ROCKING CHARACTERISTICS OF THE 2023 TURKEY-SYRIA EARTHQUAKE

T. Ther [1] & L.P. Kollár[2]

[1] Budapest University of Technology and Economics, Dept. Mechanics, Materials and Structures, Budapest, Hungary, ther.tamas@epk.bme.hu

[2] Budapest University of Technology and Economics, Dept. Structural Engineering

Abstract: *In addition to the two major earthquakes on February 6. 2023 more than 40 moderate (M_W > 5.0) aftershocks were recorded by hundreds of stations in Turkey. Based on these records the rocking characteristics of the different locations can be evaluated. Design of rocking structures subjected to earthquakes can be carried out by using the overturning acceleration (response) spectrum (OAS), which is a modification of the overturning curve defined by Housner. The simplified OAS is recommended for practical design, when the seismicity of a site is characterized by three parameters: the pga, the replacement impulse duration (t_I) and the replacement impulse moment duration (t_M). The latter two parameters are determined for two sites of the 2023 Turkey-Syria earthquake and it is demonstrated that the simplified OAS with these parameters is an excellent tool to design rocking structures for overturning.*

1 Introduction

Overturning of rigid blocks was investigated by Housner (Housner, 1963), who presented the overturning curve, which can be used to determine the possible tipover of a block subjected to an impulse load. The pulse is characterized, by the shape, duration t_p and maximum intensity of the main pulse lobe (acceleration) a_p. The overturning curve of a specific block is given on the a_p, t_p plane (Figure 1a). When the a_p and t_p parameters of a pulse correspond to a point, that is on the left side of the curve, it will not overturn the block, while if it is on the other side the block will tip over. If $a_p<a_{p,min}$ the block will not move at all. Housner introduced the frequency parameter p of a rocking block, which is inversely proportional to the square root of the block size, and extended the overturning curve for any block size, by modifying the horizontal axis to the dimensionless parameter, pt_p(Figure 1b).

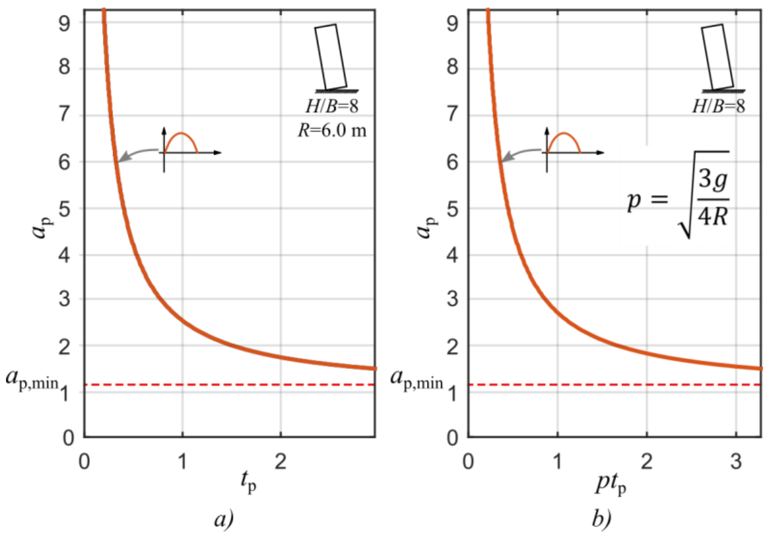

Figure 1. Overturning curve for a single block subjected to a half sine pulse (a). The effect of the block size (b).

The approaches of the possible design procedures of overturning are summarized in the excellent paper of Sorrentino (Sorrentino *et al.*, 2017) and are not reiterated here, see also (Yim, Chopra and Penzien, 1980; Ishiyama, 1982; Spanos and Koh, 1984; Hogan, 1989; Augusti and Sinopoli, 1992; Anooshehpoor *et al.*, 1999; Zhang and Makris, 2001; Vassiliou and Makris, 2011; Dimitrakopoulos and DeJong, 2012; Makris and Vassiliou, 2012; Voyagaki, Psycharis and Mylonakis, 2013, 2014; Mimoglou, Psycharis and Taflampas, 2014; Lagomarsino, 2015; Dimitrakopoulos and Fung, 2016; Ther and Kollár, 2018b; Ther and Kollar, 2021).

A modification of the overturning curve is the *overturning acceleration (response) spectrum* (OAS), where on the horizontal axis the frequency parameter p is given while on the vertical axis $a_p/a_{p,min}$. The OAS can be evaluated for any earthquake, as it was suggested in (Ther and Kollár, 2018b) (Figure 2a). For an earthquake a_p is the peak ground acceleration (pga) while for an impulse it is the amplitude. Furthermore, at least in theory, a design OAS curve can be determined for any location by the statistical evaluation of the relevant earthquakes of the site.

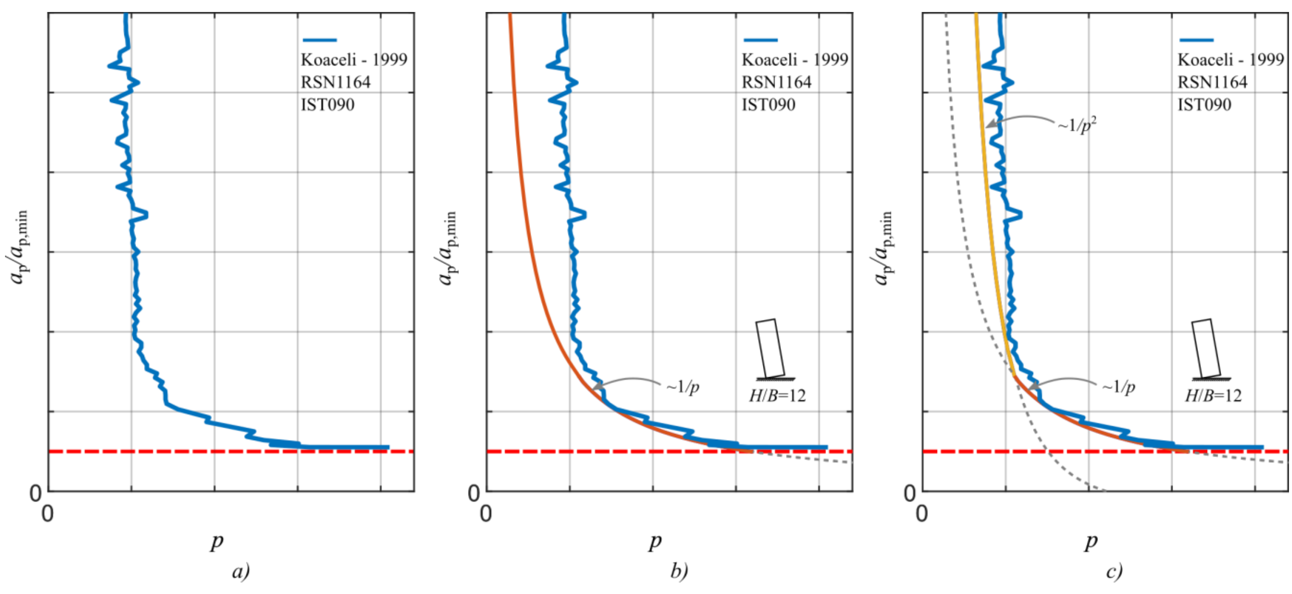

Figure 2. The OAS of the Koaceli – 1999 earthquake (a) and the corresponding simplified OAS (b).

For design purposes a simplified OAS was introduced (Ther and Kollár, 2018b), which consists of two lines, a horizontal one, and one which is proportional to $1/p$ (Figure 2b). These two curves are the function of only one earthquake characteristic, which is called *replacement impulse duration*, and denoted by t_I. In a companion paper (Ther and Kollár, 2023 – under review) the simplified OAS was improved, and a third curve was added which is dominantly proportional to $1/p^2$ (yellow line in Figure 2c). This new curve is a function of two earthquake characteristics: the *replacement impulse duration* (t_I) and the *replacement impulse moment duration*, the latter one is denoted by t_M (see also (Ther and Kollár, 2018a)). The actual characteristics of an earthquake (t_I and t_M) are determined from the response of a rocking (slender) structure subjected to the corresponding earthquake excitation.

Although the applicability of the method was demonstrated by using individual earthquake records (Ther and Kollár, 2018b), the question arises, whether a specific location can be characterized significantly well by these two parameters for the design of structures against overturning? The availability of several earthquake records enables us to investigate the earthquake characteristics concerning overturning.

Six days after the Kahramanmaraş earthquake, as a member of a Hungarian-Turkish university engineering team, the first author of the present paper arrived to Antakya to investigate the ruined and damaged buildings and to offer professional assistance to the local disaster-management organization (AFAD). The structural-engineer professional team was formed by Budapest University of Technology and Economics (BME) and Istanbul Technical University (ITU). The fieldwork was carried out in two cities: Antakya - capital of Hatay province and Kahramanmaraş - capital of Kahramanmaraş province (Figure 3). This is the reason that in this article the seismicity of these two cities is investigated.

Figure 3. Damaged or ruined rocking structures in Kahramanmaraş (a, c) and in Antakya (b)

2 Problem statement

In addition to the two major earthquakes on February 6, 2023 in Kahramanmaraş more than 50 moderate ($M_W \geq 5.0$) aftershocks were recorded by hundreds of stations in Turkey (Figure 4) (*AFAD*, 2023). Based on these records the characteristics t_I and t_M for a given location can be evaluated for several earthquake accelerograms, which belong to different pga-s, earthquake depths, distances from the epicenter, soil characteristics, etc. In this paper we focus on two locations, namely Kahramanmaraş and Antakya.

The aim of this paper is to answer the following questions:

- Can the seismicity of a specific site be represented acceptably well by three parameters, the pga, t_I and t_M for the analysis of overturning of rocking structures?
- How significant are the effects of earthquake depth, soil type, magnitude, pga, distance of the epicenter (near-field or far-field record) on t_I and t_M?

3 Approach

A total of 53 earthquake events with $M_W \geq 5.0$ that occurred in the year 2023 (Figure 3a) have been processed. Both in Kahramanmaraş and Antakya (Figure 4b,c) the accelerograms recorded by 10-10 stations resulted in 344 and 196 records, respectively. For every record the OAS of a slender (B/H=12) block was determined using time history analysis for the $1 < \frac{a_p}{a_{p,\min}} < 25$ interval. (Note that the OAS of blocks, the slenderness of which are over 8, are practically identical to these curves.) The components of an event recorded by a station was considered as two different records: the HNE and HNN component of the record. The vertical components of the records were not considered.

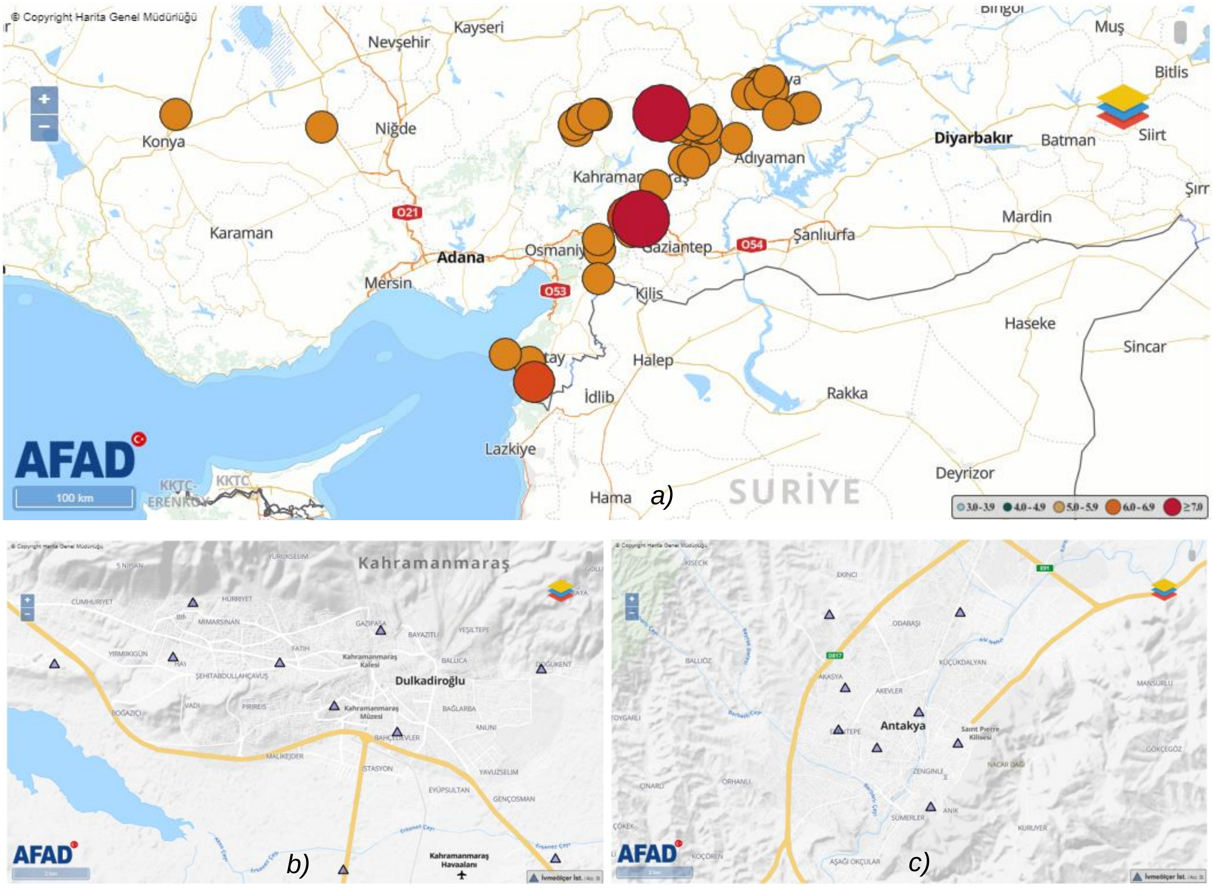

Figure 4. Earthquake events in Turkey in 2023 with $M_W \geq 5$ (a). The stations considered in Kahramanmaraş (b) and in Antakya (c). (Data: www.tadas.afad.gov.tr – 16.09.2023.)

The equations of the three curves of the simplified OAS are as follows (Ther and Kollár, 2023) (Figure 2b):

$$\frac{a_p}{a_{p,\min}} = 1 \qquad (1)$$

$$\frac{a_p}{a_{p,\min}} = \frac{1}{t_\mathrm{I} p} \qquad (2)$$

$$\frac{a_p}{a_{p,\min}} = \frac{1-pt_\mathrm{M}}{t_\mathrm{M} t_\mathrm{I}} \frac{1}{p^2} = \frac{1}{t_\mathrm{M} t_\mathrm{I}} \frac{1}{p^2} - \frac{1}{t_\mathrm{I}} \frac{1}{p} \qquad (3)$$

The simplified OAS-s were determined as the envelopes of the accurate OAS-s. Two typical examples are shown in Figure 5 a-b. As a result, for each record a t_I and a t_M value are determined.

Note that the primary parameter of the simplified OAS is t_I. When the third curve (Eq.3) is not applied the two curves (Eqs. 1 and 2) can be used as conservative estimates (Figure 2). t_M may play a role for higher a_p values. Also observe that by increasing t_I the curve moves downward, and hence if at a given site several t_I values are determined their maximum value is a conservative approximation.

Now the determined characteristics t_I and t_M are investigated.

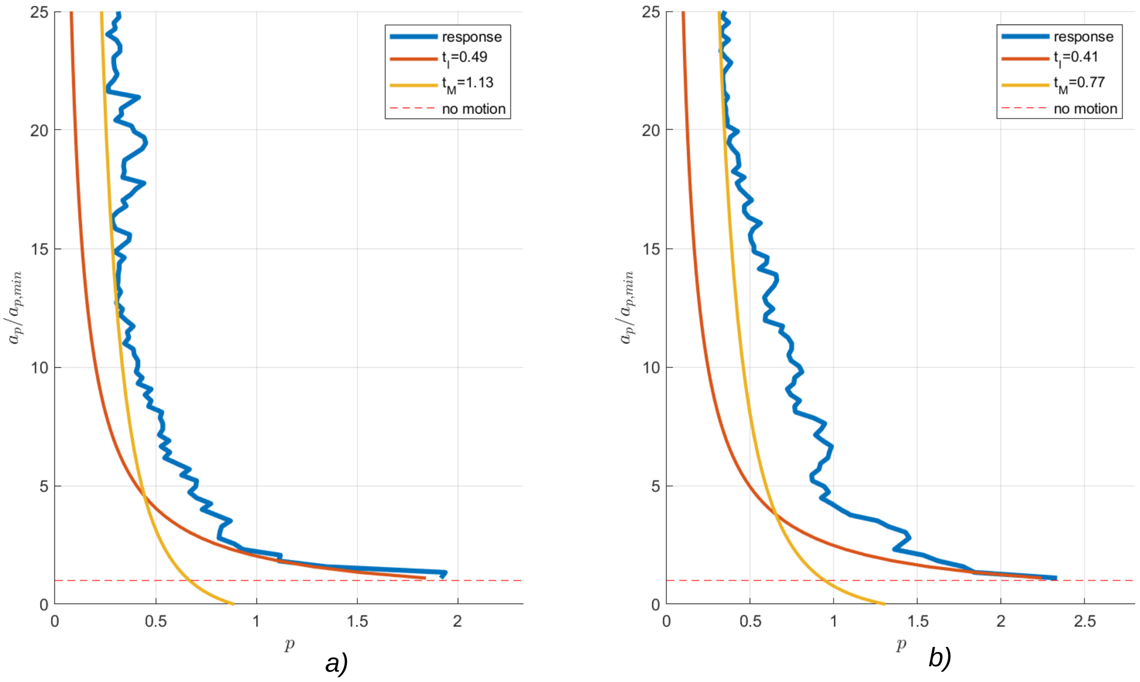

Figure 5. OAS of the HNE component of the same earthquake event (M_W=7.7) recorded by the station 4620 in Kahramanmaras (a) and the station 3125 in Antakya (b) on the 6 February 2023, 01:17.

4 Results of the analysis

The results for the different sites are given in Figures 6 to 11. The following comparisons are made:

- effect of pga on t_I and t_M (Figure 6).
- effect of earthquake *depth* on t_I and t_M (Figure 7).
- effect of the *distance of the epicenter* on t_I and t_M (Figure 8).
- effect of the *magnitude* on t_I and t_M (Figure 9).
- effect of *soil type* on t_I and t_M (Figure 10).
- relationship between t_I and t_M (Figure 11, 12).

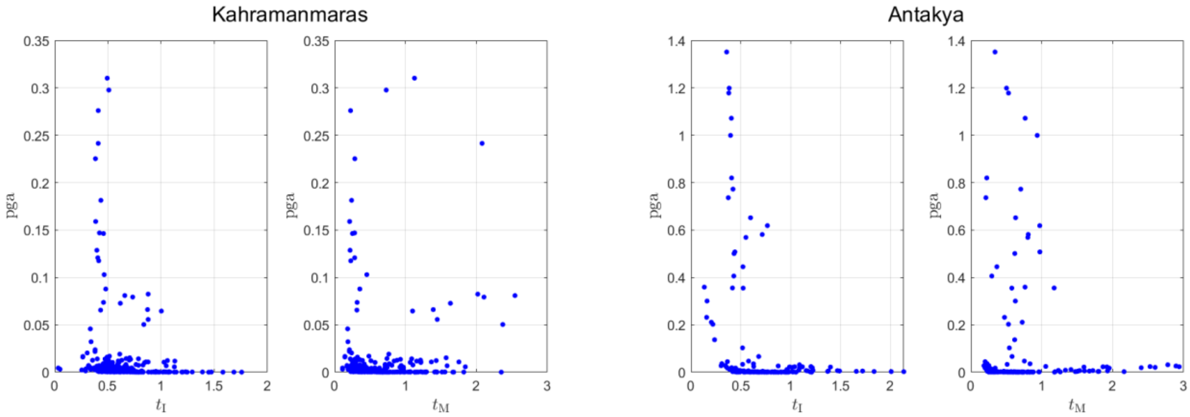

Figure 6. Effect of pga [g] on t_I and t_M [s]

The most important new findings of our analysis is demonstrated in Figure 6, where the effect of pga was investigated. *For higher pga (pga>pga$_{max}$/3, i.e. 0.1 and 0.4 respectively) t_I can be well represented by a single value regardless of the above listed parameters.* Note that for design purposes low values of pga-s are irrelevant. In Kahramanmaras the maximum of the *replacement impulse duration* for higher peak ground accelerations (pga>0.1g) is $t_{I,Maras}=0.51$ s, while in (pga>0.4g) Antakya it is $t_{I,Antakya}=0.766$ s. *Hence, it seems that t_I is a perfect candidate to represent the seismicity of a specific location for the investigation of overturning.*

In Figures 7 to 12 the results of different pga intervals are denoted by different colors. Because of the above arguments, the dots with red color, which belong to higher pga-s (pga>0.1) have practical interest.

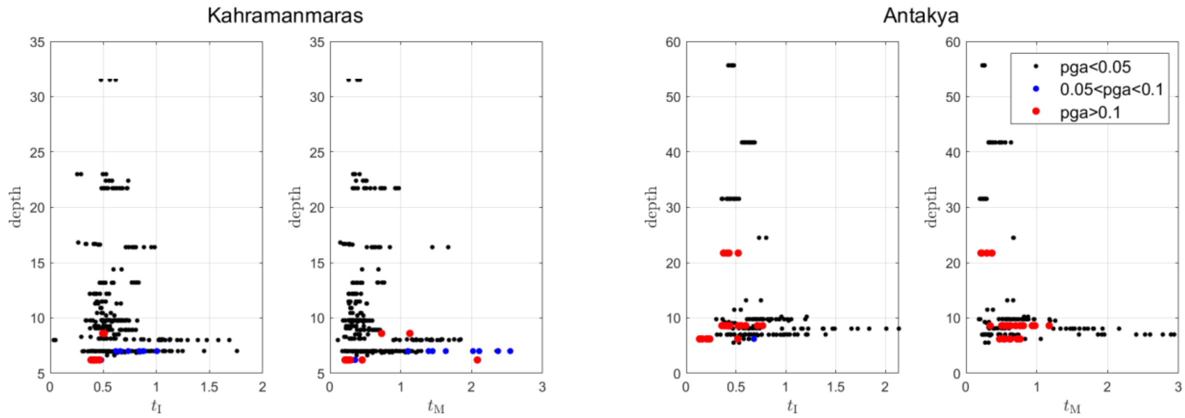

Figure 7. Effect of event depth on t_I and t_M [s]

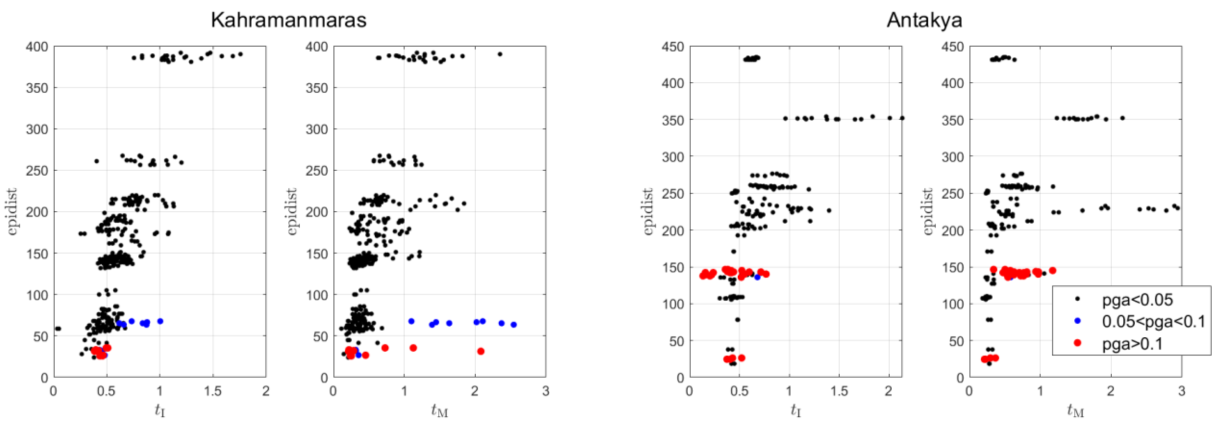

Figure 8. Effect of epicentral distance [km] on t_I and t_M [s]

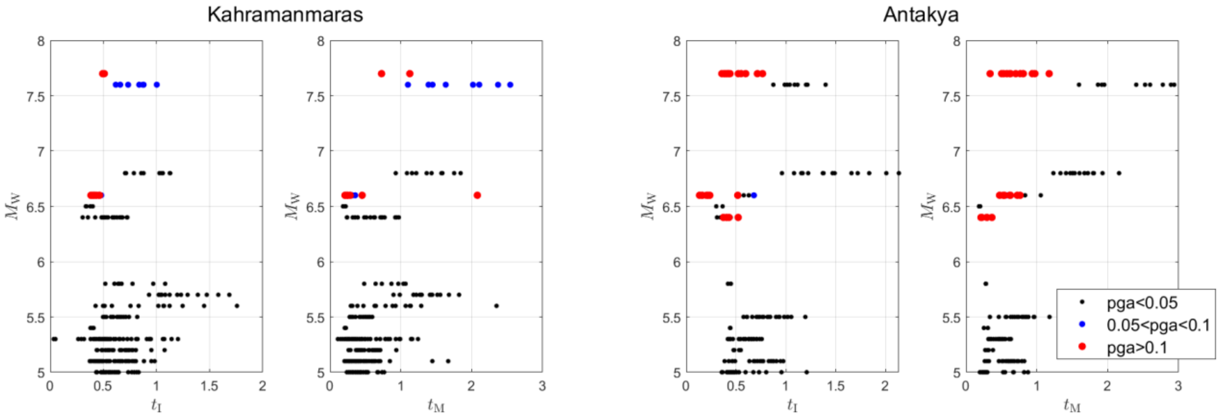

Figure 9. Effect of event's moment magnitude on t_I and t_M [s]

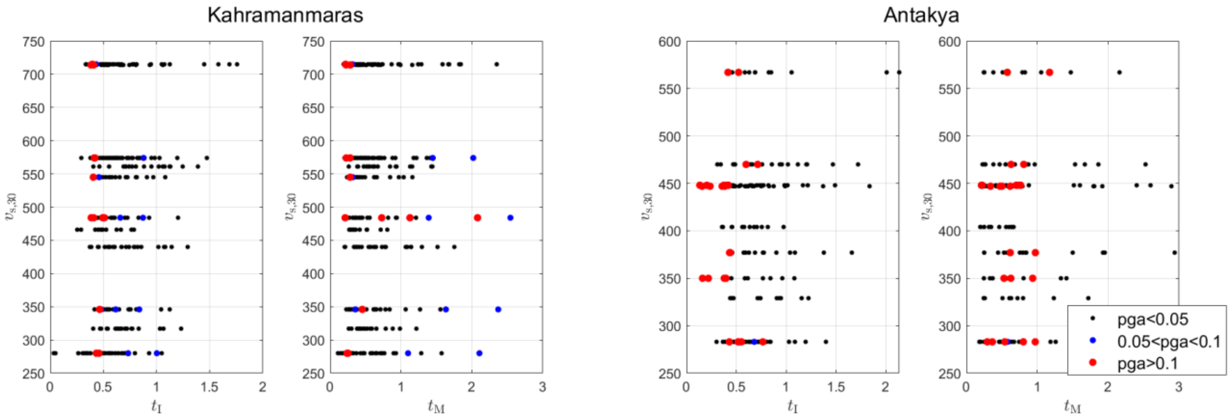

Figure 10. Effect of soil quality on t_I and t_M [s]

Figure 10 clearly shows that – surprisingly – the soil type has no effect on t_I and t_M. (The soil type affects the pga, and hence it affects the overturning, see the vertical axis in Figure 2.)

As we stated above t_M can be used to refine the simplified OAS. Although there is a scatter in the calculated values, it seems that $t_M \approx 1.0\, t_I$ is a reasonable approximation, considering every record (Figures 11 and 12).

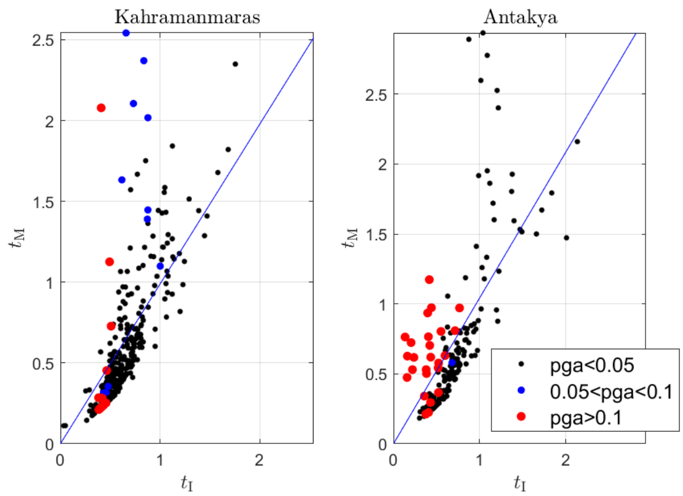

Figure 11. Ratio of t_I and t_M in Kahramanmaraş and in Antakya

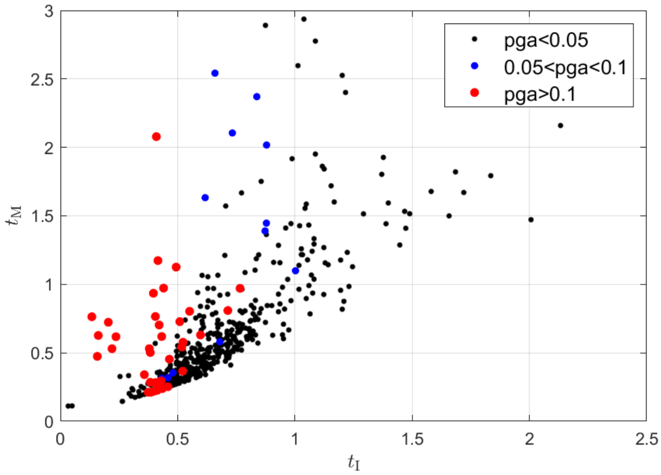

Figure 12. Ratio of t_I *and* t_M *[s]*

5 Conclusion

The analogy between the suggested design methodology for overturning of rocking structures and the response spectrum analysis (RSA) of elastic MDOF structures was highlighted before (Ther and Kollár, 2018a), see Figure 13. Instead of a complex structure a SDOF structure is investigated in both cases: for the RSA a spring-dashpot system, which is defined by the period of vibration and the damping ratio, while for the rocking structure a (slender) monolithic block characterized by the frequency parameter and the limit peak ground acceleration. The response of the SDOF structure is calculated: for RSA the (pseudo) acceleration response spectrum (S_d), while for rocking structures the *overturning* acceleration (response) spectrum (OAS). For the RSA the design spectrum, S_d depends among others on a_g, T_C, T_D, while the simplified OAS on a_g, t_I and t_M.

In this paper the applicability of the simplified OAS was demonstrated for two specific sites, namely for Kahramanmaraş and Antakya. It was found by time history analyses of 540 records that the different records can be well represented by a single t_I for each site. It was also shown that t_M can be approximated by $t_M \approx 1.0\, t_I$.

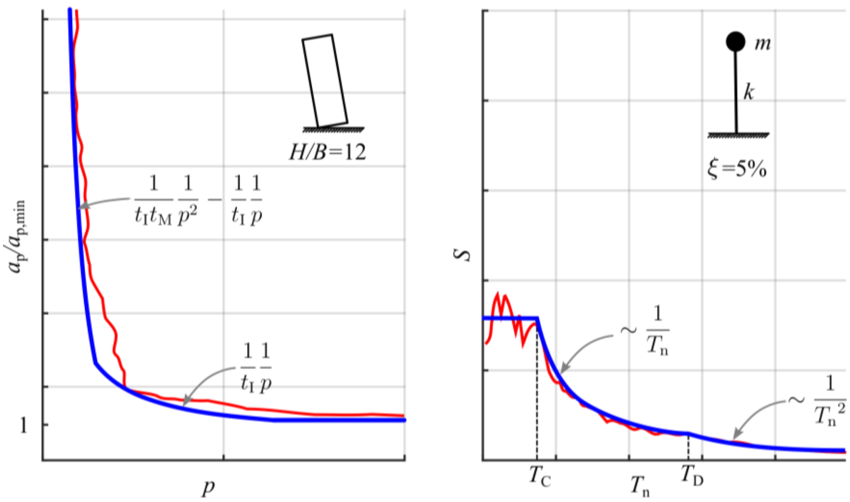

Figure 13. Analogy between the OAS and the RSA

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