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Usage of SAP2000 OAPI to parametrically investigate the effect of soil deformability on the peak seismic response of base isolated buildings

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Abstract

This paper utilizes the Open Application Programming Interface (OAPI) provided by the structural analysis software SAP2000 in order to parametrically perform dynamic analyses to assess the effect of soil deformability on the peak seismic response of base isolated buildings. A number of base isolated buildings with different number of floors, are subjected to a set of strong earthquake excitations and simulated with SAP2000, which interacts, through the OAPI, with a custom-made software developed in Python. The parametric analyses aim to assess the influence of the soil deformability in the computed peak seismic responses, by considering rock, sand and clay as supporting ground, using simplified soil springs to model its deformability, for two different sets of seismic excitations, categorized as near-fault (NF) and Far-Fault (FF) ground motions.

Keywords: soil deformability, base isolated buildings, SAP2000 OAPI, near- vs. far fault seismic excitations.

1 Introduction

In general, soil deformability is usually neglected while performing dynamic analyses of structures under seismic excitations, assuming that the supporting ground is infinitely rigid (Mylonakis and Gazetas [1]). Nevertheless, some research studies have suggested that ignoring the soil deformability, may not always be a conservative approach, especially in the case of base-isolated buildings (Mahmoud et al [2]). In their relevant research work, Wu and Chen [3] concluded that the computed interstory drifts might be increased when the soil deformability is taken into account. In addition, the soil deformability could reduce the effectiveness of base isolation, due to increased deformations of the superstructure (Aden et al [4]). Furthermore, near-fault and low-frequency earthquakes might be more detrimental for base isolated buildings when soil flexibility is considered.

In the presented research work, dynamic analyses of typical base isolated buildings with 2, 4, 6, 8 and 10 floors are parametrically conducted, using the SAP2000 structural analysis software, under 5 near-fault (NF) and 5 far-fault (FF) strong ground motions, as recorded in the two horizontal perpendicular directions. The parametric analyses aim to assess the influence of the soil deformability in the computed peak seismic responses by considering rock, sand and clay as supporting ground, using simplified soil springs to model its deformability.

The parametric studies are conducted through a custom-made software developed in the Python programming language, utilizing the OAPI to communicate with SAP2000, in order to not only send the proper analysis input data and control the conducted analyses, but also retrieve the computed results and postprocess them.

2 Accessing SAP2000 through the OAPI with Python

Python is a very simple, interpreted, interactive, object-oriented high-level programming language, which incorporates a lot of modern programming capabilities and paradigms, such as modules, exceptions, dynamic typing, high level of dynamic data types and classes. The simple syntax of Python and its dynamic typing in combination with its interpreted nature, make it an ideal programming language for scripting and rapid application development, for many practical problems, enabling software development in much fewer lines of code in comparison with other high-level compiled programming languages. Although Python is relatively slow as it is not a compiled language, the main computational cost of parametrically performing dynamic analyses relate to the actually performed dynamic analyses, which are conducted by the compiled executable files of SAP2000. Therefore, there is no significant computational overhead, while parametrically performing structural analyses through the SAP2000 OAPI with Python, whose usage is limited to the effective preparation of the input data and the post-processing of the computed results.

The SAP200 OAPI provides an interface that allows interactions between custom-made software, developed in Python, C#, Matlab, etc., with the SAP2000 software, through a set of simple command calls. The SAP2000 OAPI delivers requests and returns responses between the custom-made software and SAP2000, which can be used programmatically through a software and not interactively. In this way, the SAP2000 OAPI enables the automation of many of the processes required to configure, analyse, and design structural models, while it allows the user to specify certain parameters to be varied in order to conduct parametric analyses.

Specifically, the SAP2000 OAPI is used by the custom-made software developed in Python to access the SAP2000 structural analysis software (Figure 1). The OAPI translates the given data from Python to SAP2000 in order to create the structural model and execute the requested dynamic time-history analyses, controls the conducted dynamic analyses and provides access to the computed results. Certain parameters can be iteratively varied and SAP2000 can be automatically called in order to effectively conduct parametric analyses. The corresponding peak seismic responses are collected, after each dynamic analysis is conducted, and effectively post-processed to compare the peak seismic responses with respect to the varying parameters.

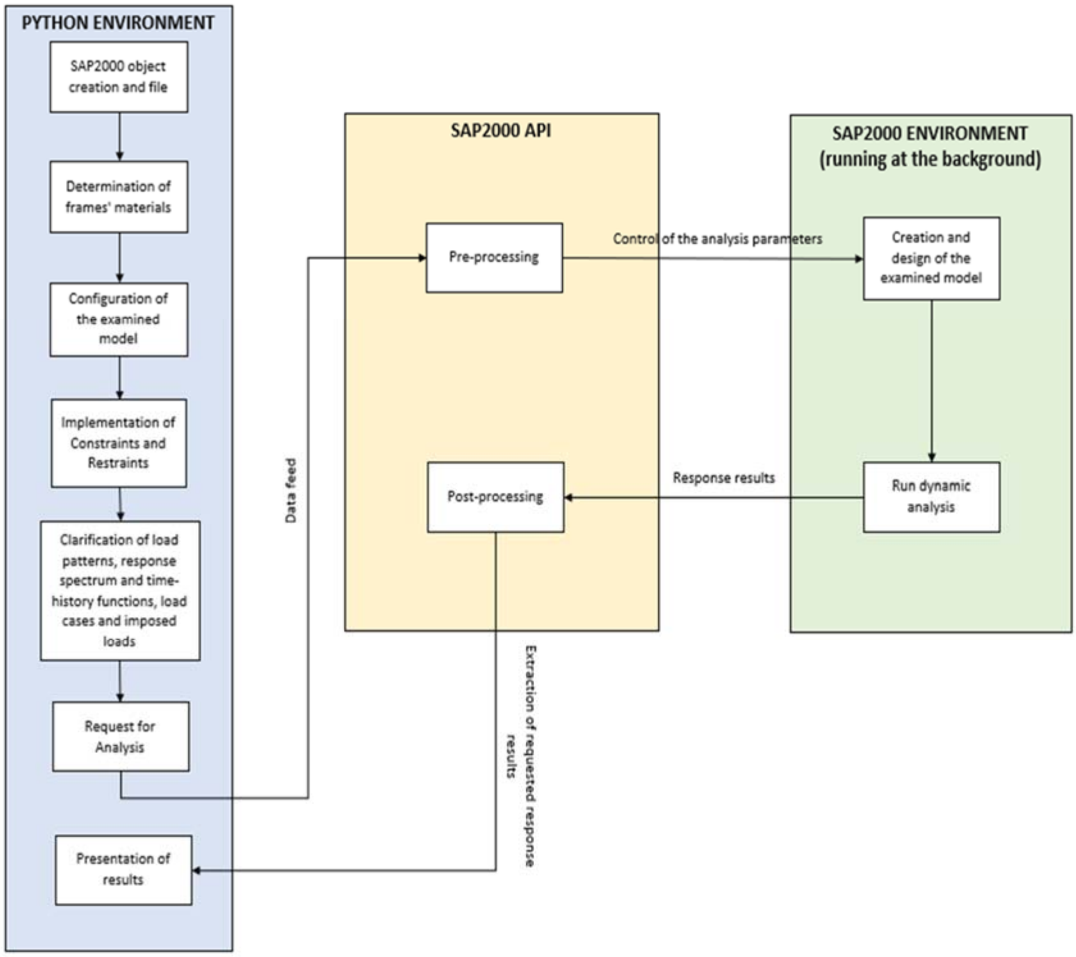

Figure 1: Flowchart of SAP2000 OAPI utilized through a Python software.

3 Structural and supporting soil deformability modelling

Typical base isolated reinforced concrete (R/C) buildings, with 2, 4, 6, 8 and 10 floors and a rectangular (15 m x 16 m) plan view with the height of each floor to be 3 m, are used in the conducted parametric analyses. The seismic isolation system consists of 20 rubber bearings, one under each of the 20 columns, with 12 Natural Rubber Bearings (NRBs) and 8 Lead Rubber Bearings (LRBs), under the outside columns.

In order to assess the influence of the soil deformability in the computed peak seismic response, rock, sand and clay are considered as supporting ground, using simplified soil springs to model the corresponding deformability. The mechanical properties are assessed according to Bowles [5] and Fjaer et al. [6] and provided in Table 1. Rock corresponds to the case in which soil deformability is not considered.

Soil Type	Young's Modulus E (GPa)	Poisson's ratio v	Shear Modulus G (KN/m2)
Rock	60	0.25	24000000
Sand	0.12	0.35	44444
Clay	0.03	0.50	10000

Table 1: Parameters for the considered soil types.

Since the examined base isolated buildings are assumed to be founded on isolated square-shape foundations with tie beams, the stiffnesses of the springs are estimated according to the relevant expressions suggested by Gazetas [7], based on the soil characteristics and the type and the shape of the foundation, as shown in Table 2.

Direction of Spring	Type of Spring	Coefficient
Vertical (Z)	Translational	$Kz = \frac{4.54GB}{1-v}$
Horizontal (Y)		$Ky = \frac{9GB}{2-v}$
Horizontal (X)		$Kx = \frac{9GB}{2-v}$
Around horizontal X axis (RX)	Rotational	$Krx = \frac{3.6GB^3}{1-v}$
Around horizontal Y axis (RY)		$Kry = \frac{3.6GB^3}{1-v}$
Around vertical Z axis (RZ)		$Krz = 8.3\mathrm{G}B^3$

Table 2: Calculation of the coefficients of the soil springs.

4 Considered NF and FF earthquake excitations

The simulated base isolated buildings are subjected to 5 NF and 5 FF pairs of strong seismic ground acceleration records in the two perpendicular horizontal directions, which have been obtained from the Pacific Earthquake Engineering Research (PEER) Center Database [8], according to the criteria set by Mavronicola et al [9]. The horizontal ground acceleration records act simultaneously in the two horizontal directions, the Fault-Normal (FN) and Fault-Parallel (FP), (Somerville [10]).

Descriptions of the selected horizontal NF and FF ground motions are provided in Tables 3 and 4, respectively. All seismic excitation records are scaled to a 0.3 g peak ground acceleration (PGA), so that the corresponding peak seismic responses can be more meaningfully compared.

EQ #	Event	Year	Station	M_w	FN	FP	R_{rup} (km)	V_{S30} (m/sec)
					PGA (g)	PGA (g)		
1	Imperial Valley-06	1979	El Centro Meloland G. Array	6.53	0.32	0.30	0.07	264.57
2	Superstition Hills-02	1987	Parachute Test Site	6.54	0.43	0.38	0.95	348.69
3	Chi Chi - Taiwan	1999	CHY057	7.62	0.28	0.24	3.80	487.30
4	Kocaeli - Turkey	1999	Cekmece	7.50	0.23	0.32	4.80	297.00
5	Irpinia Italy - 01	1980	Arienzo	6.90	0.23	0.32	10.80	1000.00

Table 3: Selected horizontal NF ground motions.

EQ #	Event	Year	Station	M_w	FN	FP	R_{rup} (km)	V_{S30} (m/sec)
					PGA (g)	PGA (g)		
6	Cape Mendocino	1992	Centerville Beach_Naval	7.01	0.15	0.18	41.91	337.46
7	Northridge - 01	1994	Pico Canyon Rd	6.69	0.05	0.07	46.91	572.57
8	Irpinia Italy - 01	1980	Sturno	6.90	0.03	0.03	52.94	612.78
9	Loma Prieta	1989	Saratoga - Aloha Ave	6.93	0.24	0.33	58.65	190.14
10	Loma Prieta	1989	Gilroy - Historic Bldg	6.93	0.07	0.12	78.41	512.27

Table 4: Selected horizontal FF ground motions.

5 Indicative computed peak seismic responses

Selected results from the computed peak seismic responses are indicatively presented next. Figure 2 provides the maximum values of the peak interstory drifts in the X direction of the 6-story base isolated building for the load combination G+0.3Q+Ex+0.3Ey under the excitation of the aforementioned 5 sets of NF accelerograms, all scaled to a PGA of 0.3 g, for each soil type.

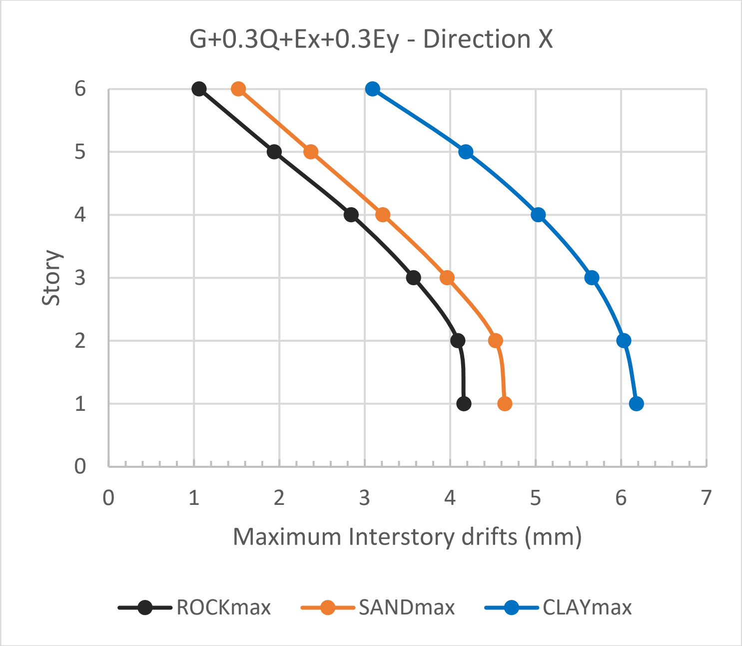

Figure 2: Maximum values of the peak interstory drifts in the X horizontal direction of the considered 6-floor base-isolated buildings under the loading combination G+0.3Q+Ex+0.3Ey for rock, sand and clay.

Figure 3 selectively provides the maximum values of the peak interstory drifts for the load combination G+0.3Q+Ex+0.3Ey in the X horizontal direction, for all examined base isolated buildings, founded on rock, sand and clay, under the excitation of all NF seismic ground motions.

It is evident that the maximum values of the peak interstory drifts in the X horizontal direction of the considered base-isolated buildings, regardless of the number of floors, under the loading combination G+0.3Q+Ex+0.3Ey, are highest for the case of clay, followed in turn by the cases of sand and rock, which is the lowest and corresponds to the case of rigid supporting ground, essentially without flexibility.

Similarly, Figure 4 provides the maximum values of the peak interstory drifts for the load combination G+0.3Q+0.3Ex+Ey in the X horizontal direction, for all the examined base isolated buildings, founded on rock, sand and clay, under the excitation of all FF ground motions. The peak interstory drifts are increasing in the lower floors for all cases, with higher values under the excitation of the NF ground motions than under the corresponding values of the FF ground motions for all considered buildings and soil types. Similar results are obtained while considering the maximum values of the peak interstory drifts in the Y direction for all base-isolated buildings. Also, similar trends are computed for the load combination G+0.3Q+Ex+0.3Ey.

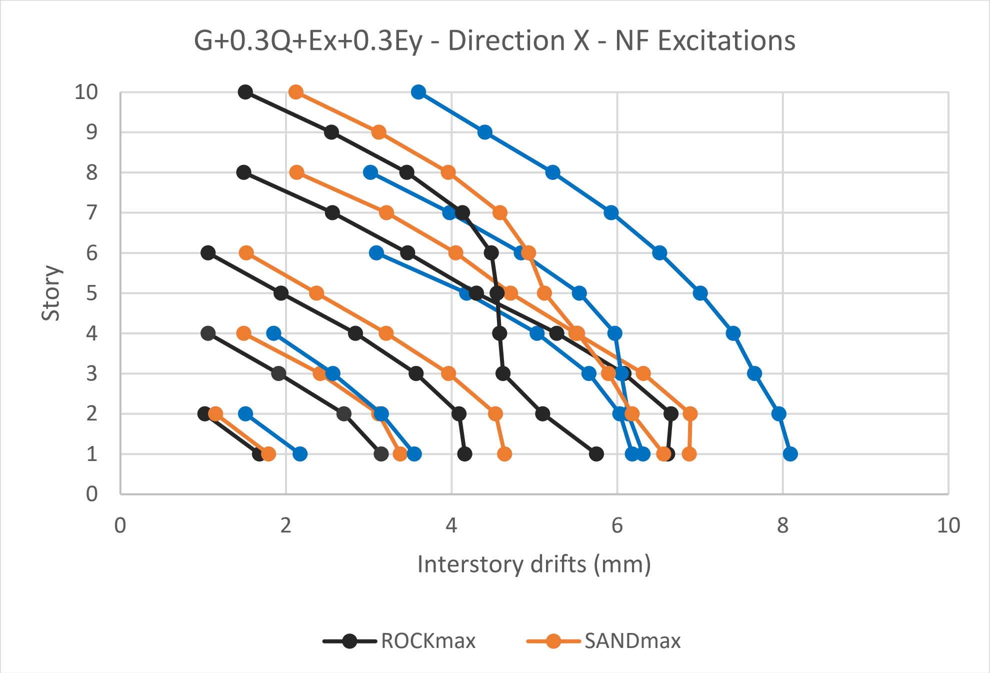

Figure 3: Maximum values of the peak interstory drifts in the X direction of all base-isolated buildings for the G+0.3Q+Ex+0.3Ey combination, under all NF excitations.

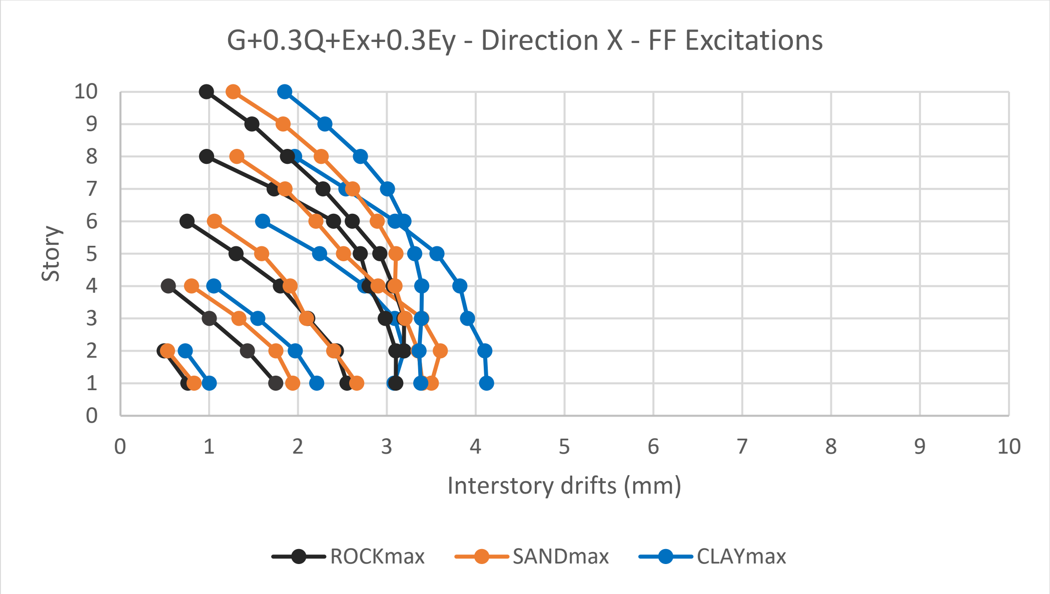

Figure 4: Maximum values of the peak interstory drifts in the X direction of all base-isolated buildings for the G+0.3Q+Ex+0.3Ey combination, under all FF excitations.

Computed results regarding the peak absolute floor accelerations reveal the influence of soil deformability on the peak floor accelerations, as well. Specifically, Figure 5 provides the maximum values of the peak absolute floor accelerations for the load combination G+0.3Q+Ex+0.3Ey in the horizontal X direction, for all the examined base isolated buildings, founded on rock, sand and clay, under all NF seismic excitations. Similar, results are derived under the FF ground motions.

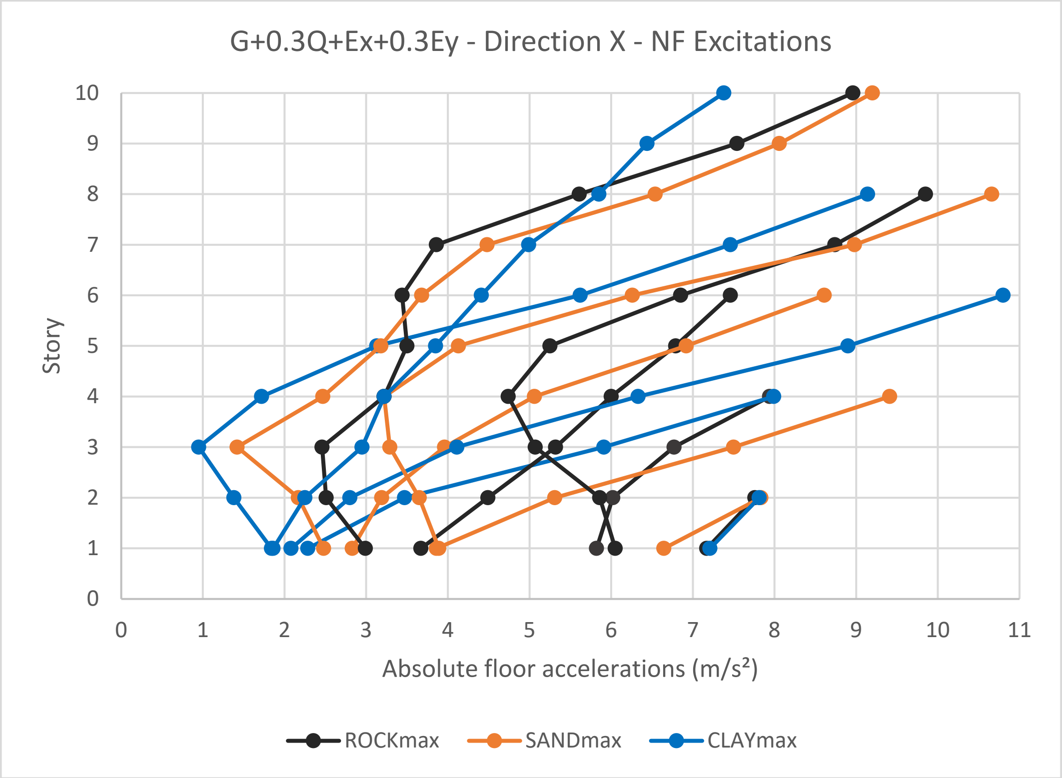

Figure 5: Maximum values of the peak absolute floor accelerations in the X direction for the G+0.3Q+Ex+0.3Ey combination, under all NF excitations.

6 Conclusions and Contributions

A number of base isolated buildings with a varying number of floors have been considered, assuming that they are founded on three different soil types: rock, sand and clay, in order to examine the potential effect of the soil deformability on their peak seismic responses. Through parametric studies, it is evident that the computed the peak interstory drifts and the maximum absolute floor accelerations might be higher when the soil deformability is taken into account, with respect to the case of rock, which correspond to the case of rigid supporting ground in which the soil flexibility is not taken into account.

In addition, through this research work, it has been shown that the SAP2000 Open Application Programming Interface (OAPI) can be used to effectively interact with SAP2000 in order to efficiently perform parametric analyses without the need of any human intervention. This has been achieved with a custom-made software developed in the Python programming language, in order to not only send the proper analysis input data and control the conducted analyses, but also retrieve the required computed results and postprocess them in a very timesaving way.

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