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SPECTRAL ACCELERATION AMPLIFICATION EFFECTS ON THE PERFORMANCE POINT OF REINFORCED CONCRETE SILOS

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ABSTRACT

Reinforced Concrete Silos may be classified as storage structures, generally used for storing coal, cement, food grains and other granular materials. In current research, two existing models of reinforced concrete silos of a cement factory are chosen and Modal Pushover Analyses are carried out on them. Capacity Curves are achieved from the modal pushover analysis of models and Performance Point characteristics are computed according to spectral acceleration amplification levels for three soil categories of Rock, Dense Soil and Loose Soil, due to ATC-40 guideline recommendations, by using UBC97 pseudo-acceleration spectrums.

Keywords: Reinforced Concrete Silos, Spectral Acceleration, Modal Pushover Analysis, Performance Point, Capacity Curve

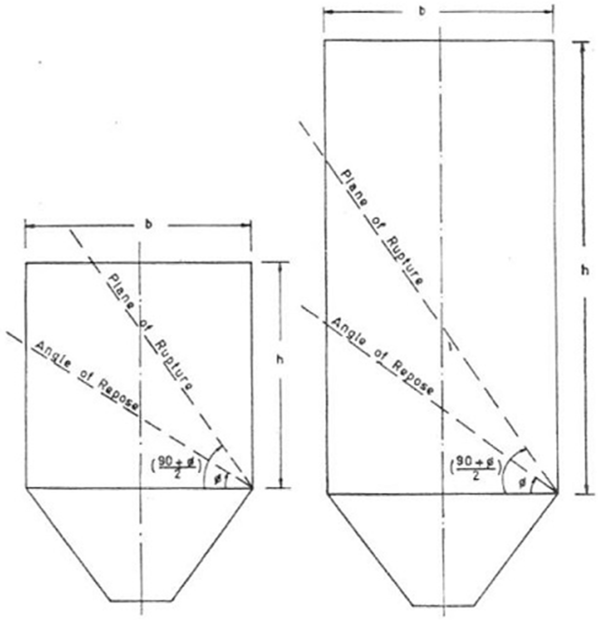
INTRODUCTION

Previous experience of earthquakes illustrates that many types of structures behave nonlinearly during a severe earthquake. So a huge amount of input energy is mainly dissipated through the form of damping and hysteresis. According to this, the structures are usually designed for much lower lateral forces than those demanded by aseismic design codes in elastic range. The aseismic behavior analysis and accurate design of structures for severe earthquakes are mainly carried out using Nonlinear Time history Analysis method (NTHA). Using the NTHA method for analysis of somehow simple structures in consulting engineers offices is not appropriate enough, due to the complexity and time taking behavior of the method. So according to simplicity and popularity of structural linear analysis techniques, they are mainly proposed in most aseismic design codes using the reduced lateral forces meanwhile. The seismic linear force for structural design purposes is achieved from a linear earthquake spectra. The computed lateral force from the spectra is decreased by the means of a reduction factor according to ductility, damping, overstrength and so on. Due to the development of industrial constructions and reinforced concrete silos as well, studying the behavior of such structures is of much importance. According to Figure 1, in a silo the vertical walls are considerably taller than the lateral dimensions resulting in a tall structure. Consequently, the plane of rupture of the material stored meets the opposite side of the structure before meeting the top horizontal surface of the surface of the material as shown in Figure1. Due to high ratio of height to the lateral dimensions, a significant portion of the load is resisted by the friction between the material and the wall. Only a fraction of the total weight of the material acts on the floor of the structure.

If B=Breadth, H=Height of the structure , φ=angle of repose

For a structure to be classified as a silo:

$$H > B \tan(90 + \varphi) / 2 \quad (1)$$



(a) (b)

Fig. 1 - General view of (a) Bunker and (b) Silo

In current research we would try to determine the "Ductility Demand" of Reinforced Concrete Silos, using existing structures of this type. For this purpose, 2 conventional models of R.C. silos, which are supposed to demonstrate a typical type of this structures according to author's point of view, are selected, analyzed and designed according to ACI 313-97 and ASCE 7-10 code for seismic requirements. Proposed models are analyzed for both soil-structure interaction effects and without it, considering filling strategy of Empty, 50% Full and 100% Full cases. By using Nonlinear Time History Analysis method and completing a "Modal Pushover" analysis, the seismic behavior of R.C. silos are studied and related ductility demands are determined using ATC40 guideline.

GENERAL SEISMIC BEHAVIOR OF STRUCTURES

Both structural and non structural collapses during earthquakes, usually occur due to lateral displacements, so the determination of "Ductility Demand" in Performance based design

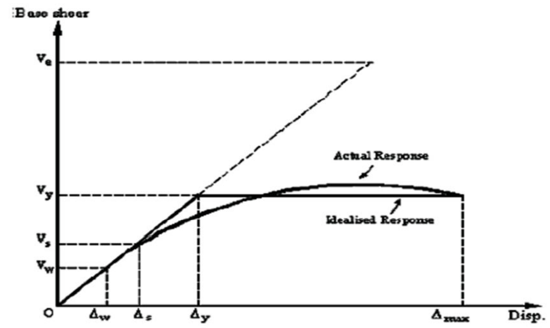


Fig. 2 - General seismic response of structures

method is of much importance. According to the reduced lateral forces, the lateral displacements computed through a linear analysis, should be increased in order to estimate the real displacements during a severe earthquake. In Fig. 2, Δ_{max} is the maximum inelastic displacement, Δ_e is the maximum linear displacement. In Figure 2 the real behavior of the structure is replaced by a bilinear elasto-plastic model. In equation 2, μ is the Ductility Factor and is described as follows:

$$\mu = \Delta_{max} / \Delta_y \tag{2}$$

PERFORMANCE POINT DETERMINATION BASES (DUE TO ATC-40)

There are three procedures described in ATC40 to find the performance point, procedures A, B & C. The most transparent and most convenient for programming is Procedure "A". To find the performance point using Procedure A, the following steps should be taken:

1- A 5% damped response spectrum appropriate for the site, for the hazard level required for the performance objective is developed.

2- The capacity curve obtained from the static nonlinear analysis is converted to a capacity spectrum, using related equations [4].

3- A trial performance point Sa_{pi}, Sd_{pi} is selected. This could be done on the basis of engineering judgement.

4- A bilinear representation of the capacity spectrum is developed such that the area under the capacity spectrum and the bilinear representation is the same.

5 the spectral reduction factors SR_A and SR_V are computed using related equations and the demand spectrum is reduced as shown in Fig. 3. The reduced demand spectrum is plotted together with the capacity spectrum.

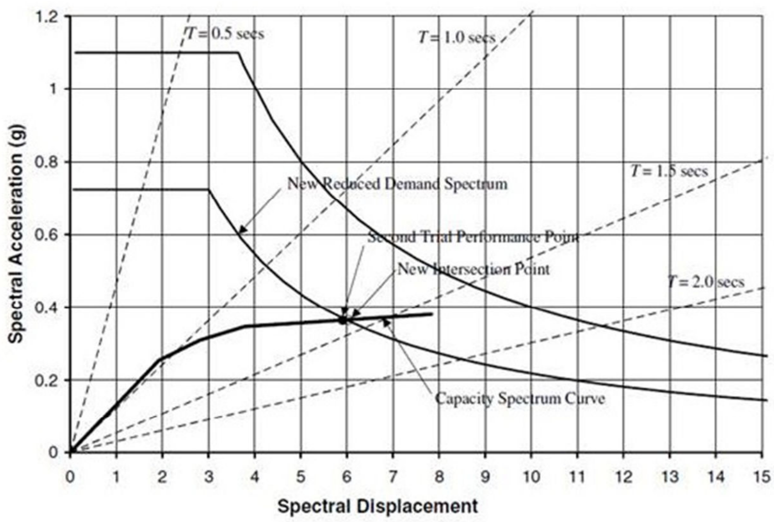


Fig. 3 - General seismic response of structures

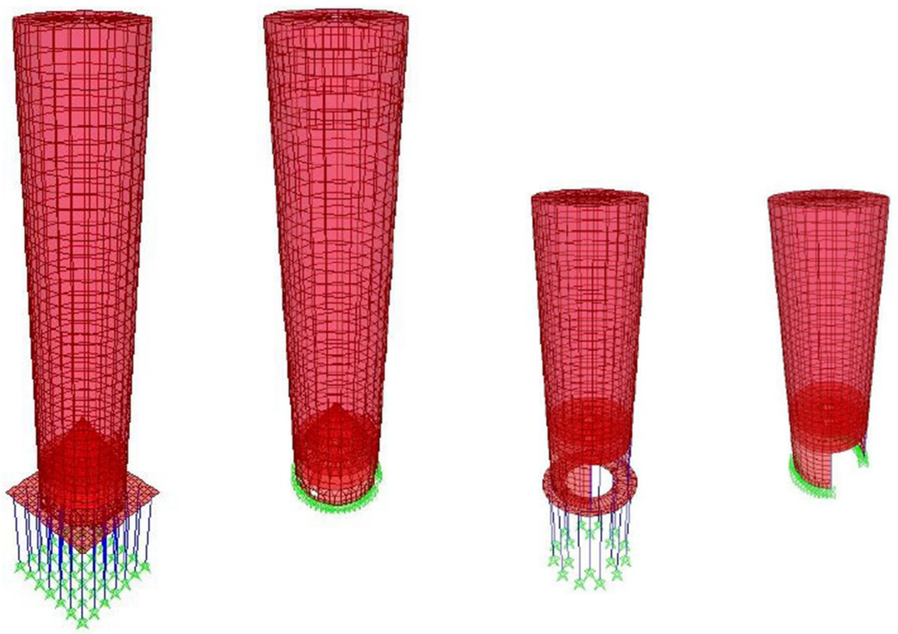
6- If the reduced demand spectrum intersects the capacity spectrum at Sa_{pi}, Sd_{pi} or if the intersection point Sd_p is within 5% of Sd_{pi}, then this point represents the performance point.

7- If the intersection point does not lie within acceptable tolerance (5% of Sd_{pi} or other) then another point is selected steps 4 to 7 is repeated.

Procedure B is also an iterative method to find the performance point, which use the assumption that the yield point and the post yield slope of the bilinear representation remains constant. This is adequate for most cases, however in some cases this assumption may not be valid. Procedure "C" is a graphical method and is convenient for hand analysis.

FINITE ELEMENT COMPUTATIONAL MODELS AND ANALYSES

In order to study the seismic behaviour of R.C. tall silos, two samples of previously analysed and designed silos of Abyek cement plant is chosen due to Fig.4. Model (a) is demonstrating a Blending silo, with a capacity of 12500 ton and 79.0 m high. The internal diameter of model (a) is 16.0m, carrying an approximate 52.0 Tons of mechanical facilities on the upper level.



Model (a) with SSI Model (a) w/o SSI Model (b) with SSI Model (b) w/o SSI

Fig. 4 - Proposed finite element models

For Model (a) a pile foundation system is designed to bear the vertical and lateral loads safely. Pile cap dimensions are 20.0x20.0x3.0 meters, containing 49 cast in place piles of 20 meters depth and a diameter of 120cm. The wall thickness is estimated to be 120cm for the first 10.1m height and 50cm for the rest of the height of the silo. Model (b) is demonstrating a Reject silo, with a capacity of 2000 ton and 35.4 m high. The internal diameter is 11.0m containing a wall thickness of 80cm for the first 11.0m height and 35cm for the rest. As could be observed, the foundation system of this model is also a pile foundation system with a pile cap of ring type. The external diameter of the ring is 13.5m with a width of 3.4m. The thickness of the pile cap is estimated to be 200 cm. The total quantity of piles are 18 with a diameter of 120cm and 15.0m depth. For both cases, the structural concrete is estimated to have a 28 days strength of f'_c=240 kg/cm^2 and the reinforcing bars are AIII type with a yielding stress of F_y=4000 kg/cm^2. In current research the Soil-Structure Interaction effects are determined using Equivalent Spring - Dashpot Theory. In this method, the soil-foundation system is replaced by a spring and a dashpot. For the dynamic analysis of the soil-structure system, the stiffness and the damping coefficient of the springs and dashpots are included in the stiffness and damping matrices of the total system.

The response for the equivalent spring-dashpot analysis could be carried out using direct integration method. An approximate analysis method can also be performed by ignoring the off-diagonal terms of the transformed damping matrix *($\Phi^T C \Phi$)*. The equivalent amounts off stiffness and damping for current research are summarized in Tables 1 & 2.

Table 1 - Stiffness And Damping for the Piles and Pile Cap (Model "a" with SSI)

Soil Category	K_v (kg/m)	C_v (kg-sec/m)	K_h (kg/m)	C_h (kg-sec/m)
Rock	99.76×10^8	12.08×10^8	5.26×10^8	6.88×10^5
Dense Soil	25.11×10^8	5.9×10^8	1.32×10^8	3.37×10^5
Loose Soil	6.79×10^8	3.0×10^8	3.58×10^7	1.69×10^5

Table 2 - Stiffness And Damping for the Piles and Pile Cap (Model "b" with SSI)

Soil Category	K_v (kg/m)	C_v (kg-sec/m)	K_h (kg/m)	C_h (kg-sec/m)
Rock	51.65×10^8	3.23×10^8	7.78×10^8	9.66×10^5
Dense Soil	13.0×10^8	1.58×10^8	1.96×10^8	4.62×10^5
Loose Soil	3.51×10^8	8.0×10^7	5.29×10^7	2.33×10^5

Nonlinear Pushover analyses are completed using Perform-3D analysis software. For nonlinear analyses, the damping ratio is determined equal to 0.05 for all mode shapes. For analysis purposes, the lumped mass method is used for determination of the total mass of the material inside of silos. The computed mass of the material for the cases of 50% Full and 100% Full is uniformly distributed on the framework of the models. In order to illustrate the structural concrete nonlinear behavior, the "Takeda" behavior model is taken into account.

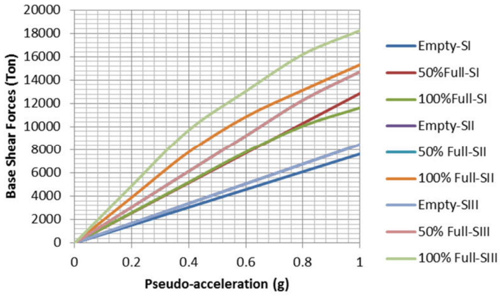
NONLINEAR ANALYSES RESULTS

The results from the modal pushover analyses are summarized according to Table 3.

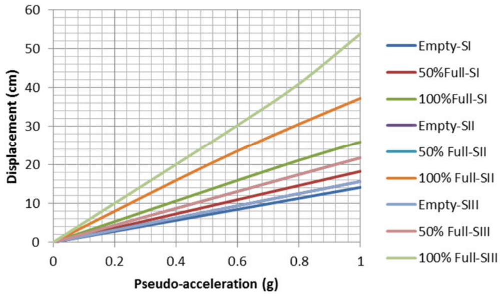
Table 3 - Performance Point results according to ATC-40 guideline. V(ton), D(cm)

	Soil Type	P.P.	Model "a"					Model "b"				
			0.20g	**0.40g**	**0.60g**	**0.80g**	**1.0g**	**0.20g**	**0.40g**	**0.60g**	**0.80g**	**1.0g**
Rock	**Empty**	V	1526.3	3052.5	4578.8	6105.0	7631.3	867.4	1734.9	2602.3	3469.8	4326.5
		D	2.82	5.64	8.46	11.29	14.11	1.04	2.08	3.12	4.16	5.20
	50% Full	V	2573.9	5147.8	7721.7	10295.6	12869.5	1421.4	2842.8	4264.2	5394.2	6506.0
		D	3.65	7.30	10.95	14.60	18.25	1.68	3.35	5.03	6.76	8.49
	100% Full	V	2602.1	5204.2	7806.3	10070.6	11637.3	1808.6	3617.1	5036.1	6391.2	7283.6
		D	5.31	10.63	15.94	21.12	25.91	2.46	4.93	7.37	9.76	11.98
Dense Soil	**Empty**	V	1691.7	3383.3	5075.0	6766.6	8458.3	867.4	1734.9	2602.3	3469.8	4326.5
		D	3.13	6.25	9.38	12.51	15.63	1.04	2.08	3.12	4.16	5.20
	50% Full	V	3072.4	6144.9	9217.3	12289.7	14723.3	1421.4	2842.8	4264.2	5394.2	6506.0
		D	4.36	8.71	13.07	17.43	21.75	1.68	3.35	5.03	6.76	8.49
	100% Full	V	3902.5	7804.9	10858.1	13146.1	15321.7	1808.6	3617.1	5081.6	6517.2	7545.5
		D	7.97	15.94	23.53	30.52	37.18	2.46	4.93	7.45	9.98	12.72
Loose Soil	**Empty**	V	1691.7	3383.3	5075.0	6766.6	8458.3	867.4	1734.9	2602.3	3469.8	4326.5
		D	3.13	6.25	9.38	12.51	15.63	1.04	2.08	3.12	4.16	5.20
	50% Full	V	3072.4	6144.9	9217.3	12289.7	14723.3	1421.4	2842.8	4264.2	5394.2	6506.0
		D	4.36	8.71	13.07	17.43	21.75	1.68	3.35	5.03	6.76	8.49
	100% Full	V	4902.2	9714.4	13051.4	16205.9	18248.4	1808.6	3617.1	5081.6	6517.2	7545.5
		D	10.01	20.03	30.23	40.90	53.78	2.46	4.93	7.45	9.98	12.72

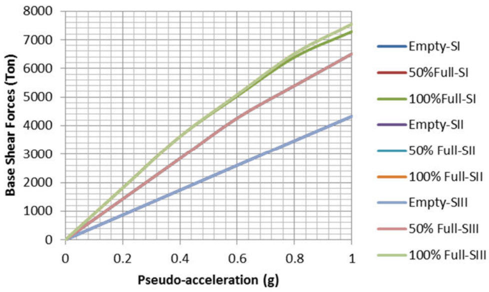
As could be observed in Table 3, the effects of spectral acceleration amplification get more accelerated when the material volume inside the silo is increased. In order to have a better imagination, the contents of Table 3 is converted into diagrams of displacement and base shear force versus pseudo acceleration for both models which could be observed in Fig. 5.



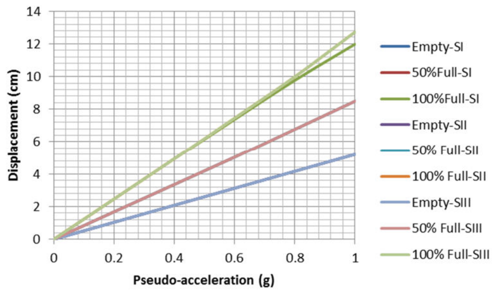
Base Shear Force versus Pseudo-acceleration
For Model “a”



Displacement versus Pseudo-acceleration
For Model “a”



Base Shear Force versus Pseudo-acceleration
For Model “b”



Displacement versus Pseudo-acceleration
For Model “b”

Fig. 5 - Performance Point results according to ATC-40 guideline.

CONCLUSION

As could be observed, by filling the silos, the performance point grows to a higher value for all soil categories and spectral acceleration amplitudes. For both models when empty, base shear force and displacement grows linearly when a/g amplifies. For model “a” a reduction is observed in amplification of base shear force when 100% full for all soil categories, while the displacement increases nonlinearly. The same happens for model “b”, except, when degrading from SII to SIII, no changes could be observed in results when spectral acceleration amplifies. It means that for short silos, no changes could be observed in performance points when degrading the soil type from SII to SIII, while the spectral acceleration level increases.

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