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AMPLIFICATION EFFECTS OF A SITE IN THE CITY OF SALERNO

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ABSTRACT

In the city of Salerno (Campania region, 50 Km South of Napoli) the New Law Court Buildings are going to be constructed. The project involves a large area, whose subsoil was thoroughly investigated by means of conventional tests, with the aim to characterise the mechanical properties of the soils and individuate the proper foundation typology. The design of the structures was then carried out, computing the seismic forces according to the indications of the national code, which takes into account the subsoil amplification role by means of an oversimplified approach. After the recent earthquake which struck Molise (Southern Italy, November 1st, 2002) the Regional Government has updated Campania seismic classification; hence many important works, already designed according to the previous classification, need to undergo a new structural design. In the case of Salerno, according to the new classification, seismic forces acting on the Law Court Buildings would seriously increment. Hence, a specific geotechnical study has been requested, with the aim to better investigate on the local seismic effects at the design site. In the whole area an in-situ dynamic investigation has been performed to determine the shear modulus of soils at low strain levels from the surface down to a depth of about 30 m, inside a more rigid base formation of Argille Varicolori (varicoloured clay). Some dynamic analyses of the subsoil behaviour have been performed. The input motions at the base formation were defined on the basis of real accelerograms recorded during the Irpinia 1980 earthquake (Ms=6.9), which produced considerable effects in Salerno area. The wave propagation along depth has been investigated; in particular the seismic response has been studied at the different levels of the foundation structures.

INTRODUCTION

Seismic zonation studies can be typically grouped in three different categories:

- microzonation of very large areas (regional or urban territories), for which the features of existing or designed buildings are neglected and the site response at the free-field surface is evaluated;
- local site effect studies in limited area, relevant to buildings under design, for which the structural features of the buildings, and the potential types of foundations, should be taken into account;
- local site effect for a specific building, already designed or even constructed, for which the complete interaction analysis involves the seismic motion at bedrock, the subsoil and the structure.

Depending on the relation between the time of the study and the time of the building construction, the three approaches can be respectively defined as: *"a priori"* microzonation, *"in itinere"* microzonation and *"a posteriori"* analysis. The case studied here is a typical example of the *"in intinere"* microzonation, and highlights the important role that such a kind of geotechnical analysis can play in defining the seismic actions on a building structure.

CASE UNDER STUDY

In the Eastern area of the city of Salerno (Campania region, 50 Km South of Napoli) the New Law Court Buildings are going to be constructed (Figure 1). There include 6 main structures, which have from 6 to 15 floors in elevation, and 2 underground floors; hence the foundation level lies at -7 m from the ground surface. The project involves a large area, whose subsoil was thoroughly investigated by means of conventional tests, with the aim to characterise the mechanical properties of the soils and individuate the proper foundation typology. The design of the structures was carried out in the years 2000-2001, computing the seismic forces according to the indications of the current national code, which takes into account the subsoil amplification role by means of an oversimplified approach. In particular the Italian Code (D.M. 16.01.1996) provides a foundation coefficient which increases seismic action (coefficient $\varepsilon \geq 1$) when local soil amplification effects are expected. Nevertheless, the application is quite crude, since it is normally assumed ε equal to 1 but for the case of "alluvial deposits (5 to 20 m thick) overlying a stiff soil formation", in which the value 1.3 is assumed.
After the earthquake which struck Molise region (Southern

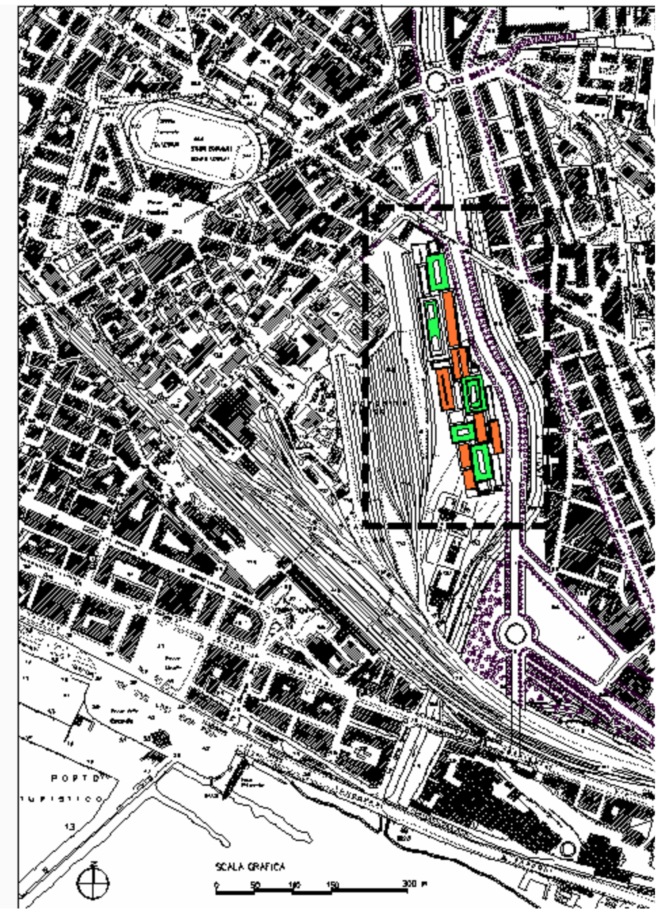

Figure 1. Location of the New Court Buildings in the city of Salerno.

Italy) on November 1st, 2002, the Campania Regional Government has updated the seismic classification. According to the new classification of the city of Salerno, seismic forces acting on the New Law Court Buildings would seriously increase, and the designed structures would result largely under-dimensioned. Hence, a specific geotechnical study was requested, with the aim to better investigate on the local seismic effects at the design site, and to accurately determine the seismic forces acting on the structures.

In the following, first the geotechnical characterization of the site is presented and then some simple analyses assessing the influence of local soils on amplification of seismic forces are illustrated. Finally some comments are given about the seismic actions computed using the new Italian building code that has been drawn very recently, as a further consequence of the recent Molise earthquake.

SUBSOIL GEOTECHNICAL CHARACTERIZATION

The geotechnical investigation performed in the design area was constituted of in situ tests including boreholes, SPT and CPT tests, groundwater measurements, and Down Hole (DH) tests. Also conventional laboratory tests on undisturbed and partially disturbed soil samples were carried out. The stratigraphy and the mechanical characterization of each single soil layer was achieved.

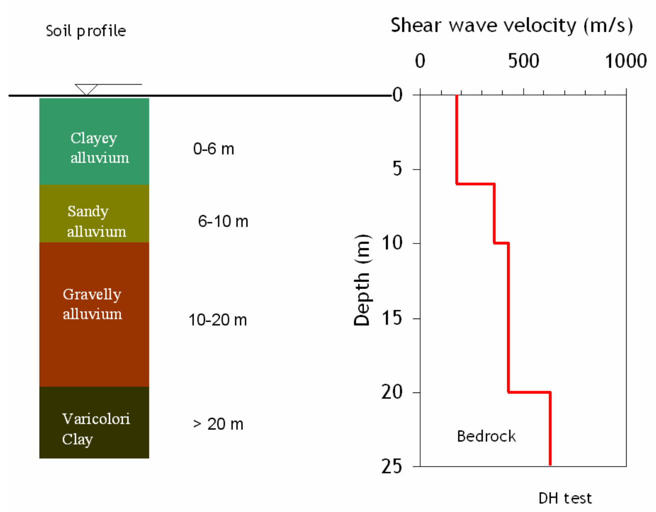

Figure 2. Main geotechnical units and shear wave velocity profile for the New Law Court Building site.

As regards the “dynamic” soil properties, the shear modulus Go of the soils at low strain levels was determined through the shear wave velocity values, obtained by the DH tests performed from the surface down to a depth of about 30 m, inside the more rigid base formation of Argille Varicolori (see Figure 2). The available geotechnical characterization does not allow us to directly assess the decay laws of shear modulus G and damping ratio D with strain level for all the lithological formations constituting the subsoil at the New Law Court Buildings site. Therefore, non-linear soil properties were defined with reference to similar soils in the nearby city of Benevento, where seismic zonation studies are in progress (Santucci de Magistris et al., 2004). Figure 3 shows the assumed non-linear curves for all materials that are presented in the site under analysis.

LOCAL SOIL EFFECT ANALYSES

Dynamic analyses of the subsoil behaviour have been

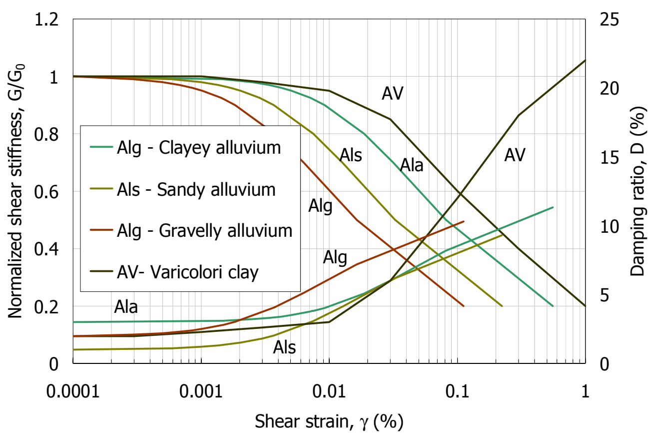

Figure 3. Main geotechnical units and shear wave velocity profile for the New Court Building site.

performed, with the aim to investigate the local soil effect and eventually validate the simplified approaches proposed by the National Building code. The analyses were performed using the EERA code (Bardet et al., 2000), which operates in the frequency domain and assumes that soil behaves as a continuous 1-phase equivalent linear material. This code uses the same algorithm employed in the well-known Shake code (Schnabel et al., 1972), and therefore has its advantages and limits, but a more convenient user-interface.

The accelerometric time history recorded at Mercato San Severino during the Irpinia 1980 earthquake (Ms=6.9) has been utilised as input motion at the outcrop bedrock.
The November 23, 1980 Irpinia earthquake was one of the major quakes that hit Italy in the last centuries, producing considerable damages in Salerno prefecture. Considering the historical seismicity records for the Irpinia-Lucania area combined with a proper recurrence law, a returning period of about 375 years was estimated for this event.
Being not available any instrumental seismic record in the city of Salerno, Mercato San Severino accelerogram was used in the following analyses since this town is located at the same distance of the city of Salerno from the Irpinia 1980 epicenter, as can be seen from Figure 4. In the same figure, the recorded horizontal time-history (NS component), which has the peak acceleration equal to 0.145 g, is also plotted. It is remarkable the long duration of the motion (about 80 s), due to the fact that the earthquake was characterised by three distinct sub-events occurring along different faults, starting at different times.

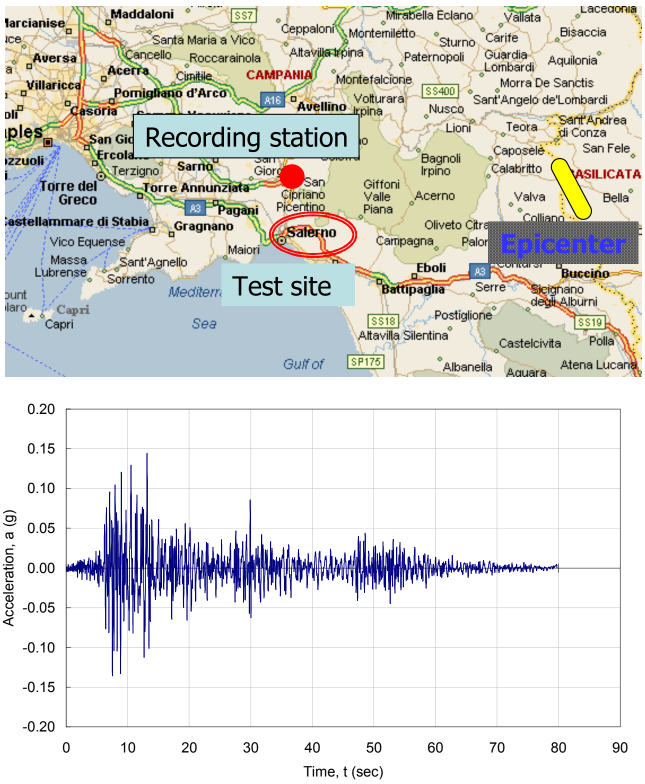

Figure 4. Seismic input motion recoded at Mercato S. Severino during 1980 Irpinia earthquake utilized for the analysis.

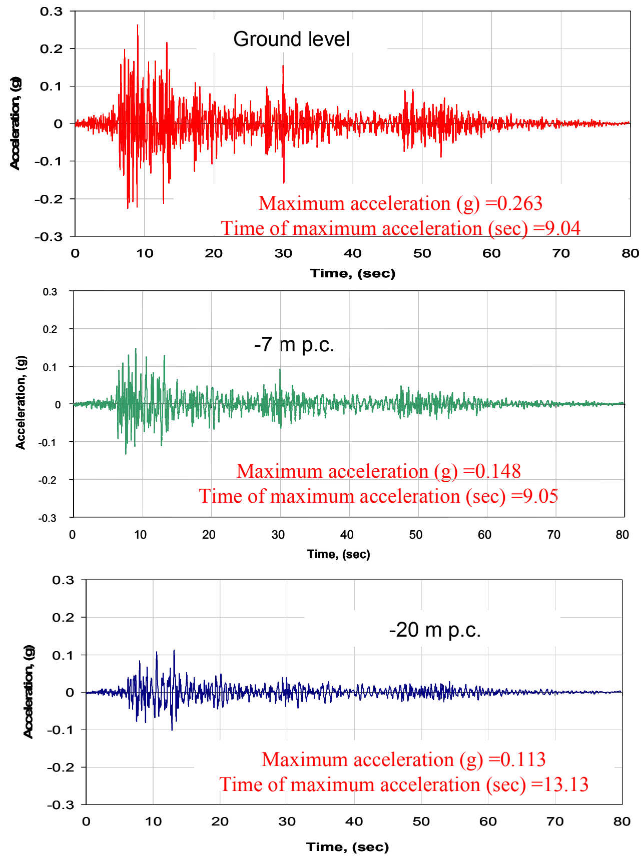

Figure 5. Changes in acceleration time histories with depth for the New Law Court Buildings site.

Since Mercato S. Severino recording station is not located above a stiff soil, some site-specific amplification probably affected the motion coming from the bedrock. Nevertheless, the time history recorded at the surface has been firstly utilised as outcropping bedrock motion, such assuming a more severe input.
The seismic wave propagation along depth has been investigated. In particular Figure 5 illustrates the acceleration time histories at the bedrock level (–20 m from the ground surface), at the foundation level (–7 m) and at the ground surface. The amplification of the seismic motion moving from the bottom to the top of the site is clearly shown by this figure, and also in the derived Figure 6, in which the variation of the maximum horizontal acceleration (PGA) with the depth is also plotted. It can be seen that the signal amplification mainly concentrate in the top subsoil layer (about 6 m in thickness), that is characterized by very low shear wave velocity values. The same conclusion can be derived by the analysis of the signal propagation in the frequency domain, comparing the Fourier spectrum of the acceleration time history at the bedrock outcrop, with those at level –7 m and at the ground surface. Moving from the stiff base to the ground, the seismic signal is practically unmodified at frequencies lower than 3 Hz.
As regards larger frequencies, at the foundation level the signal is slightly amplified only between 3 and 4 Hz, while for frequencies larger than 4.5 Hz it is even decreases. On the contrary, at the ground level the signal amplification is not

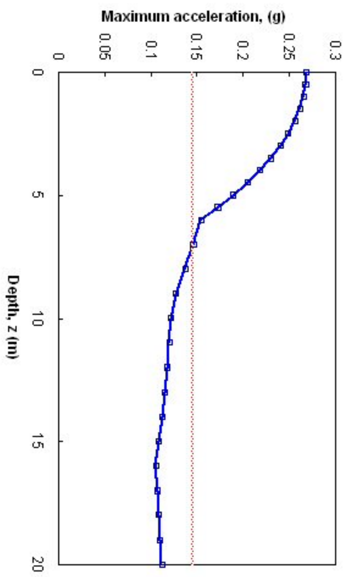

Figure 6. Changes in peak ground acceleration with depth for the New Law Court Buildings site. The vertical line indicates the value of the maximum acceleration on outcrop bedrock.

negligible for frequencies larger than 3 Hz; actually the dominant frequency is about 3.8 Hz. This behaviour is summarised by the spectral amplification ratios plotted in Figure 8: at the ground surface some amplification factors larger than 2 are measured in a frequency range spanning from 3 to 6 Hz, while the amplifications are lower outside such frequency range (the peak amplification value is 2.4 for the frequency component 4.6 Hz); at the foundation level the amplification is negligible up to 4 Hz, and becomes even negative between 4 and 8 Hz.

ENGINEERING CONSEQUENCES

The analysis results presented above suggest that no relevant seismic amplification of the seismic motion deriving from local

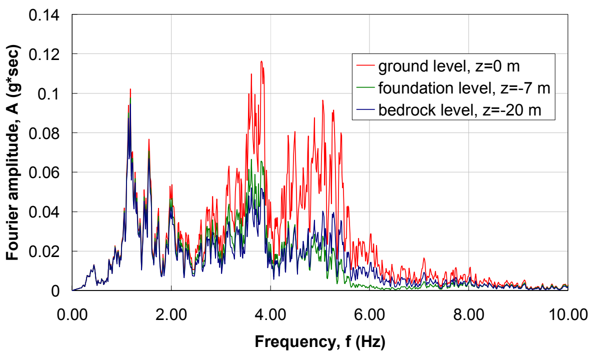

Figure 7. Fourier spectra at the bedrock level, at the foundation level and at the ground level for the New Law Court Building site.

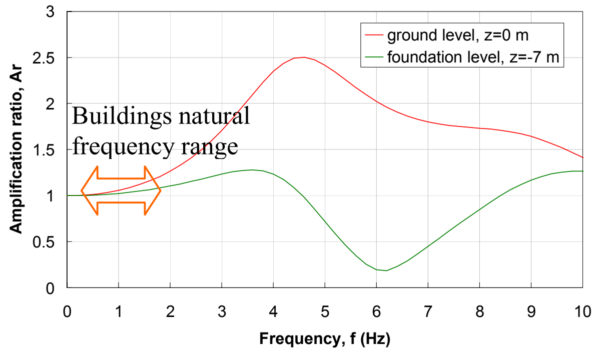

Figure 8. Amplification functions between bedrock and ground level and between bedrock and – 7 m b.g.l. .

soil conditions has to be considered in the design of the buildings of the New Law Court. In particular, Figure 8 indicates that, in the range of the main frequencies of the buildings, amplification ratios about one have been computed; in other words the seismic motion remains unchanged moving from the bedrock to the building foundations, which lie at –7 m from the ground surface. As a consequence, in the application of the design procedure suggested by the traditional national code, a value of the foundation coefficient ε equal to 1 has to be adopted, in order to achieve a reliable evaluation of the seismic actions on the New Law Court Buildings.

A further confirmation of the above statements can be obtained looking at the evolution of the response spectra with depth, which might be also more significant from an engineering viewpoint. Figure 9 shows the response spectra of the signal as evaluated at the bedrock level (- 20 meters), at the foundation level (- 7 meters) and at the ground level.

Figure 9 confirms what was already observed by using the Fourier spectra, that is 1) noticeable modification of the seismic signal appears only in a well defined frequency range; and, 2) signal amplification is evident only between the ground level and the foundation level, not between the foundation level and the bedrock.
In the same figure, the response spectra proposed by the new Italian Building Code (DM 20.03.2003) are plotted. This new Code for construction in seismic areas has been recently proposed, following the mainstream of the Eurocode 8 (EC8), which is now in preparation (CEN, 2003). Referring to the latter (but please notice that the Italian code is very close to the proposed EC8) shear wave velocity profile can be summarized by the equivalent (Simonelli, 2004) $v_{s,30}$ value that is defined as:

$$v_{s,30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{v_i}}$$

where h_i and v_i denotes the thickness and the shear wave velocity of the i-th formation or layer existing in the top 30 m.
A given subsoil can be classified into one out of five categories according to the $v_{s,30}$ value and a normalized response spectra is associated to each category. A horizontal elastic spectrum can

be finally obtained once the design ground acceleration on a stiff ground is established. The latter will be fixed by National Macroseismic zonation studies.
Two special ground types are also included, for which appropriate studies for the definition of the seismic action need to be performed.
It must be emphasised here that, unfortunately, both EC8 and the derived Italian code allow site classification not only by the shear wave profile but also on the basis of N_{SPT} and undrained shear strength (c_u) values.
According to the measured shear wave velocity profile drawn in Figure 2, the site of the New Court Buildings belongs to class B, being $v_{s,30}$ = 501 m/s for the first 30 m subsoil lying under the foundation level, as explicitly indicated in the Italian code. Nevertheless, even considering the first 30 m starting from the ground level, the subsoil still would be classified as B category, being $v_{s,30}$ equal to 360 m/s.
Please notice also that in the Italian Building code the same spectra are suggested for ground types B,C, and E.
It appears that the spectra of the input signal at the bedrock lays well below the code spectrum for bedrock outcropping, that is spectrum A in figure 9, except for a range of periods from 0.8 to 1 s, where the input signal has larger spectral accelerations. On the other hand, spectrum at the foundation level lays below (on the safe side) both the code spectra relevant for medium (spectra B,C,E) and soft soil site (spectrum D). Again this statement derives from the lack of motion amplification between the bedrock and the – 7 m level. Finally it can be seen from figure 9 that the response spectrum at the ground level is above the code spectra for type BCE and type D soil profiles for the period range 0.2-0.35 s. This observation is not relevant for the specific case history in hand, for which buildings under design are characterized by both larger natural periods and deep foundation. However, if on the same site there were some few stories buildings having shallow foundations, they would have been subjected to spectral horizontal acceleration larger than those suggested by the Building code. This would specifically happen if an earthquake with features similar to those of the 1980 Irpinia earthquake had stricken the area. Please notice that the same results are obtained if the comparison with Eurocode 8 is performed.

This statement suggested us to further investigate the shape of the response spectra induced at the test site by the 1980 Irpinia earthquake, using the same seismic input adopted in the previous analyses, but explicitly considering local soil conditions above the recording seismic station in Mercato S. Severino. Results of such analyses will be published elsewhere by the Authors.

CONCLUSION

The case history presented in this paper is a typical example of computation of amplification effects due to local soil conditions, by using an approach that is well consolidated between researchers but not between consultant engineers in Italy.

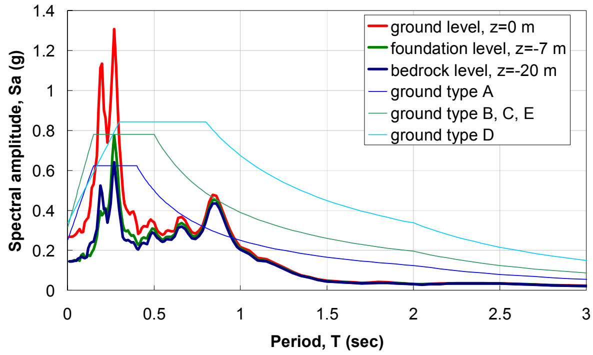

Figure 9. Response spectra at the ground level, at the foundation level and at the bedrock level. Code response spectra for different ground type are also included.

An effective evaluation of seismic actions on real structures requires proper knowledge of seismic hazard coupled with accurate knowledge of soil properties. Computations can be done using numerical approaches as well as following simplified methodologies usually implemented in Building Codes.
A proper knowledge of seismic forces on building should be achieved considering complete soil-foundation-structure interaction. However, the simple analyses here performed can be useful to derive some significant conclusions.

First this study, referring to a real case history, confirms that seismic motion highly modifies within the top soil layers; therefore the actual seismic actions which structures undergo strongly depends on the depth of the foundation level.
Hence it must be observed that conventional microzonation studies, which allow to individuate zones of equal seismic hazard by analysing seismic motion at the ground surface, should not be used to directly assess seismic forces on structures. Therefore, according to the Authors, engineers should use such microzonation maps with great care. For instance, areas in which the upper layers are constituted by man-made ground, usually characterised by poor geotechnical properties, are generally considered hazardous from a seismic viewpoint, since seismic motion tends to strongly amplify in such layers. On the other hand, however, such strata might be ineffective when building foundations are properly designed.

It derives that, even for *"a priori"* microzonation studies, the site seismic response should be defined at various depths from the ground surface, selected according to the stratigraphy and the mechanical properties of the soils which control the choice of the foundation level. The results of such a kind of multiple analyses would give rise to "multilevel" microzonation maps, which could be drawn and effectively represented by means of GIS tools.

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