Influence of suction on the behaviour of retaining walls in the city of Naples, Italy

Anna Scotto di Santolo, Lorenza Evangelista and Aldo Evangelista,

Abstract. The general principles of EUROCODE 2008 prescribe that new constructions are designed, tested and subjected to maintenance during their lifetime. Safety and performance under service conditions are evaluated through the limit states that may occur during the nominal life of the construction. As it is well known, limit states are the conditions beyond which the construction no longer meets the requirements for which the design has been made. In general, during its lifetime, a construction can experience a variation of the external loading. A clear example is the occurrence of a seismic event. Yet, when the soil is in a partially saturated condition, its hydro-mechanical properties can vary with time as a consequence, for example, of rainfall events and subsequent infiltration. A more complex approach is in this case required as a variation of both soil hydro-mechanical properties and external loading can occur. The present work deals with the above issue. In particular, it refers to the city of Naples where unsaturated pyroclastic soils are widespread. Gravity walls, made of tuff masonry, and retaining unsaturated pyroclastic backfills have been analyzed in terms of general behavior and potential damage induced by rainfall events. A Two-Phase Flow module - FLAC2D (Itasca, 2000) has been employed for the numerical analysis.

Keywords: retaining walls, pyroclastic soils, numerical model, infiltration.

Anna Scotto di Santolo
Università di Napoli Federico II, Napoli, Italy, e-mail: anscotto@unina.it

Lorenza Evangelista
Università di Napoli Federico II, Napoli, Italy, e-mail: lorenza.evangelista@unina.it

Aldo Evangelista
Università di Napoli Federico II, Napoli, Italy, email: evangeli@unina.it

1 Introduction

The study of the existing structures is a critical problem due to the number of unknowns and it is more complex than the study of the new constructions. In particular, for retaining walls, the main concerns are related to the evaluation of the hidden geometry, the materials properties, the construction procedure and the loading history. In Naples, because of the land morphology (markedly steep) and the high population density, several walls have been built in the last century for a total length of about 200 km (Fig.1a). A schematic map is shown in Fig 1b.

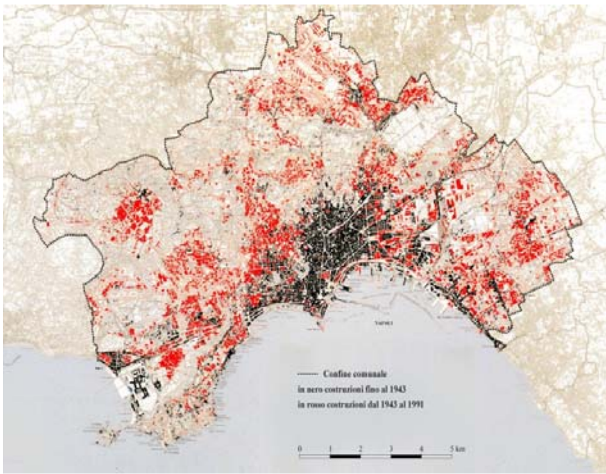

Fig. 1a. Urbanization of city of Naples, after the 2nd world war.

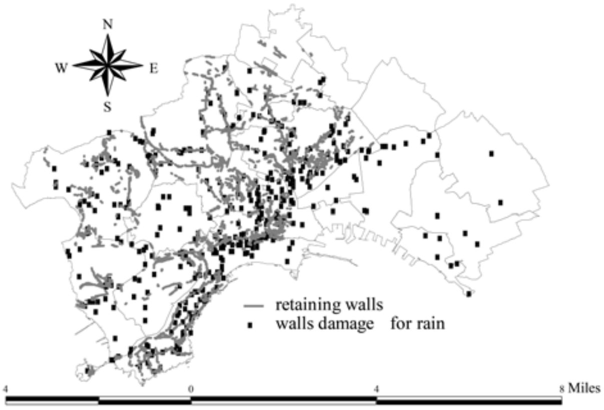

Fig. 1b. Map of walls (200km) and damages in the city of Naples, Italy

The walls are made of Neapolitan Yellow Tuff (NYT), a soft rock widespread in the area (Evangelista 1980, Ceroni et al., 2004), and used as construction material, even for buildings, given its good mechanical properties. Although the NYT is sensitive to erosion and rainfalls, structures like walls have shown a good durability. A picture of some historical walls is shown in Fig. 2.

Partially saturated pyroclastic deposits exert a modest thrust for their higher strength as compared to the saturated ones. This is highlighted by the low ratio thickness/ height above the ground, which ranges between 0.25÷0.3 (Evangelista et al., 2002) against 0.4÷0.6 recommended by technical literature. However, significant damages can occur during rainfall events. Figure 3 shows a data record, from 1986 to 2002, of wall damages and rainfall events. It is interesting to note, that in this period, the mean rainfall was almost constant and that the main peak of rainfall and also of instability phenomena occurred during the winter 1996-1997. In the same period, more than 300 shallow landslides in pyroclastic deposits occurred.

Fig. 2. Walls on San Martino hill, from “San Martino immagini e memorie” (Spinosa, 2000)

On the basis of many observations of rainfall and suction, in the pyroclastic covers of the hill up to 4m in depth, it is possible to define three periods during the year. The first, from September to December, is characterized by intense and recurrent precipitations with a consequent increase of water content in the subsoil (wet-stage); the second with a reduction of the rainfall events but with intense isolated precipitations; the third one characterized by dry months (dry-stage).The wet stage is the most dangerous for the retaining walls due to the considerable increase of water content, reduction of shear strength and the consequent raise of the thrust.

This paper illustrates the hydraulic and mechanical response of a typical gravity walls of Naples analyzed under different initial water content, by using the numerical code FLAC. The typical geometry and stratigraphy was deduced from a statistical analysis on the walls of the city. The effect of the suction variation in the backfill and in the tuff masonry represents a peculiar aspect in the present analysis.

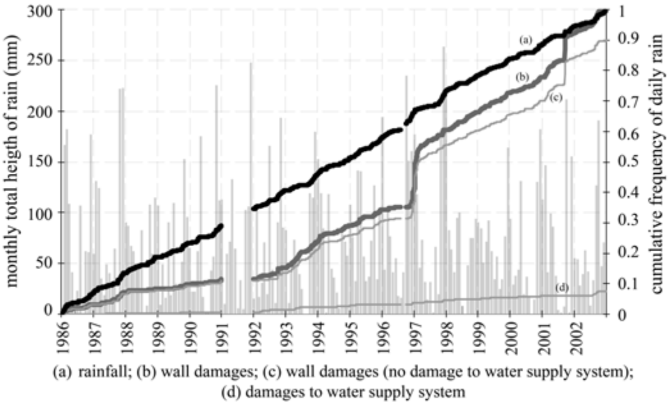

Fig. 3. Historical data of rainfall and instability of walls in the city of Naples, Italy (after Evangelista et al., 2002)

2 Adopted model and input parameters

As observed by Fredlund and Rahardjo (1993) the lower is the soil water content the higher is the soil strength and therefore the thrust on the retaining wall. Design of retaining walls need the knowledge soil degree of saturation and suction values of the backfill behind the wall. Numerical analysis have been carried out adopting the module “Two Phase Flow” of the FLAC code to investigate the effects of rainfall (or some other phenomena) and consequent variation in the regime of pore pressure (suction) inside the backfill and the wall masonry. The two phase module of FLAC allows to know and take into account both the infiltration in unsaturated deposits and stress-strain conditions of the medium with the effective stress Bishop’s approach (1936). The present study has not been carried out with the aim of drawing up a schedule calculation but only to show, in a simple way, the effects mentioned above. To better highlight the effects induced by some significant parameters, it has been considered a trapezoidal wall with the ratio thickness/height above ground equal to 0.25, which corresponds to the typical value for the Neapolitan ones. Two wall heights have been considered: 10 and 5 meters, fixed for 2 and 1 meters respectively (Fig.4). The considered stratigraphy is homogeneous and the mechanical properties of pyroclastic backfill and tuff are reported in Table 1. Van Genucthen model has been adopted for the hydraulic behaviour: parameters (reported in Table 2), have been determined by a best fitting of some pressure plate test data on both materials (Scotto di Santolo & Evangelista, 2011).

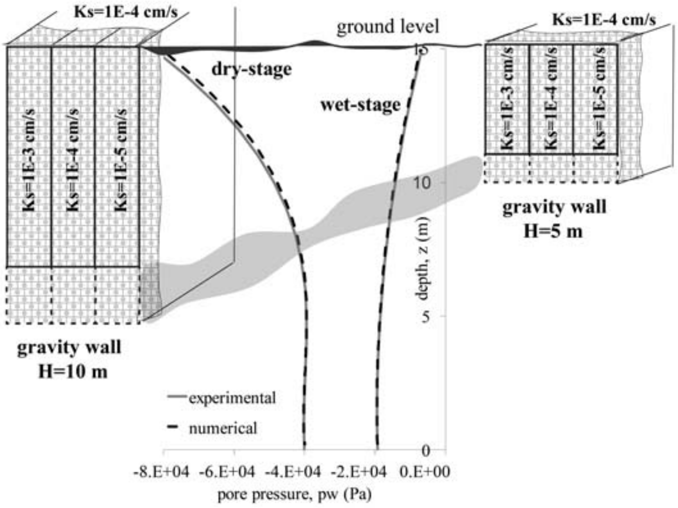

Fig. 4. Sketch of numerical analysis and hydraulic properties of masonry tuff and backfill compared to the in situ initial condition of pore pressure distribution.

It is important to highlight, that specific studies on the tuff masonry of the retaining walls and in particular on its hydraulic properties have never been carried out. Therefore in this study, values close to those of the intact rock have been assumed, suitably amplified or reduced.

The analyzed domain is 20x15 m with a uniform square mesh of 0.2 m. Two different initial in situ pore pressure conditions (introduced by a fish developed by the Authors) have been assumed according to the slope hydrology response carried out with tensiometers monitoring for 5 years (Evangelista & Scotto di Santolo, 2010). The first initial condition refers to the dry stage (§1) while the second one is typical of the spring season with low and constant suction until 4 m (wet stage).

For the study of seepage, it was adopted the model used for small hydrological basins which consists in the persistent presence of a film of water on the ground surface. Other boundary conditions of the wall are: seepage face along the wall, bottom and the left side impervious. Moreover the presence of a permeable channel has been modeled near the base of the wall, Fig. 5. Three different values of saturated permeability masonry have been assumed to take into account the different behavior of the wall affected to the discontinuities related to the texture typology, construction modalities and erosion phenomena. The summary of the numerical analysis carried out is reported in Fig. 4.

Table 1. Elasto-plastic properties of materials

Material	G (Pa)	B (Pa)	ν (-)	c (Pa)	φ (°)	ψ (°)	σt (Pa)	σc (Pa)
Pozzolana	6E+6	1E+7	0.3	-	35	0	-	-
Tuff	3E+7	7E+7	0.33	1.41E+6	30	0	5E+5	5E+6

Table 2. Hydraulic properties of materials

Material	Initial dry density, γd (kN/m^3)	Initial porosity, n (-)	Saturated permeability, ks (cm/s)	Van Genutchen's parameters, P0*, a, b, c
Pozzolana	10	0.5	$1x10^{-4}$	27.7, 0.36, 0.5, 0.5
Tuff	10	0.6	$1x10^{-3}$, $1x10^{-4}$, $1x10^{-5}$,	12, 0.4, 0.5, 0.5

*(Pa).

3 Results

The wall-backfill interaction during rainfall infiltration has been assessed by imposing a critical value of 1.2 to the ratio between the tilting and stabilizing moments (Mr/Ms) of the wall. This approach, similar to that adopted for the sheet pile, it is simple but suitable for the studied problem. The results of numerical analysis are summarized in Table 3 and in Figure 5, where for each analyzed case, the pore pressure distributions, the plastic points and the deformed mesh magnified at the critical time are shown. Performed analysis show that the initial conditions imposed assume a significant role in the non steady state analysis (Tab. 3). It is interesting to note the trend of the thrust behind the masonry. In all the initial conditions characterized by a dry-stage, there are negative (tensile) horizontal stresses for about 1/3 of the height from the top of the wall, while they are positive until the base. This trend is quite unusual for saturated or dry soils as evidenced by Stainer and Tarantino (2010). The hydraulic behaviour of the wall has been investigated by assuming a constant parameter for the water retention curve, while the saturated permeability is variable. It is possible to note that, higher is the saturated permeability of the masonry related to the backfill, lower is the load on the structure.

Furthermore the time necessary to reach the conditions assumed as critical (M_S/M_R=1.2) grows as the permeability of the masonry decreases and from dry to wet initial conditions. The study shows the complexity of the design of structures in partially saturated soils, until now modelled only to evaluate the stability of slope. The uncertainties related to the apparent cohesion is certainly exceeded compared to the constitutive modelling of unsaturated soils. However the uncertainties of the input data are significant and this can hinder the introduction in numerical codes of models for unsaturated soils.

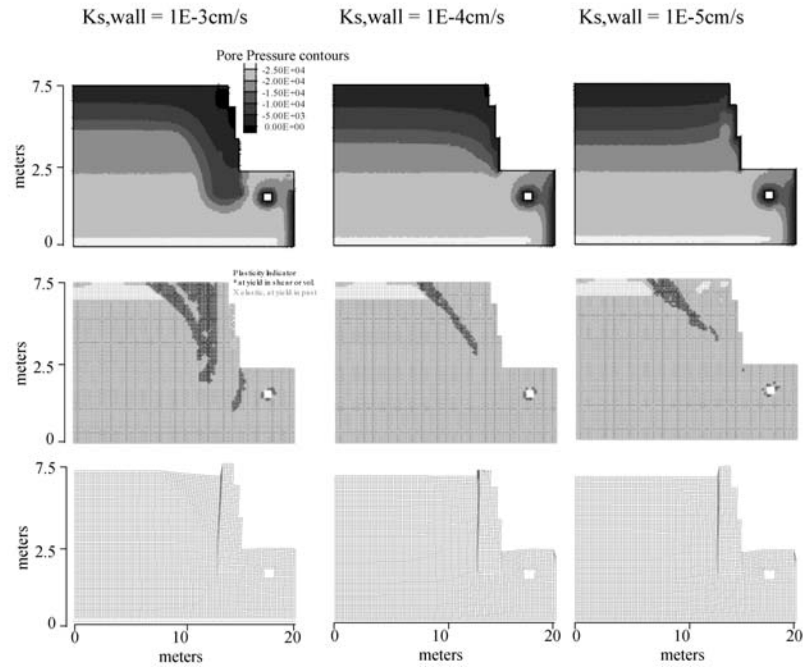

Fig. 5. Results: (a) Pore pressure distribution; (b) plastic points; (c) deformed mesh

Table 3. Results of numerical analyses.

H wall (m)	Initial Condi-tions	Ratio of ksat wall/backfill	Total Thrust (kN/m)	Water Thrust (kN/m)	Critical time (hs)	Critical Total Thrust (kN/m)	Abs(ΔS) variation (%)
6	WET	0.1	15	-82	47	22	47
6	WET	1	15	-82	40	20	33
6	WET	10	15	-82	21	17	13
6	DRY	0.1	-51	-263	36	27	153
6	DRY	1	-51	-263	31	25	149
6	DRY	10	-51	-263	18	22	143
10	WET	0.1	79	-210	27	90	14
10	WET	1	79	-210	23	86	9
10	WET	10	79	-210	34	80	1
10	DRY	0.1	-77	-435	122	96	225
10	DRY	1	-77	-435	111	89	216
10	DRY	10	-77	-435	100	83	208

Conclusion

The present work reports the effects of rainfall infiltration on gravity walls in the city of Naples. They are made of Neapolitan Yellow Tuff and retain partially saturated pyroclastic soils. A numerical study has been carried out by using FLAC code which is able to analyze simplified hydrological model with a complete mechanical analysis. The initial suction condition was fixed on the basis of in situ suction measurements, and the mechanical and hydraulic behaviour of the materials was determined by means of laboratory tests. The pore water pressure distribution has been evaluated for different initial conditions with a given return time. This study represents the first application of Two Phase Flow of FLAC to the unsaturated wall-soil system. The parametric analysis performed highlights the influence of suction on the stability of the system and allows to evaluate the role of some parameters on the hydraulic response of the soil-wall system. Moreover the results shown have the potential to be employed for design issue and planning maintenance works devoted to the improvement of serviceability conditions.

Acknowledgements. This work is part of the activities within the Reluis project (MT3 area).

References

Ceroni C., Pece, M., Manfredi, G., Marcari, G., Voto, S. (2004) Analisi e caratterizzazione meccanica di murature di tufo. Atti 15° Congresso C.T.E., Bari, 4-6 Novembre 2004.

Evangelista, A. (1980) Influenza del contenuto d'acqua sul comportamento del tufo giallo napoletano. Atti del XIV Convegno Nazionale di Geotecnica, Firenze.

Evangelista, A., Cestrone, V., Conte, G., Napoli, M., Lombardi, G., Mandolini, A., Russo, G. (2002) I muri di sostegno della città di Napoli: inventario, condizioni di sicurezza, interventi di stabilizzazione. Atti CNG, L'Aquila 2002.

Evangelista, A., Scotto di Santolo, A. (2010) Matric suction in unsaturated pyroclastic slopes. In Unsaturated Soil, Alonso & Gens eds., 2011.

Fredlund D G, Rahardjo H (1993) Soil Mechanics for Unsaturated Soils. Wiley and Sons Inc., New York.

Itasca (2000). FLAC (Fast Lagrangian Analysis of Continua). Minneapolis: Itasca Consulting Group, Inc FLAC.

Stanier, A. A. and Tarantino, A. (2010) Active earth force in 'cohesionless' unsaturated soils using bound theorems of plasticity. In Unsaturated Soil, Alonso & Gens eds., 2011.