SOIL IMPROVEMENT BY INJECTIONS OF POLYURETANIC RESIN FOR MITIGATION OF SWELLING AND SHRINKING OF CLAYEY SOILS

CONSOLIDATION DU SOL PAR INJECTION DE RESINE POLYURETHANE, AFIN D'ATTENUER LE GONFLEMENT ET LE RETRAIT DES SOLS ARGILEUX

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ABSTRACT – The fast growing number of reported hazards due to drought, increased the need to study the relationship of precipitation frequency and cracking phenomena. The rainfall data and hazards number of a limited geographical area have been studied to determine the most suitable index for prediction of future problematic periods. Also the effects of drought on foundation ground have been monitored to work out a method to solve or prevent problems on construction related with swelling and shrinking of clayey soils. The comparison of the effects on soil of drought and of high expansion pressure resin injections showed that they are quite similar in terms of stiffness increase, but the higher density of soil compressed by resin injections, prevents strong future volume variations.

RESUME – La forte progression des sinistres induits par la sécheresse a renforcé la nécessité d'étudier la relation entre la fréquence des précipitations et la dessiccation des sols. Les données pluviométriques et le nombre de sinistres au sein d'une zone géographique donnée, ont été examinés afin de déterminer l'indice le plus adapté pour la prédiction des futures périodes problématiques. Les effets de la sécheresse sur les sols d'assise de fondation ont également été examinés, afin d'élaborer une méthode susceptible de résoudre ou prévenir les problèmes en matière de construction, liés au gonflement et au retrait des sols argileux. L'étude montre que les effets de la sécheresse sur le sol et ceux de l'injection de résine à forte pression d'expansion, sont quasiment similaires. Ainsi, la densité accrue des sols comprimés par la résine prévient le risque de futures fortes variations de volume.

1. Introduction

The understanding of the relationship of extreme climate changes registered in the recent past and hydrogeological hazards, especially those caused by drought on clayey soils, is not always easy.

The study of several data regarding a limited geographical area in Italy has been carried out in order to determine the correlation between increase of number of hazards and decrease of rainfall events.

The region including lower Romagna (provinces of Rimini and Forlì Cesena), northern Marche (province of Pesaro Urbino) and the San Marino Republic, which all belong to the Marecchia river basin, represents an interesting study area because of the geological and geomorphologic characters and the availability either of precipitations data ordered in representative series or of monitoring of hydrogeological hazards.

1.1. Precipitation series analysis

Four different meteorological stations were considered: Rimini, San Marino – Monte Titano, Novafeltria and Pennabilli. All these stations have been collecting data for more than eighty years and represent different climatic and geomorphologic situations.

In the recent past a general decrease of average monthly rainfall events was observed in this area, particularly during the winter seasons. Also a rise of the autumn peak and an extreme reduction of snowfalls were registered.

The alternation of very arid years (1993. 1994. 1998. 2000 and 2007), extremely arid years (2003), very rainy years (1996 and 1999) and extremely rainy years (2005) characterized the last decades.

The data referring to rainfall events were processed in order to obtain an index showing, on a monthly base, the periods characterized by nonstandard conditions. It was utilized the SPI (Standard Precipitation Index – McKee et al. 1993) worked out to have Gaussian distribution with mean equal to zero and variance equal to one, which allows a comparison among stations far away from each other and in different orographic conditions. The data processing started in 1960.

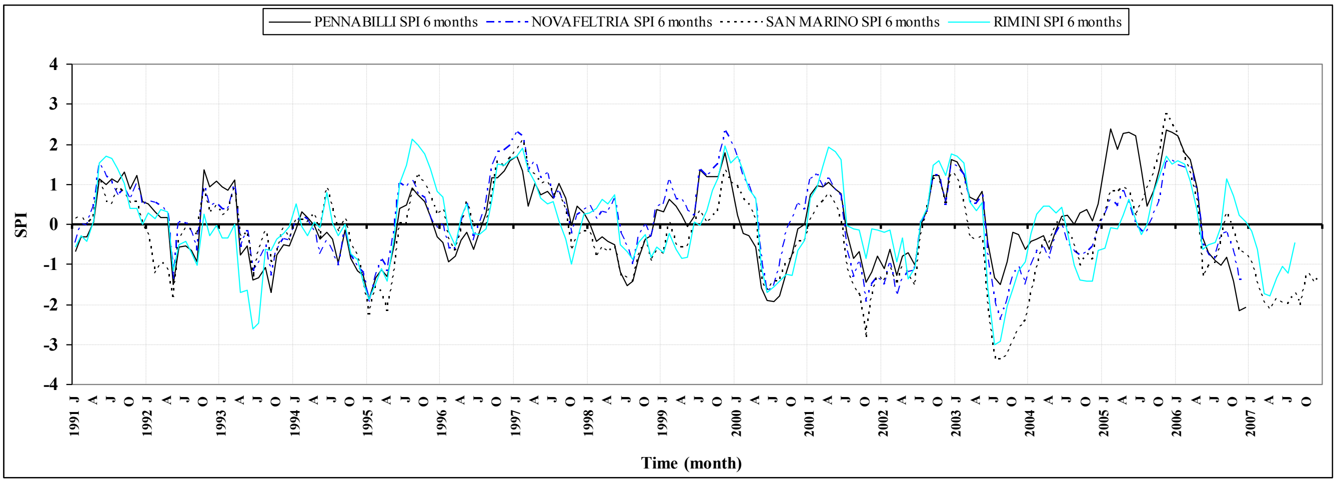

Figure 1. SPI (on a six months base) of the four reference meteorological stations.

Values of SPI included between -1,0 and 1,0 indicate standard periods, between 1,0 and 1,5 and between -1,0 and -1,5 moderately rainy and moderately arid periods, between 1,5 and 2,0 and between -1,5 and -2,0 very rainy and very arid periods and finally over 2,0 and under -2,0 extremely rainy and extremely arid periods.

A six months SPI index has been chosen, because during this period of time, rainfalls strongly influence infiltration water flow and ground water table.

The chart highlights, on a regional basis, the extreme rainy periods and most of all the extreme arid periods, which characterized the Marecchia river basin. Between 1991 and 2006, the average SPI value overcame 2,0 in the autumn of 2005 and, on the other hand, it went three times underneath -2,0, in the winter of 1995, in the summer of 2003 and in the spring of 2007.

During the previous thirty years (1961 – 1990), the average SPI value never overcame 2,0 and went only once underneath -2,0.

In order to compare recent climate changes with peaks of hydrogeological hazards, a time depending chart was arranged including both precipitation and reported hazards intensities.

1.2. Relationship of drought frequency and number of hazards

Starting from the number of reported damages and restoring interventions on building affected by differential settlements and cracks, another index was than introduced to quantify the hazards due to drying of the foundation ground on a regional basis.

The SPI trend of the four stations looks quite similar and it was therefore decided to take the mean value in order to simplify chart comprehension.

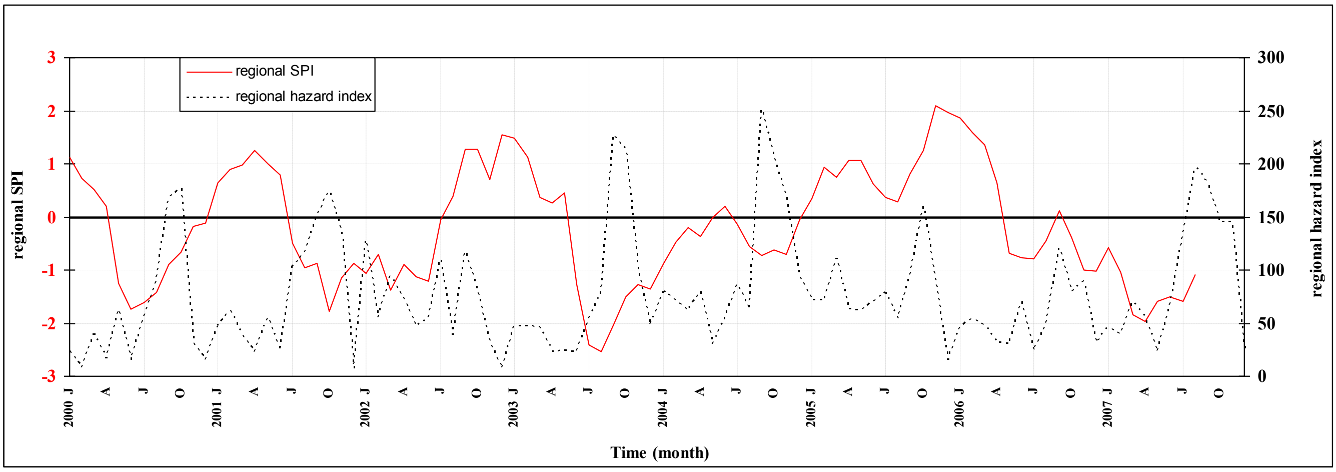

Figure 2. Chart of regional SPI (on a six months base) and regional hazard index.

By comparing the processing, a good relationship between the trend of the calculated SPI and the periods when the hazards were reported can be noticed. To very low SPI value always correspond, sometimes with a certain delay, a very high number of reported hazards.

The SPI value appears as a very important index to reveal the climate changes which are signalized by the increased number of extreme events and most of all by the increased frequency and duration of extreme arid periods.

2. Ground improvement by Uretek technology

Uretek Deep Injections® is a very particular improving technique, consisting of local injections into the soil of a high-pressure expansion resin; this produces a remarkable increase of the geotechnical properties of the foundation soil.

After having injected the soil to be treated, resin immediately starts to expand. The pressure, developed by the expanding resin, first leads to the compaction of the surrounding soil and then to the lifting of the over structure; this movements are checked by a laser receiver anchored to the building.

2.1. Comparison of the effects on soil of drought and Uretek Injections

The comparison of penetrometric tests performed in the same area before and after a long arid period, revels a rise of the penetrometric resistance; similar effects can be seen before and after a high-pressure expansion resin injection. The following figures show the resistances observed in comparison tests performed in San Marino in 1997 and 2007 in the same area and during a resin injections test field.

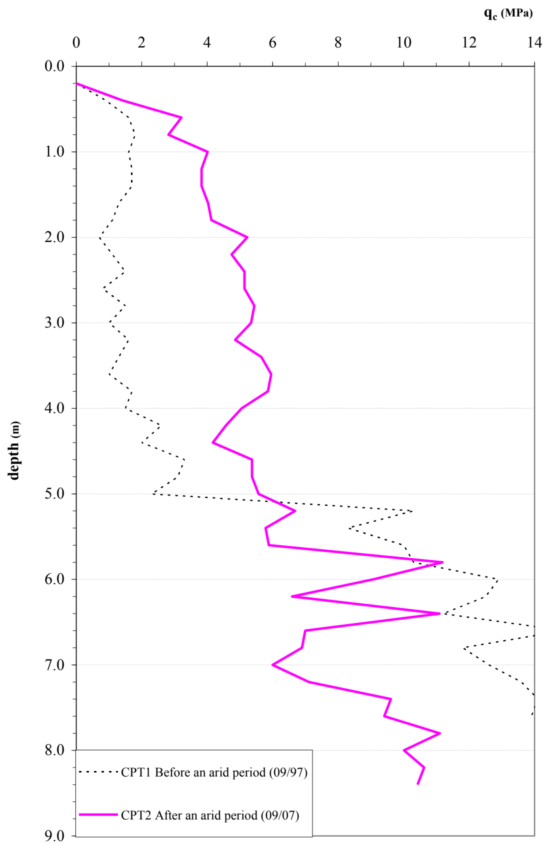

Figure 3. Penetrometric test comparison before and after an arid period

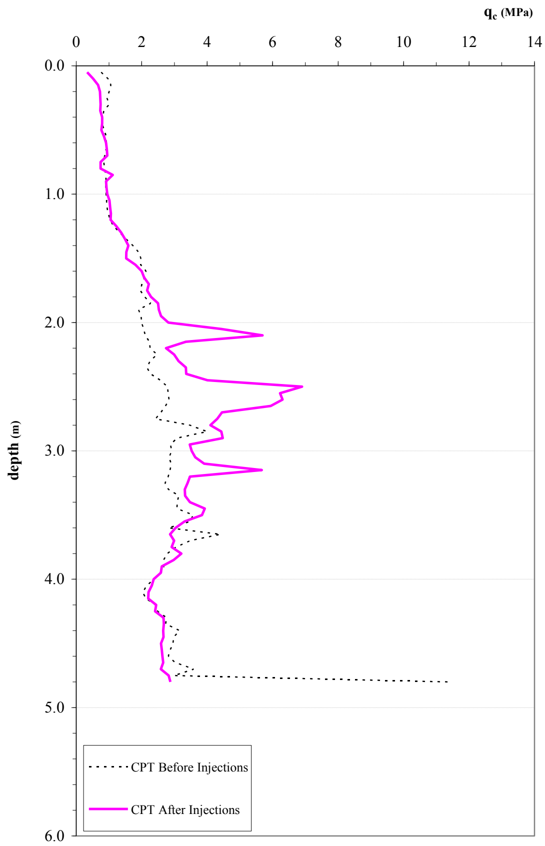

Figure 4. Penetrometric test comparison before and after injecting of 20 kg of resin at a depth of 2,80m

Remark: figure 4 intends to show the effect of one single injection at a depth of 2,80 m. In case of a foundation treatment, multiple injections would be realized with effects over the whole treated height combined with a group effect.

During arid periods, the decrease of void ratio due to decrease of natural water content *w* causes a volume loss according to a curve, similar to the one shown in figure 5, which can be determined with a laboratory dry test.

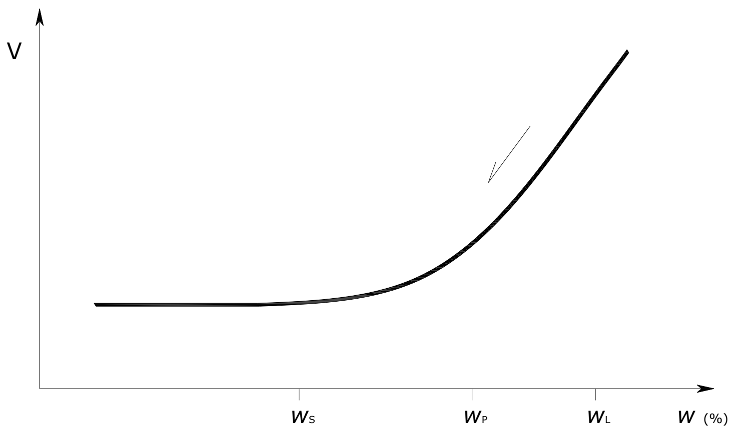

Figure 5. Relationship of volume and natural water content

The chart shows how the volume decreases until a w_s value is reached, under which further loss of water will not result in any more volume reduction.

The natural water content can be calculated as a ratio of the water weight and the soil weight:

$$w = \frac{P_w}{P_s} = \frac{\gamma_w \cdot V_w}{\gamma_d \cdot V} \quad (1)$$

In case of saturated soils (S_r=100%) the volume variation is equal to:

$$\frac{\Delta V_w}{V} = \frac{\Delta V}{V} = \frac{\gamma_d}{\gamma_w} \cdot \Delta w \quad (2)$$

According to this formula, the natural water content variation due to a water volume variation can be determined.

3. Case History

For exemplifying the above-mentioned procedure an interesting case history is reported, referring to the foundation ground improvement of a residential building in Antibes Juan Les Pins (France) interested by diffused cracks in the elevation structure.

The building is laid on strip foundations, dimensions being 0,7 m deep and 0,5 m wide, and is located in an urban area with a very light slope. It consists of one main nucleus with walkways all around it. The building has a rectangular shape on two floors. The structural damages were particularly concentrated on the perimeter of the building.

The first cracks appeared during summer of 2003 concentrated on the external walls. The extremely arid period during which the hazard showed up and also the cracks distribution suggest a settlement due to drought.

3.1. Geotechnical conditions

During August 2007 a geological survey was carried out, in order to determine the geological nature of the foundation ground and its mechanical characteristics, including four dynamic penetrometric tests, two soundings, five pressiometric tests and laboratory tests such as Atterberg limits and natural water content determination as well as dry test and oedometric swelling test.

The foundation ground is characterized by the presence of 0,6 m of ballast followed by clayey soils ($9{,}7<E_p<33{,}0$ MPa; $0{,}87<P_l<2{,}91$ MPa; $31<PI<39$ %; γ_d= 17 kN/m^3) and sandy loam starting from a depth of about 7,0 m. The dry test performed on clay, shows that a water content variation of 1% leads to a relative height variation of 0,5%, which means 5 mm of settlement if we consider one meter of foundation ground.

3.2. Ground improvement operations

The ground improvement operations, underneath the whole 46 meters of the main building shallow strip foundations took four and a half working days. It has been injected on three different depth level by improving the first three meters of foundation ground.

Considering an expansion factor equal to 4 (Dei Svaldi et al., 2005), the average expanded volume of injected polyurethane resin was of about 40 dm^3 for each cubic meter of injected ground. Considering a unit volume of improved soil, a volume replacement factor can be calculated as a percentage of the ratio of resin volume and soil volume:

$$RV = \frac{V_r}{V} = \frac{40}{1.000} \cdot 100 = 0{,}040 = 4{,}0\% \quad (3)$$

Considering the replaced volume (V_r) of (3) as equal to the water volume variation (ΔV_w), the natural water content (Δw) can be obtained.

$$\Delta w = \frac{\Delta V_w}{V} \cdot \frac{\gamma_w}{\gamma_d} = 0{,}040 \cdot \frac{10}{17} = 0{,}023 = 2{,}3\% \quad (4)$$

This value, together with the dry test curve, allows a prediction of a future settlement reduction caused by further water loss equal to about 35 mm.

4. Conclusions

Starting from the precipitation series analysis, an interesting index has been chosen to observe the trend of rainy and arid periods which characterized the last decades.

This trend has been compared with the number of reported damages and restoring intervention to evaluate the influence of drought on cracking events.

The effects of a ground improvement technology involving high expansion resin injections have been observed in order to evaluate its efficiency for mitigation of swelling and shrinking of clayey soils.

A settlement reduction calculation method is presented.

The replacement of soil water with resin strongly reduces possible future settlements due to further water loss by reducing the natural water content, but also other effects should be considered. Other of resin expansion, whose influence on soil water absorption/release There will be analyzed, in future researches, the effects of homogenization of under-foundation stress state and permeability reduction on rehydratation mitigation.

5. References

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