpha_\omega * \Delta\omega \tag{3.2}$$

$$\Delta\omega = \omega_f - \omega_0 \tag{3.3}$$

Where:-

ε_v – the swell percentage with no load (%)

α_ω - the swell coefficient

ω_f – final water content (%)

ω_0 – initial water content, after curing (%)

4. Results and Conclusions

The following sections present the main results and conclusions of the laboratory tests. This section will summarize the affect of ANSS on the swelling characteristics and their dependence on the different experimental factors; initial water content, vertical pressure and ANSS content. Several test results that quantify the influence of ANSS content on the indicative properties are also presented.

4.1 The influence of ANSS on Atterberg Limits

Figures 4.1-4.2 presents the results of the influence of ANSS on the Liquid Limit and Plastic Limit respectively. From the figures the following conclusions can be made:

(a) An addition of ANSS to the soil causes the Liquid Limit to decrease. When stabilizing the soil with 2% ANSS the Liquid Limit decreased by 6% in comparison to the Liquid Limit of the non stabilized soil. Stabilizing with 6% ANSS induces a reduction of 19% in the Liquid Limit compared to the non stabilized soil. The ratio between Liquid Limit values of the non stabilized soil to the soil stabilized material is constant at 0.75 for ANSS contents of up to 6%.

(b) The effect of ANSS content on the Plastic Limit is not linear as was seen in the case of the Liquid Limit. For ANSS contents of up to 4% ANSS there is a reduction in Plastic Limit. At higher ANSS contents the Plastic Limit reaches a value of 33%, 5% higher than the Plastic Limit of the non stabilized soil. From these results it seems that there is no uniform behavior relating Plastic Limit to ANSS content. These result is surprising, therefore, additional tests will be performed to confirm , or negate this observation

The liquid limit of fat clay soils is a parameter that indicates activity and swelling potential of the clay. Therefore, adding ANSS to the soil decreases this potential.

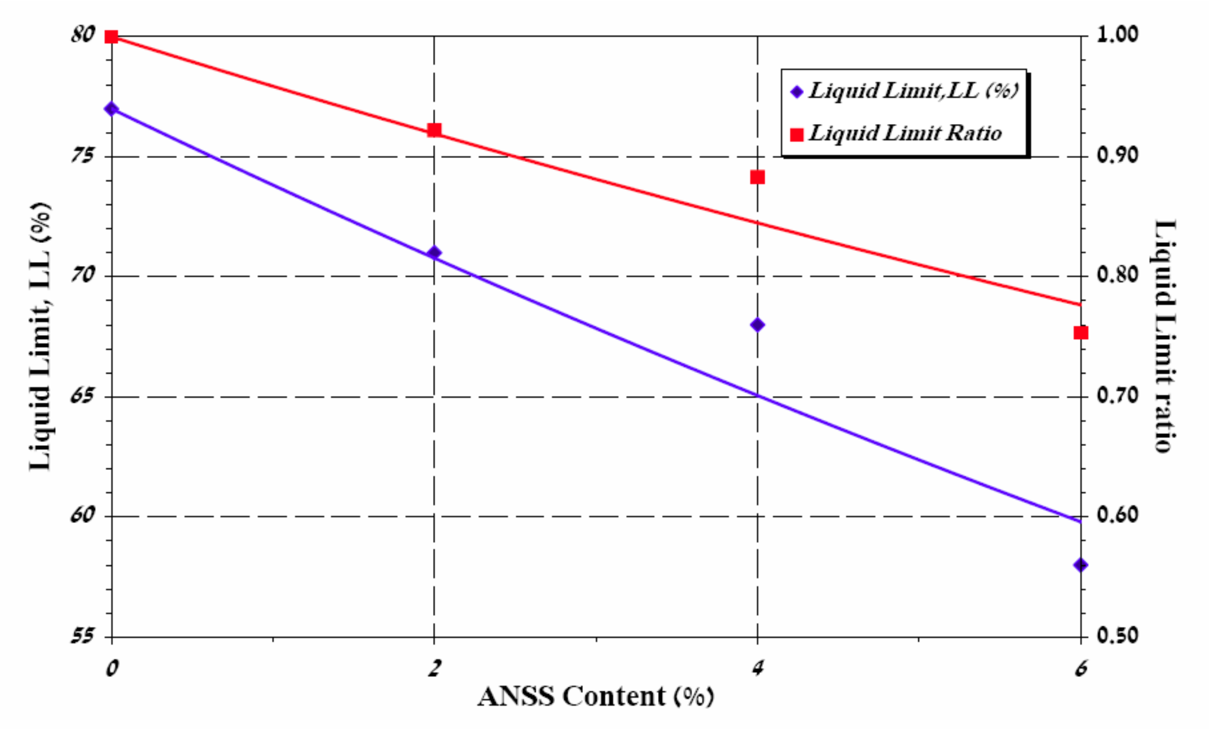

Fig 4.1 : Liquid limit vs ANSS Content

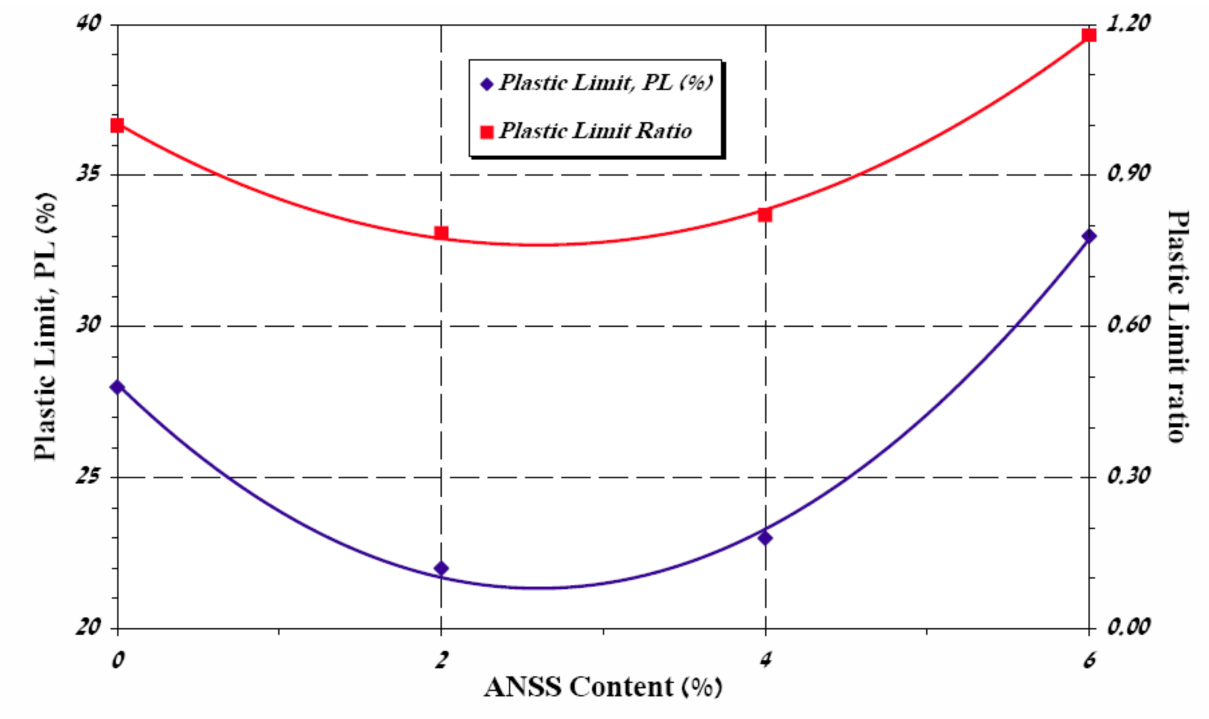

Fig 4.2 :Plastic limit at different ANSS Contents

4.2 Density and Water content of the samples

Density and water content were measured as part of the swell tests. From the values measured the following conclusions can be made:

(a) The water content of the specimens after 7 days of curing decreases in relation to the water content after compaction. The rate of the reduction depends on the ANSS content. At higher ANSS contents (4-6%) the reduction in water content is more significant then for specimens stabilized with 2%, and can be 1-2.5% in relation to the water content after compaction. It should be noted that the water content after curing is the initial water content at which the actual swell test begins.

(b) There are no significant changes in the dry density of the specimens after curing compared to that before curing.

(c) The dry density is a non linear function of the ANSS content. Up to 4% ANSS there are no significant difference in density between the stabilized and the non stabilized specimens. On the other hand, at 6% ANSS there is a reduction in the dry density of 3-5% in relation to the non stabilized clay.

4.3 Swell tests under various vertical loads

4.3.1 Vertical swell as a function of time

Figure 4.3 presents a typical test result of the vertical swell as a function of time for various ANSS contents. The figure presents the vertical swell for a nominal water content of 28% and vertical overburden of 30 kPa. The experimental data were fitted as an asymptotic regression model as follows:

$$S_v = S_f * (1 - e^{-t/\lambda}) \tag{4.1}$$

Where:

S_v – the vertical swell (%)

S_f – the maximum vertical swell in equilibrium (%)

t - time (min)

λ – time constsnt

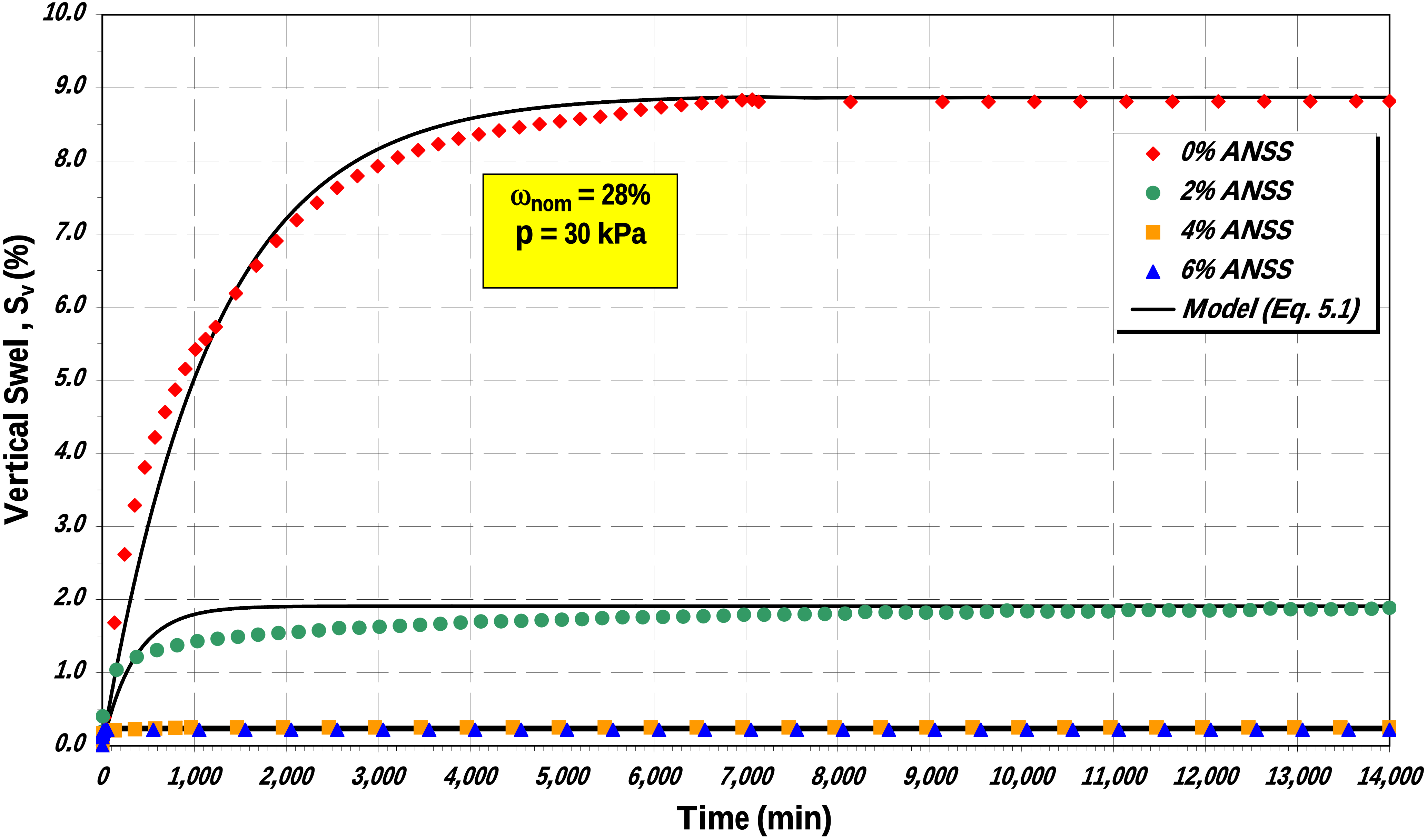

Fig. 4.3 : Vertical Swell vs. Time for Various ANSS Content at ω_{nom}=28%, p=30 kPa

For t=λ the funcion becomes S_v=0.63S_f, which implies that the time constant is equal to the time in minutes from the beginning of the test until upon reaching 63% of the maximum vertical strain at equilibrium. The value S_f in the equation expresses the vertical swell in equilibrium and the constant λ represents a mesure to the average time rate of swell.

4.3.2 Swell tests under various vertical loads

Figure 4.4 presents a typical set of results of maximum vertical swell, S_f, calculated from eq, 4.1 for various vertical pressures and nominal water content of 28%. Figure 4.5 presents the maximum vertical swell, S_f, at different ANSS contents for various vertical pressures, for a nominal water content of 28%.

From these figures the following conclusions are drawn:-

(a) In general, addition of ANSS to the clay reduces the vertical swell. The reduction is noted at all pressures and for all nominal water contents. Table 3.1 presents the maximum vertical swell in percentage at different pressures and various ANSS contents for ω_{nom}=28%

	0% ANSS	***2% ANSS***	***4% ANSS***	***6% ANSS***
1 kPa	14.4	3.1	-	0.3
10 kPa	8.9	1.9	0.3	0.2
30 kPa	4.5	1.8	0.2	0.2
50 kPa	3.6	0.5	0.2	0.04

(b) The tendency that the stabilizer effect the vertical swell is not linear, an example for the affect of ANSS content on the swell can be seen in figure 4.5. Up to 4% ANSS the reduction in the vertical swell is significant, this is true for different loads and nominal water contents, on the other hand, stabilizing with 4% and 6% ANSS almost doesn’t have any influence on the vertical swell.

(c) The vertical swell at high ANSS contents, i.e. 4 and 6% are very small and are close to zero. For example at ω_{nom}=28% for loads between 1-50 kPa the vertical swell reaches values of 0.04-0.3%.

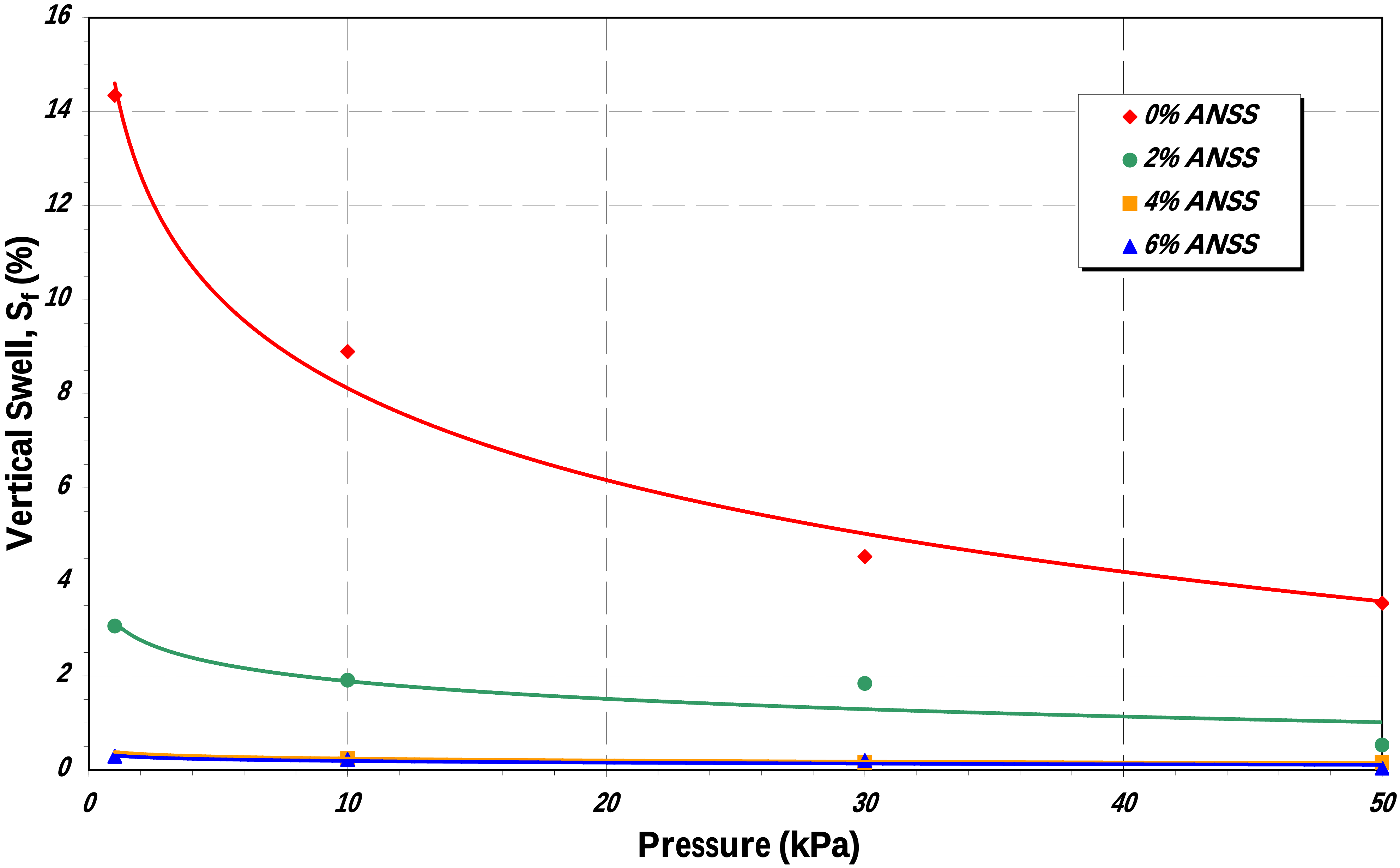

Fig 4.4 : Vertical Swell vs applied Pressure at different ANSS contents with initial water content of ω_{nom}=28%

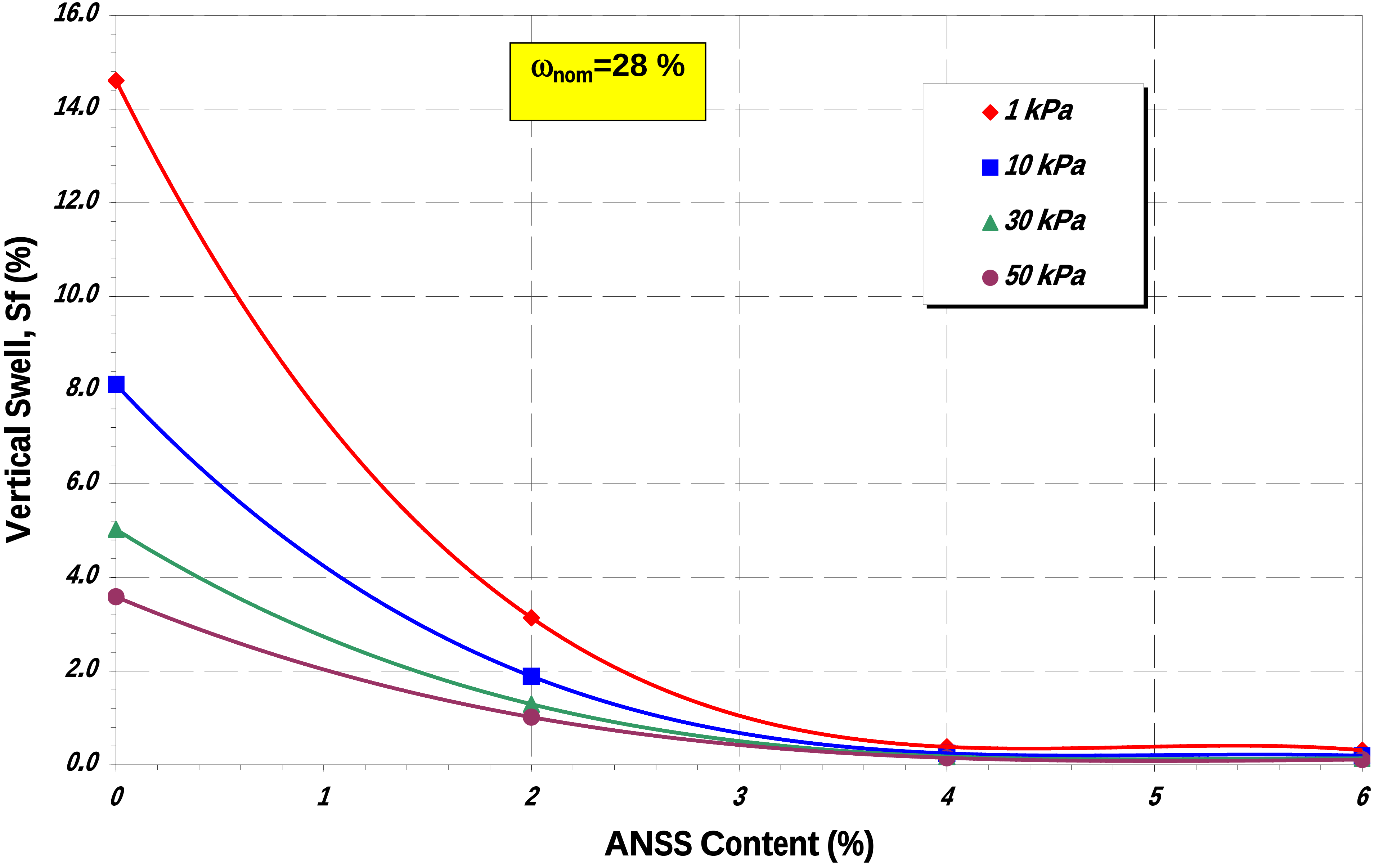

Fig 4.5 : Vertical Swell vs. ANSS contents for various applied Load with initial water content of ω_{nom}=28%

The engineering implications for all of the above conclusions are:

1. ANSS restrain the vertical swell for all loads and all nominal water contents tested.
2. At low vertical pressure, stabilizing with 2% ANSS restrains the vertical swell, but still the vertical swell is not negligible, see table 3.1
3. Higher ANSS contents reach a vertical swell that is negligible.
4. Stabilizing soil with ANSS higher then 4% doesn’t have any engineering benefit from the swelling restrain aspect.

4.3.3 Rate of Swell tests

The following section presents the results obtained from tests aimed at measuring the rate of the vertical strain per the change in water content, as a function of stabilizer content. The rate of the vertical strain and it measurement is outlined in section 3.3. The tests included 3 sets, one for each nominal water content, every set included specimens stabilized with 0, 2, 4 and 6% ANSS. Every individual test was built from 4 points, each point representing the vertical swell that the specimen reached up until the point in time (percent swell) that the test was stopped and the water content determined. A linear regression of the four points going through the origin was computed. The slope of the regression represents the rate of the vertical swell per the change in water content (α_ω). Figure 4.6 summarizes the rate values for each ANSS content, such that for any stabilizer content there is a representative rate of swell. Table 4.1 summarizes all the values of α_ω and the average rate of swell for each ANSS content as a function of initial nominal water content and ANSS content.

Table 4.1: Values of α_ω per nominal water content and ANSS content

Average α_ω	ω_{nom} = 30%	ω_{nom} = 28%	ω_{nom} = 26%	
0.98	0.88	0.94	1.12	***0%ANSS***
0.47	0.50	0.31	0.61	***2%ANSS***
0.07	0.05	0.05	0.10	***4%ANSS***
0.06	0.06	0.04	0.08	***6%ANSS***

From Table 4.1 and Figure 4.6 the following conclusion may be drawn:

(a) Addition of ANSS to the soil produces a decrease in the rate of swell (a value of α_ω is lower), the rate of swell of specimens from the natural un-stabilized soil reaches a value of 1. Stabilization with 6% ANSS reduces the rate of swell to almost zero.

(b) The initial water content does not influence the rate of swell nearly as much as stabilizer content.

(c) Figure 4.7 describes the rate of swell as a function of ANSS content. An exponential trend line (eq 4.2) is included in the plot.

$$\alpha_\omega = 0.9608 * e^{-0.4872 * ANSS} \qquad (4.2)$$

$$R^2 = 0.9427$$

Where:

α_ω– the rate of the vertical swell
ANSS – ANSS content (%)

The engineering implication from the above results is that the value of the rate of swell (α_ω) is a descriptor of the activity of the clay, and the sensitivity of the soil to changes in water content at various stabilizer contents.

Higher values of the rate of swell (α_ω) indicate that the soil is more sensitive to changes in water content. It can be seen that at higher ANSS content the soil is less prone to swell in response to increases in water content.
α_ω relates how the clay will react (swell) with no overburden when stabilized with different ANSS contents at different initial water content.

In the field of pavement design, ANSS can offer an optional solution to the problem of swelling soils (such as overburden pressure), It can be seen in figure 4.8 that by stabilizing more layers with higher ANSS content the overburden layer thickness can be reduced.

Figure 4.9 describe typical Maximum swelling contours for different ANSS contents and varied vertical pressure for nominal water content of 26%. From this figure it can be evaluated what will be the maximum vertical swell at varies conditions.

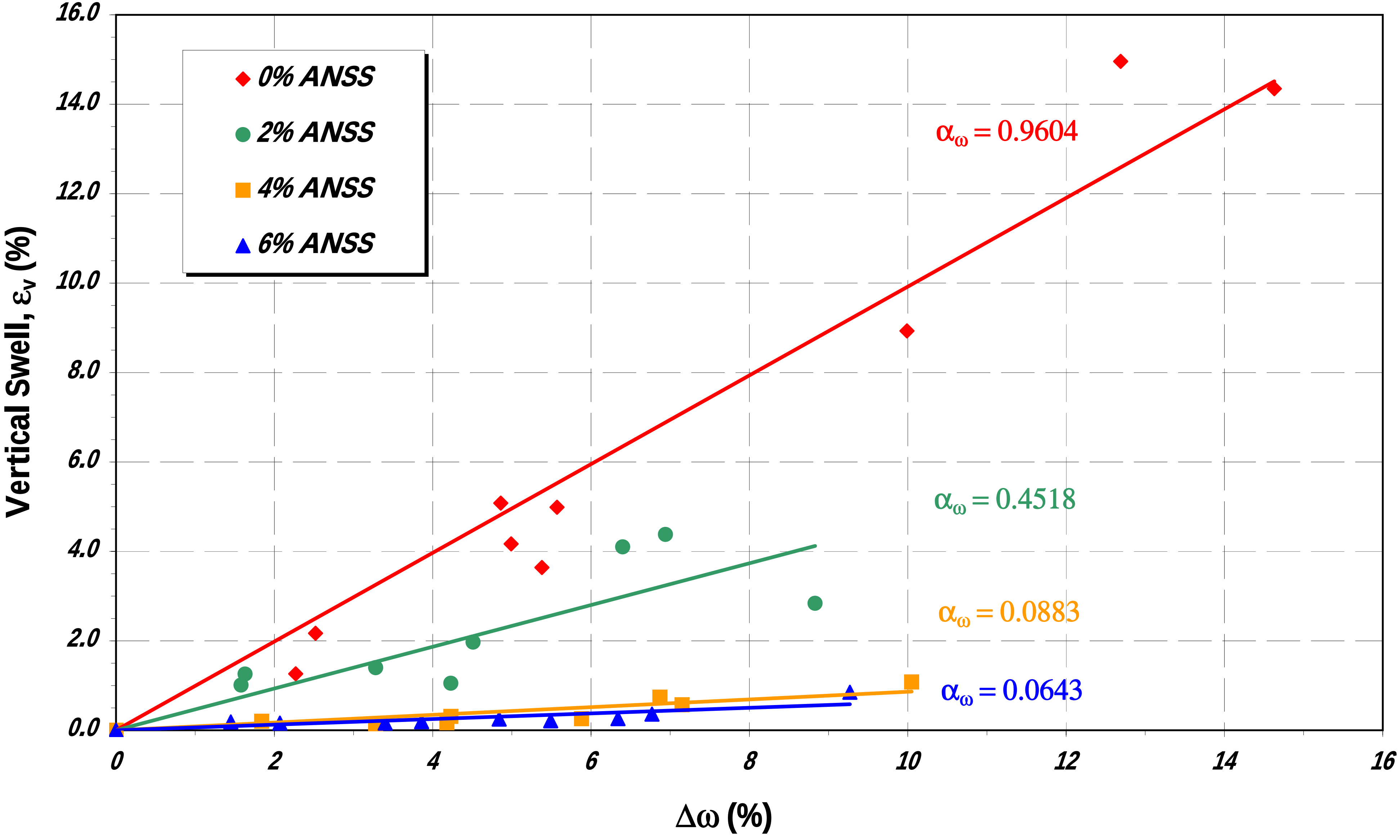

Fig 4.6 : The rate of the Vertical Strain at different initial water contents and different ANSS contents

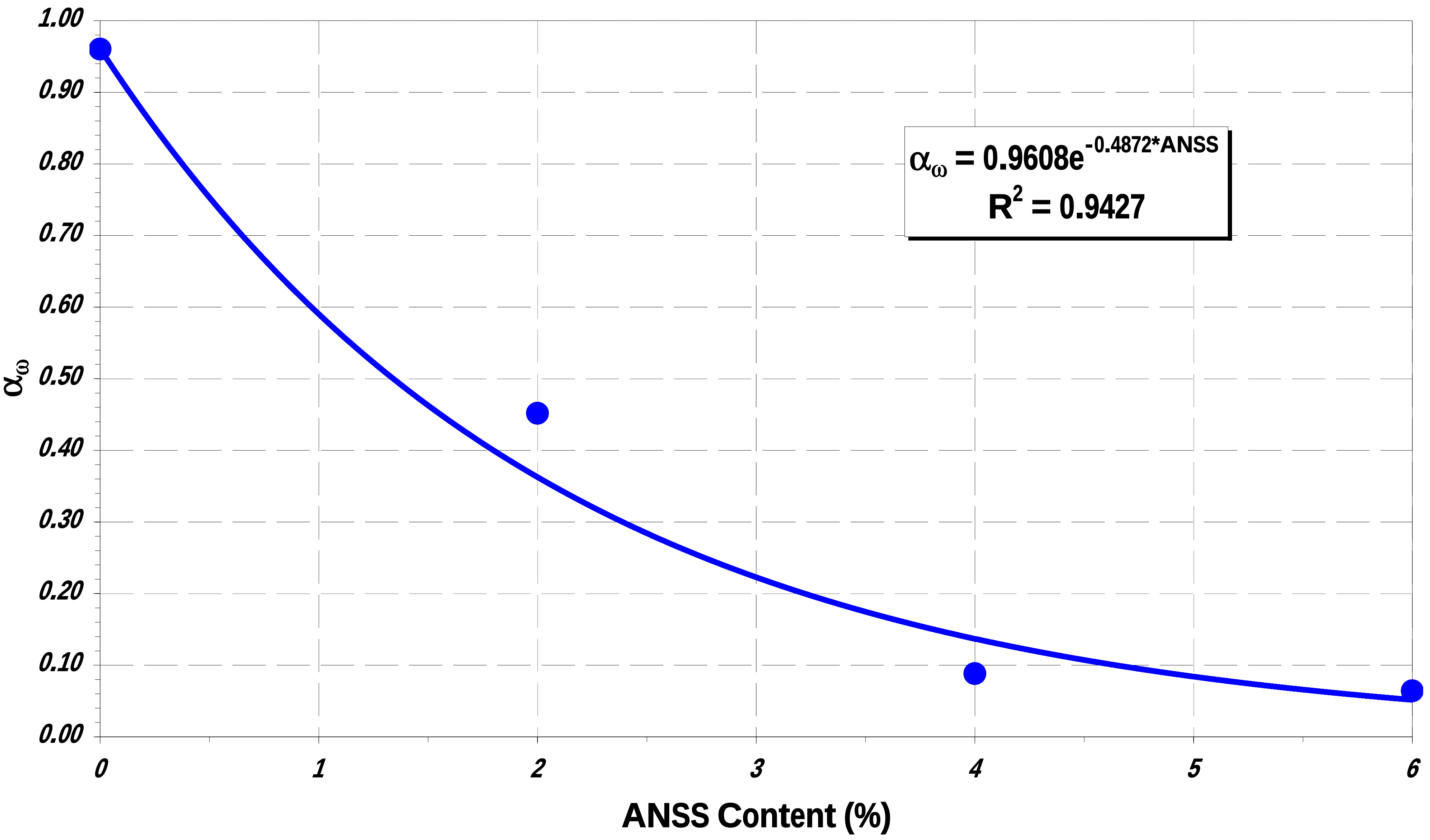

Fig 4.7 : the Rate ofSwell as a function of ANSS Content

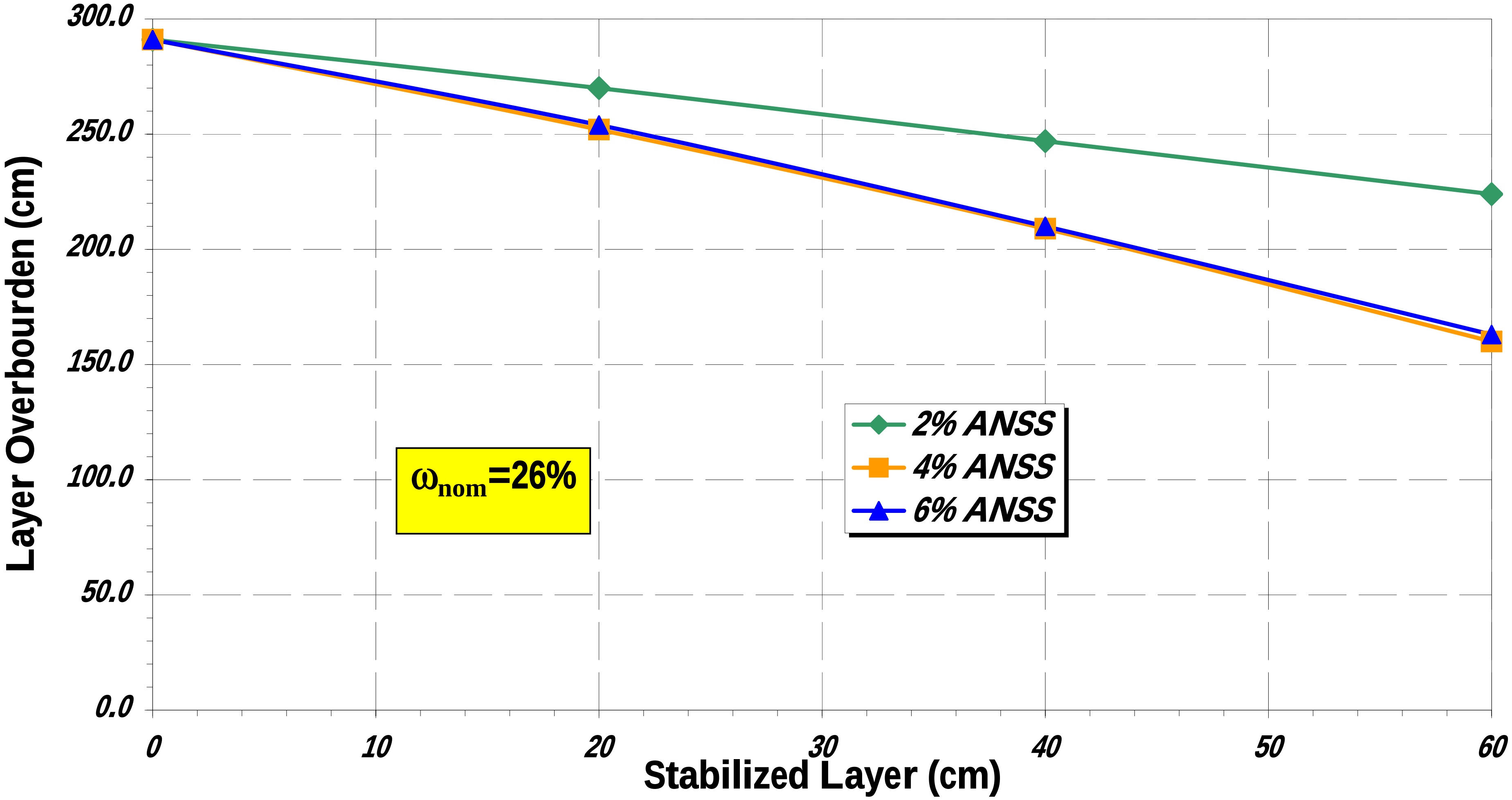

Fig. 4.8 : Layer Overburden for different ANSS contents