SEISMIC RESPONSE OF A PILOTIS SYSTEM

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Abstract: *In the present paper the dynamic response of three two-storey frames - that were tested on the shaking table of the Laboratory for Earthquake Engineering (L.E.E.) of N.T.U.A. - is presented. More specifically, a bare frame, a pilotis frame and a reinforced pilotis frame are examined. The main objectives of this work is to: a) study the effects of pilotis system and b) compare the results that were obtained by the two different finite element codes, SEISMOSTRUCT and DRAIN 2D. The codes have been developed on two different approaches related to plastic hinge formation under seismic loads. Also a push-over analysis was conducted by the two codes and the results were used to apply the N2 method.*

Key words: *pilotis system, seismic response, push-over analysis.*

1. INTRODUCTION

The seismic response of building structures with a soft ground floor presents various types of weaknesses which are rather challenging to study.

The configuration of the ground floor of multistorey buildings without infill walls (pilotis) has been common practice in several countries including Greece since 1973. Other buildings can be classified in the same category, such as buildings with decreased infill panels at their ground floor. In comparison with the other floors, e.g., shops, offices at the ground floor of buildings with flexible partitions that do not contribute to the ground floor stiffness. Pilotis can be also created with the configuration of a flexible (soft) ground storey with much greater height in comparison to the other floors [1], [2], [3], [4].

2. PURPOSE OF THE STUDY

The present research examines the behavior of pilotis systems under seismic motions using two computational programs: DRAIN 2D [5] and SEISMOSTRUCT [6],[7] that have been developed on two difference plastic hinge formation approaches. Also, the accuracy of the N2 pushover method proposed by Fajfar [8] is examined to determine the displacement requirements which resulted analytically.

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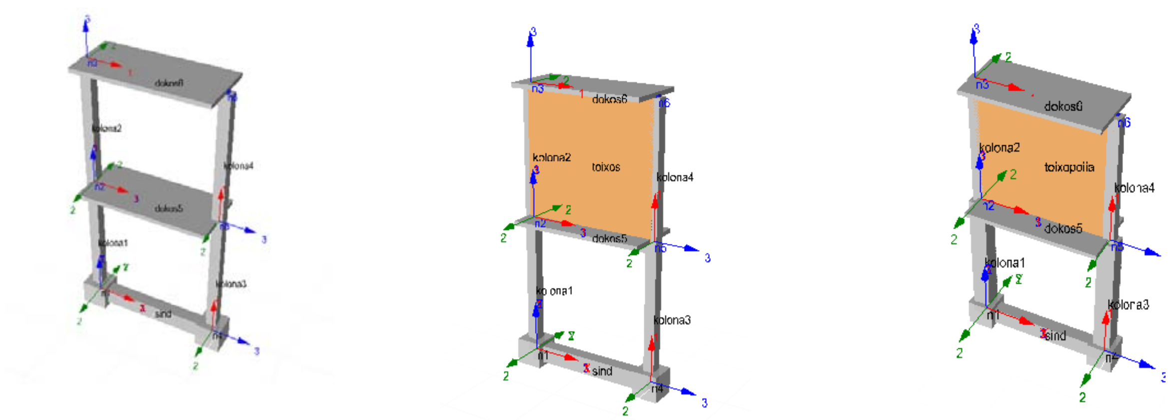
3. DESCRIPTION OF THE ANALYTICAL MODELS

The types of reinforced concrete frames that are studied are shown in Figure 1; 1) a bared frame, 2) a pilotis frame, and 3) a strengthened pilotis frame [9]. The two-storey one-bay frames consist of a typical storey 3 m high and a typical bay 3.05 m wide. Square column sections 0.25 m x 0.25 m and T-type beam sections are used, as shown in Figure 2. The slab width reacting with the beam is calculated to be 1.4 m. Foundation tie beams of 0.30 m x 0.40 m are used. A mass of 4 kNs^2m^{-1} is considered for each floor. The response of the bare frame, which is modelled by both programs was used as a prototype to evaluate the response of the other two frames.

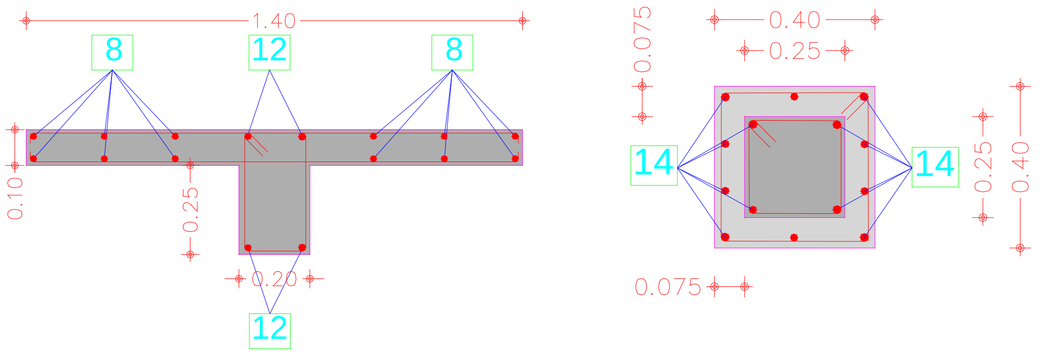
The pilotis frame, with an infill panel at the first storey, has the same geometry with the bare frame. A compressive strength of $f_b = 15MPa$ and $f_m = 3{,}8MPa$ is considered for the brick and the mortar, respectively [10]. The strengthened frame of pilotis type has the same geometry with the bare frame, except for the columns of the ground floor, that have been strengthened with reinforced concrete jackets 7,5 cm thick.

The characteristic value for the compressive strength of concrete is $f_c = 16MPa$, and the corresponding value for the concrete jacket is $f_s = 20MPa$. The characteristic value for the compressive strength of steel is $f_s = 220MPa$ and $f_s = 500MPa$ for the reinforcement bars of frames and concrete jackets, respectively [11].



(a) **(b)** **(c)**

Figure 1: Frame models: (a) bare frame, (b) pilotis type frame, and (c) strengthened pilotis type frame.



(a) **(b)**

Figure 2: Reinforced concrete sections of: (a) beams, (b) columns and jackets for the strengthened frame.

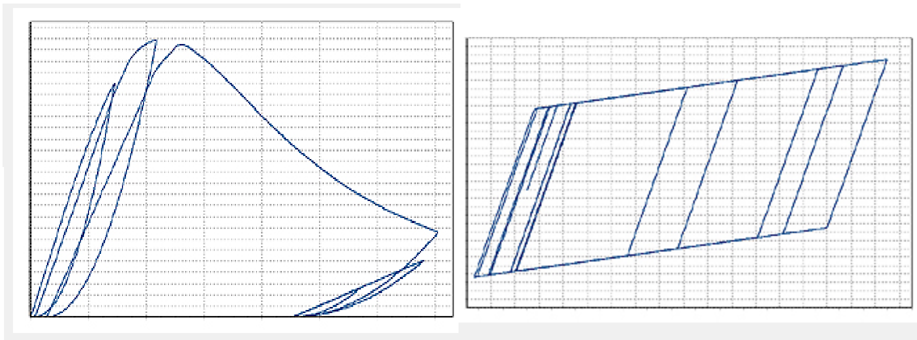


Figure 3: Hysteretic curves (σ,ε) for concrete and steel.

4. EIGENVALUE ANALYSIS

Initially, an eigenvalue analysis of the three frames has been performed. The first eigenperiod for the three frames is shown in Table 1.

1^{st} eigenperiod (sec)	SEISMOSTRUCT	DRAIN 2D
bare frame	0.384	0.396
pilotis type frame	0.351	0.383
strengthened pilotis type frame	0.152	0.179

Table 1: First eigenperiod of the frames.

The values of the corresponding eigenvectors are given on Table 2.

		SEISMOSTRUCT	DRAIN 2D
bare frame	2^{nd} storey	1	1
	1^{st} storey	0,623	0,655
pilotis type frame	2^{nd} storey	1	1
	1^{st} storey	0,981	0,955
strengthened pilotis type frame	2^{nd} storey	1	1
	1^{st} storey	0,91	0,873

Table 2: Eigenvectors for the three frames.

5. SEISMIC LOADING

The E–W component of the Griva 1990 earthquake of M=5.9 magnitude has been considered for the time history analysis. The earthquake was recorded at the town of Edessa in Northern Greece at a distance of 31km from the epicenter on soft soil conditions. The acceleration time history has a roughly sinusoidal shape with predominant period of about 0.60 sec and peak horizontal acceleration of 0.10 g. Scaling factors were applied to this original earthquake record and then nine successive acceleration time histories, shown on Figure 4, were applied to each frame to obtain the dynamic response.

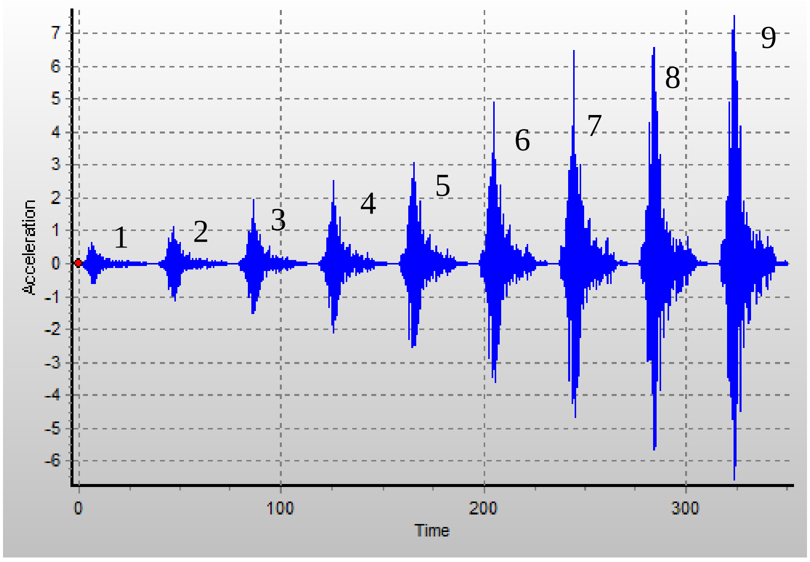


Figure 4: Acceleration time history of the analysis.

6. SEISMIC ANALYSIS FOR ELASTIC BEHAVIOR

In the following diagrams (Figure 5) the results of the two codes are compared regarding the dynamic response of the pilotis frames. For the pilotis type frame indicative results are presented in Figure 5 and Table 3 for the first scaled time history, where the entire structure remains in the elastic behaviour.

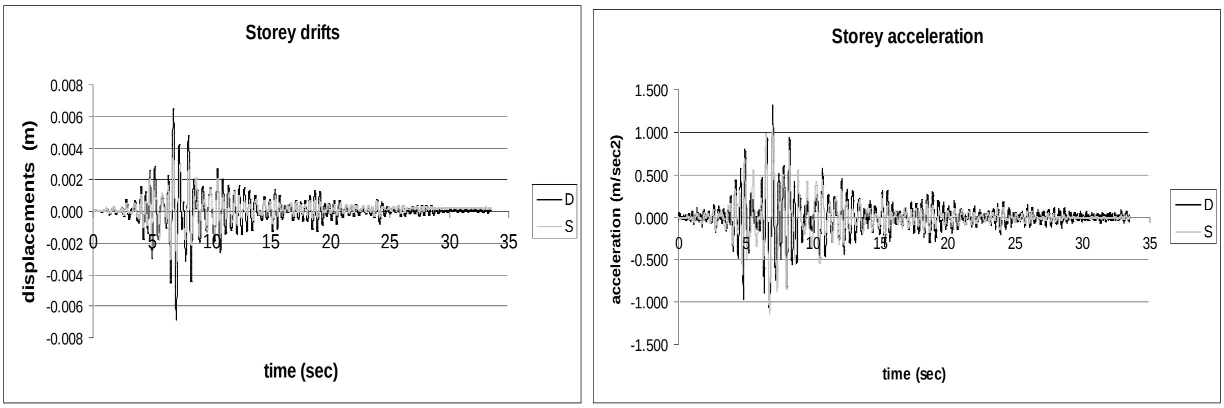


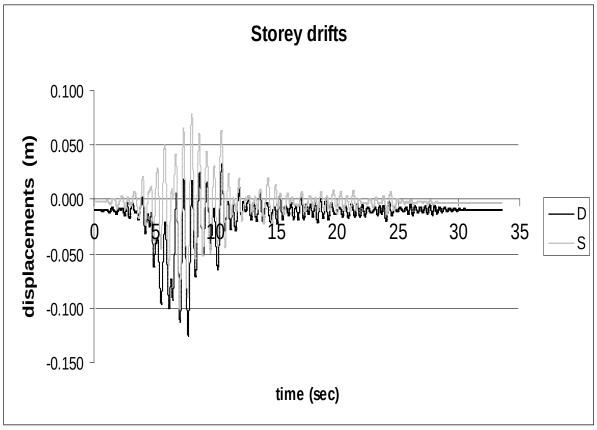
Figure 5 (1 2): Comparison of: (a) the first storey drift, and (b) the first storey acceleration, obtained by the DRAIN 2D and the SEISMOSTRUCT code for the first time history.

	a/a	Maximum values	Minimum values
1st Storey drift (cm)	DRAIN 2D	0.65	-0.69
	SEISMOSTRUCT	0.38	-0.34
1st Storey acceleration (m/sec^2)	DRAIN 2D	1.31	-1.10
	SEISMOSTRUCT	1.08	-1.14

Table 3: Comparison of maximum and minimum values of first storey drifts and acceleration obtained by DRAIN 2D and SEISMOSTRUCT codes.

7. DYNAMIC ANALYSIS FOR PLASTIC BEHAVIOR

In the following diagrams (Figure 6) the results of the two codes are compared for the pilotis type frame when the ninth scaled time history is applied. Plastic hinges are formed at the top and bottom of the ground floor columns and some indicative results are presented in Figure 6 and Table 4.



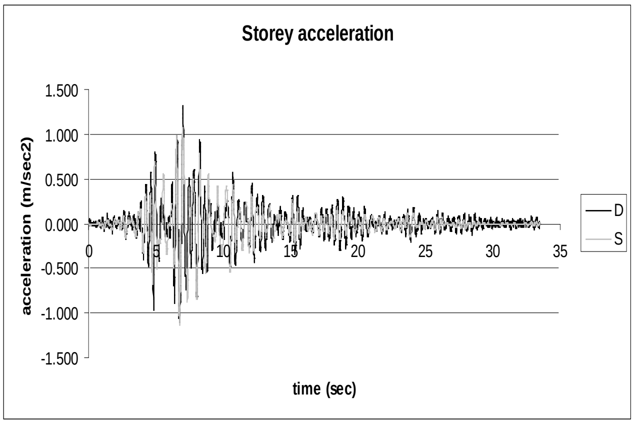


Figure 6 (3, 4): Comparison of: (a) the first storey drift, and (b) the first storey acceleration, obtained by the DRAIN 2D and the SEISMOSTRUCT code for the last (ninth) time history.

	a/a	Maximum values	Minimum values
1st Storey drift (cm)	DRAIN 2D	3.26	-12.52
	SEISMOSTRUCT	7.81	-10.02
1st Storey acceleration (m/sec^2)	DRAIN 2D	8.39	-9.21
	SEISMOSTRUCT	9.12	-10.21

Table 4: Comparison of maximum and minimum values of first storey drifts and acceleration obtained by the DRAIN 2D and SEISMOSTRUCT codes.

8. PUSH – OVER ANALYSIS

In the following, the acceleration – displacement response spectra (ADRS) for each time history are calculated, [12]. The push over curve is evaluated for each frame using an appropriate load distribution for each frame. The results of the analysis for the pilotis type frame as well as the comparison of the results for the two codes are shown in Figure 5.

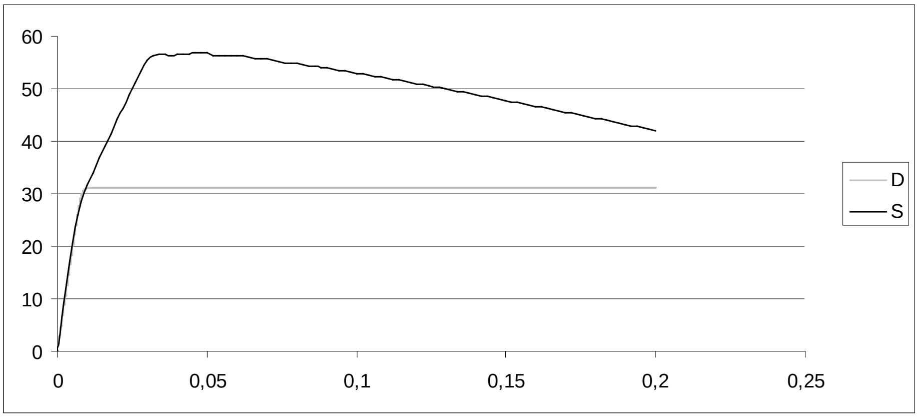


Figure 7: Push over curve for the pilotis type frame obtained by the DRAIN 2D (grey line) and SEISMOSTRUCT codes.

The push over curve is converted to an acceleration-displacement curve of an equivalent single-degree-of-freedom (SDOF) system of eigenperiod T*, according to the procedure proposed by Fajfar [3]. This curve and the acceleration – displacement response spectrum for each time history are superimposed in the same diagram to obtain the target displacement for the equivalent single-degree-of-freedom system. Finally the displacement requirement for the multi-degree-of-freedom (MDOF) system is properly evaluated. Figure 8 shows the results of the method applied example for the pilotis type frame using the SEISMOSTRUCT code.

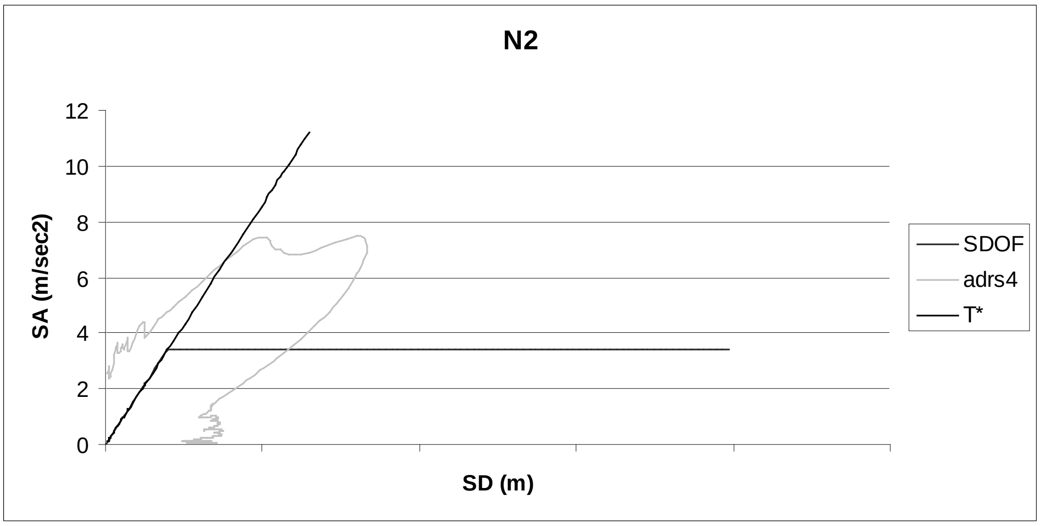


Figure 8: Application of the N2 method for the second time history and the pilotis type frame.

The intersection point between the straight line describing the behavior of an elastic SDOF system with a period T* and the ADRS spectrum defines the required displacement for the SDOF system, SD = 0,016965 m. The corresponding acceleration value is SA = 3,378 m / sec ^{2}. The behaviour factor R_μ is calculated as follows:

$$R_\mu = \frac{S_{ae}}{S_a} = \frac{3,738}{1,926} = 1,9408 \quad (1).$$

The plasticity is evaluated as follows

$$\mu = (R_{\mu} - 1)\frac{T^{*}}{T_{c}} + 1 = 1{,}644 \quad (2).$$

Finally the target displacement for the MDOF system can be obtained by multiplying the displacement of the SDOF system by the factor Γ according to N2 method, as follows:

$$D_t(MDOF) = \Gamma \cdot \mu \cdot S_d = 0.01628m \quad (3).$$

9. CONCLUSIONS

A satisfactory convergence of the two programs used in this research is observed, regarding the eigenvalue analysis. In the case of the pilotis type frame and the strengthened pilotis frame the results from the two codes converge well. The luck of complete convergence should be attributed mainly to the different simulation of the infill panels that has been applied.

The differences are more pronounced for the time histories in which members of the frames enter the plastic zone. The differences can be primarly attributed to the considerations adopted by the two codes. The Drain 2D uses elements with plastic hinges that can be formed only at their critical regions of null length which are placed at their edges, while the rest of their length remains elastic. Yield is expressed via interaction diagrams of moment and axial loads on each cross-section. On the contrary the SEISMOSTRUCT uses elements of distributed plasticity. The distribution of plasticity in the cross-sections is achieved with the subdivision of every cross-section in many fibers parallel to the element main axis. Yield is possible at every fiber of the cross-section where the developing stress exceeds the yield stress. Thus, the plasticity is distributed along the height and the length of the elements.

The application of N2 method for triangular and orthogonal load distribution with SEISMOSTRUCT results in quite more realistic target displacement values than the ones obtained by the DRAIN 2D.

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