Site characterization by seismic dilatometer (SDMT): the Justice Court of Chieti

Caractérisation du site par dilatomètre sismique (SDMT): la Cour de justice de Chieti

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ABSTRACT: A detailed investigation of several seismic dilatometer (SDMT) tests was performed in 2011 on Chieti hill to restore the Justice Court, an historical building damaged by the April 6, 2009 L'Aquila earthquake. Moreover, boreholes were carried out to investigate foundation base level and cyclic simple shear tests with double sample were realized to analyze the seismic site response. The paper illustrates the potential of the seismic dilatometer to efficaciously approach a geotechnical problem by the interpretation of SDMT parameters, as the shear wave velocity V_S, the constrained modulus *M* and the horizontal stress index *Kd*. Finally, the paper combines SDMT results with laboratory data to analyze the site response of the Justice Court.

RÉSUMÉ : Une étude détaillée de plusieurs sismiques dilatomètre (SDMT) tests a été réalisée en 2011 sur la colline de Chieti pour restaurer la Cour de justice, un bâtiment historique endommagé par le tremblement de terre qui a eu lieu le Avril 6 2009 à L'Aquila . En outre, des sondages ont été effectués pour étudier le niveau de base de fondation et cycliques essais de cisaillement simple avec échantillonnage double ont été réalisées pour analyser la réponse sismique du site. Cet article montre efficacement le potentiel de la dilatomètre sismique à l'approche d'un problème géotechnique par l'interprétation des paramètres SDMTs, comme la vitesse de l'onde de cisaillement V_S, le module *M* et l'indice de contrainte horizontale *Kd*. Enfin, le document combine les résultats SDMT aux données de laboratoire pour analyser la réponse du site de la Cour de justice.

KEYWORDS: seismic dilatometer, horizontal stress index, shear wave velocity, site response analysis, local site effetcs.

1 INTRODUCTION

The April 6, 2009 L'Aquila (Italy) earthquake (M_W = 6.3) caused heavy damages not only in the city of L'Aquila basin but also in few cities, as Chieti, approximately 100 km far from the epicenter. In this respect, a detailed investigation of several seismic dilatometer (SDMT) tests (Marchetti et al., 2008) in virgin soils and inside boreholes backfilled with sand (Totani et al. 2009), foundation boreholes and cyclic laboratory tests were performed in 2011 on Chieti hill to restore the Justice Court, an historical building damaged by the above mentioned earthquake. The geotechnical campaign allowed to characterize the subsoil, to investigate foundation base level and to analyze the seismic site response of this construction. In particular, the paper illustrates the potential of the seismic dilatometer to efficaciously approach a geotechnical problem by the interpretation of SDMT parameters, as the shear wave velocity V_S, the constrained modulus *M* and the horizontal stress index *Kd*, even combinig SDMT results with laboratory data for the evaluation of the local site effects (e.g. topography, soil conditions) with modo-dimensional (1D) and bidimensional (2D) seismic site response analyses.

2 GEOTECHNICAL INVESTIGATION ON CHIETI HILL

A detailed investigation of eleven SDMT tests, six in virgin soil, each 10-20 m in depth, and five inside boreholes backfilled with sand, each 30-50 m in depth, were performed in 2011 on Chieti hill to restore the Justice Court, an historical building damaged by the April 6, 2009 L'Aquila earthquake. Moreover, boreholes were carried out to investigate foundation base level and cyclic simple shear tests with double sample were realized to analyze the seismic site response. The historical centre was built on sandy and arenaria deposits (45 m in depth), while moving towards the bottom of the slope the colluvial cover start to emerge over the OC silty clay, as shown in Figure 1 together with the shear wave velocity V_S profiles.

Figure 2 emphasizes the main reason of the damage due to the seismic action on the construction. As shown by the inspection, the structure appears to be considerably fissured in its Southern part, while in the Northern area it seems to be intact (Figure 2a). This aspect can be justified referring to the four SDMTs performed along the perimeter of the building (Figure 2b). SDMT1 and SDMT4, as well as SDMT3 and SDMT2 profiles, can be coupled. In fact, in the Northern part of the Justice Court the constrained modulus *M* reaches on average values over 100 MPa and the horizontal stress index *Kd* indicates OC soils. Instead, in the Southern area, until about 8.00 m in depth, *M* assumes very low values (under 50 MPa) and *Kd* is about equal to 2 and thus *Kd* individuates NC layers (TC16, 2001). In both the cases V_S appears less sensible to the stress history and the stiffness of the deposits compared to *M* and *Kd*. In addition, the boreholes on the foundations illustrate that in the Southern part the base level is at about 4.90 m in depth. Then, before intercepting sandy and arenaria deposits, it was found a landfill layer from 4.90 to 8.00 m. In terms of stiffness it means that in the Northern portion of the structure the foundations stand on soil with higher mechanical properties compared the soil in the Southern part. A possible solution to restore the historical building is to improve the stiffness of the soils placed in the Southern portion, without acting on masonry foundations. This achievement could be realized for example, using, from 4.90 to 8.00 m in depth, special injections at low pressure, able to penetrate and mix with the existing soil structure.

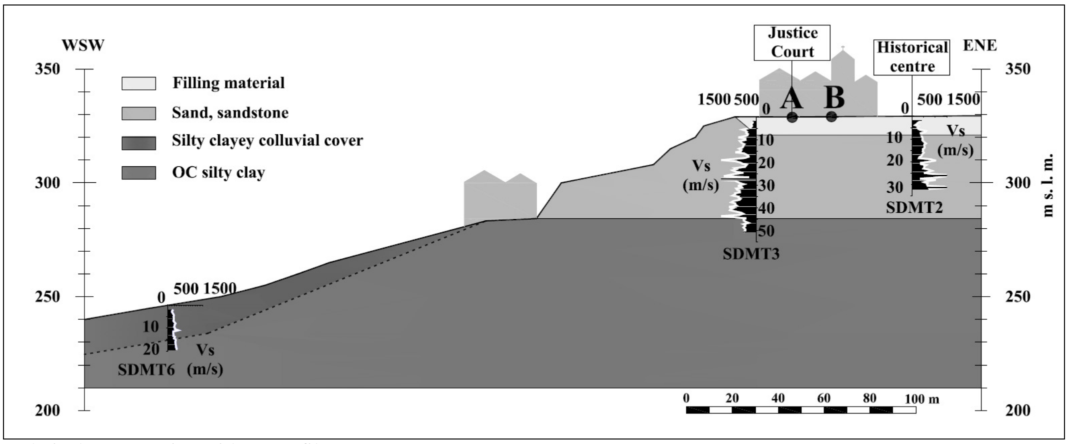

Figure 1. Geotechnical cross section with V_S profiles.

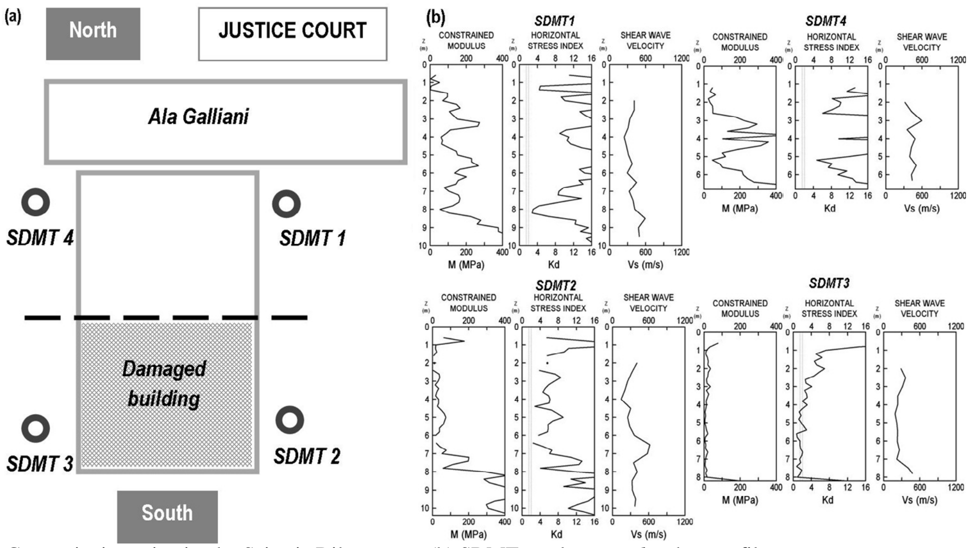

Figure 2. (a) Justice Court: site investigation by Seismic Dilatometer; (b) SDMT results: M, Kd and V_S profiles.

3 SITE RESPONSE ANALYSIS

Numerical analyses of seismic site response were carried out using the computer codes EERA (Bardet et al. 2000), a monodimensional linear equivalent model, and QUAD4M (Hudson et al. 1994), a bidimensional linear equivalent model. that considers a cross section of 3.5 km of width, with 5860 elements and 5844 joints.

The evaluation of the local site effects (e.g. topography, soil conditions) plays an important role in the non-uniform amplification response obtained at different sites (Paolucci 2002).

In order to compare the 1D and 2D analyses, the 1D elastic response spectrum were multiplied by the topographic amplification factor, assumed equal to 1.2 (CEN 2003). Both the analyses were performed on the top of Chieti hill, in correspondence of Southern portion of the Justice Court. Moreover, a 1D comparison was carried out between the Northern portion (absence of filling material) and the Southern portion (presence of filling material) to evaluate the site effects due to the different mechanical behaviour of the upper 8 meters.

3.1 *Input ground motions*

For the numerical analyses two natural accelerograms, applied on the bedrock, were selected as input ground motions. Both the accelerograms were chosen from the software REXEL (Smerzini et al. 2012) and the Italian Accelerometric Archive ITACA (Working Group ITACA 2010).

The first accelerogram “UM_EW” is the strong motion recorded at the Assisi station (Italy) during the September 26, 1997 Umbria-Marche (UM) earthquake (Mw = 6, on outcrop, normal fault, site-source distance ≈ 20 km), scaled, according to CEN (2003), to a peak ground acceleration of 0.164g, for a return period TR = 475 years and a soil type, for the site of Chieti. The second accelerogram "VN_NS" is the strong motion recorded at the Cascia station (Italy) during the September 19, 1979 Val Nerina (VN) earthquake (Mw = 5.8, on outcrop, normal fault, site-source distance ≈ 9 km), scaled to the same peak ground acceleration of UM earthquake.

3.2 *Geotechnical model*

The geotechnical model of Chieti hill, used in the numerical analyses, is illustrated in Figure 1 and 3 and Table 1, by including the soil and dynamics parameters (unit weight γ, Poisson coefficient ν, shear wave velocity V_S, stiffness decay curves G/G_0 and damping D curves).

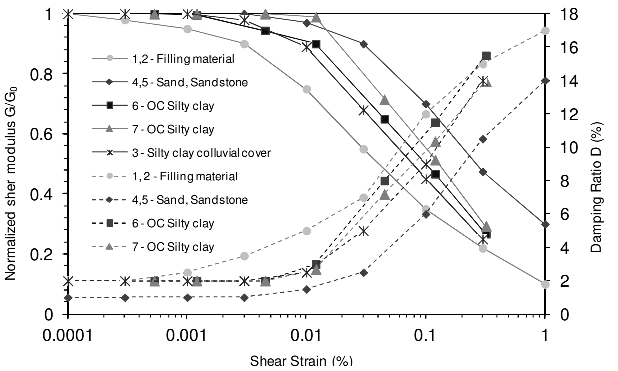

Figure 3. Stiffness decay curves G/G_0 and damping D curves of Chieti hill for numerical analyses.

Table 1. Geotechnical model of Chieti hill for numerical analyses.

Layer	*Material*	*γ* *(kN/m³)*	*ν*	V_S *(m/s)*
1	Filling material	17.1	0.30	220
2	Filling material	17.1	0.30	440
3	Silty clay colluvial cover	18.7	0.45	280
4	Sand, sandstone	20.6	0.30	580
5	Sand, sandstone	20.6	0.30	870
6	OC silty clay	20.2	0.45	600
7	OC silty clay	20.2	0.45	800
8	Bedrock	21.0	0.30	1000
9	Bedrock	22.0	0.30	1300

On the top of the hill, in correspondence of the Justice Court, the subsoil was modelled by considering in the upper 8 m filling material in the Southern portion of the Justice Court and sand and sandstone in the Northern portion, sand and sandstone between 8 m and 42 m of depth, OC silty clay between 42 m and 342 m of depth and the bedrock beyond 342 m of depth, while on the hillside the model reflects the silty clay colluvial cover in the upper 15 m up to the OC silty clay layer. In the upper 50 meters the V_S profile was defined as an average of SDMT profiles, while in the lower OC silty clay V_S was estimated by using an average value interpolated from the experimental relationship Crespellani et al. (1989) and SDMT profiles.

The site campaign of the Justice Court had provided only a cyclic simple shear tests with double sample in OC silty clay. In this respect, the following reference laboratory curves were assumed to evaluate the non-linear and dissipative soil behaviour: Anh Dan et al. (2001) for filling material, Marcellini et al. (1995) for sand and sandstone, MS–AQ Working Group (2010) for silty clay colluvial cover. The bedrock has G/G_0 - γ and D – γ linear behaviour.

3.3 *Results*

1D numerical analyses of seismic site response were carried out by considering the Northern portion and the Southern portion. The spectral accelerations (Figure 4) highlight the different mechanical behaviour of the upper 8 meters: the Southern portion shows pronounced amplifications for a period of 0.1-0.2 s, that is the fundamental period of the filling material, while the spectral accelerations of Northern portion appear lower.

2D numerical analyses of seismic site response were performed by considering in the Southern portion two point, A and B, 20 m far from each other, shown in Figure 3. The peak ground accelerations (Figure 5) doesn't appear influenced by spatial position and input ground motion, even thought the analyses consider only two time histories. In addition, the spectral accelerations emphasize the site effect due to the topography: point A, closer than point B to the hillside, shows higher amplifications for a period of 0.2-0.4 s, compared to the ones of point B .

The comparison of the average results from 1D and 2D numerical analyses in the Southern portion of the Justice Court (Figure 6) illustrates that the 1D peak ground accelerations are higher than the ones evaluated from 2D analyses, probably due to the higher sensitivity of 1D model to stratigraphic effects. In addition, 2D method shows local site effects mainly due to topography for a period of 0.3-0.4 s, that is the fundamental period of the Justice Court.

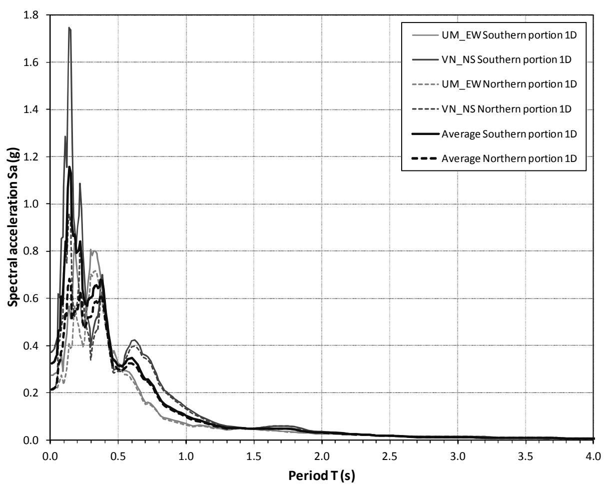

Figure 4. Spectral accelerations form 1D analyses.

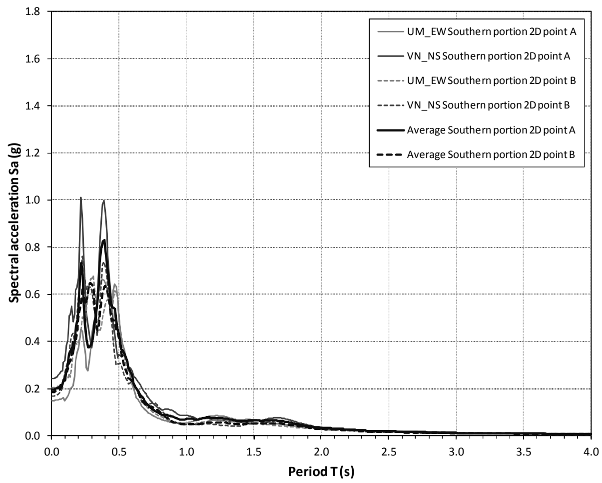

Figure 5. Spectral accelerations from 2D analyses.

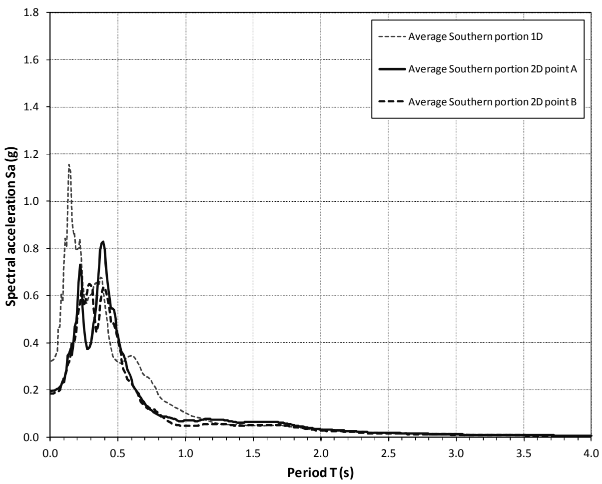

Figure 6. Comparison between 1D and 2D spectral accelerations.

4 CONCLUSION

The paper illustrates the potential of the seismic dilatometer to efficaciously approach a geotechnical problem by means of the results analyses. While V_S appears less sensible to both the stress history and the deposits stiffness, *M* gives precious information on soil stiffness, while *Kd* provides for important details about the deposits overconsolidation. Combining SDMT results with laboratory data it has been possible to evaluate the the local site effects by means of 1D and 2D seismic site response analyses of the Justice Court. These numerical analyses indicates that in complex stratigraphic and topographic conditions, it appear appropriate to combine 1D and 2D methods.

5 ACKNOWLEDGEMENTS

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