ASEISMIC DESIGN OF CEREAL SILOS IN ROMANIA

C.Pavel (I)

R.Agent (II)

A.Pușcă (III)

SUMMARY

The behaviour of large storage cereal silos in Romania during the 1977 earthquake is reviewed. The conclusions drawn thereof are also presented in the report together with their due effect upon improving the design philosophy of this type of buildings.

INTRODUCTION

The earthquake of March the 4th, 1977 was the first strong seismic action that confronted the modern constructions in Romania, including the large storage cereal silos made of reinforced concrete.

In the predominantly flat areas of the east and south of the country where grain is produced and stored, the seismicity index on the M.S.K. scale varied between 7 and 8. In terms of acceleration at the ground level that meant between o.1 g and o.2 g. Due to the over 1oo km depth of the hhypocenter, the fundamental vibration period of the ground at the moments of highest intensity was large, i.s. up to 1.4 sec. This lead to more unfavourable effects for flexible buildings, i.e. with the fundamental period in the range over 1.o sec. (Ref. 1). The cereal silos were not amongst the most unfavourably affected buildings owing to their massive character reflected in fundamental periods below o.8 sec. Under these circumstances and benefitting from a generally robust structural setting, the silos practically had an elastic dynamic response whereas the multistorey and other high rise buildings displayed considerable excursions into the inelastic range.

The large silos in Romania were built in several distinct periods. The ones erected before 195o had storage capacities below lo ooo tones and were designed regardless of any aseismic concept. In the years followed the concern for ensuring by appropriate design a good behaviour of this type of buildings under seismic action rose. Newly built larger silos were designed in accordance with the evolution of the aseismic design principles.

Twenty eight old and new silos have been investigated after the 1977 earthquake. They were charged at various levels, some of them full, at the moment of seismic motion.

(I) Ph.D., Associate Professor, Department of Concrete Structures, Faculty of Civil Engineering, Bucharest

(II) Ph.D., Professor, ibidem

(III) Eng., Director, Department for Contracting, Receiving and Storing of Agricultural Products, Bucharest

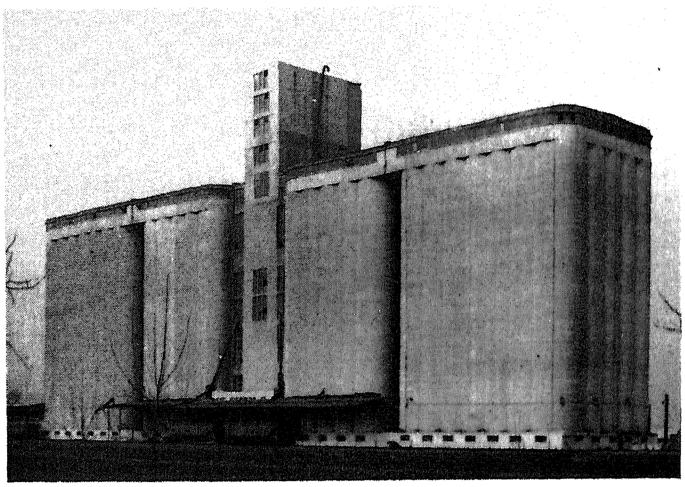


Fig.1. Typical new large storage cereal silo in Romania

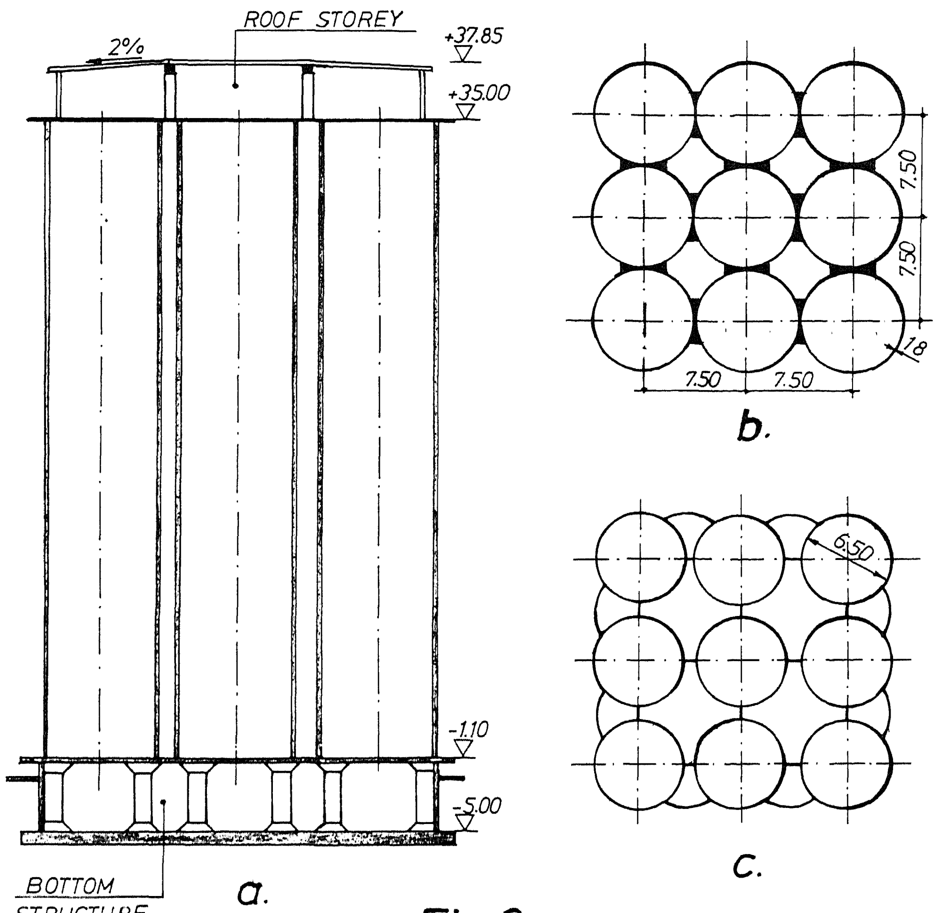
DESIGN PRINCIPLES OF NEW SILOS ERECTED BEFORE THE 1977 EARTHQUAKE

The structural system currently adopted for large storage R.C. silos consisted of slip-formed connected groups of cells. The frame or shear-wall structure of the elevator tower was separated by joints from the cells (see Fig. 1). Either tangent (Fig. 2.b) or distanced on both directions (Fig. 2.c) circular cells were used. The diameters of the cells were of up to 7.5o m whilst the storage height was under 4o m. Based on considerations regarding the nature of the foundation soils the length of the connected groups was limited to three or four rows of cells. Between the groups, settlement joints taking aseismic joint functions too were provided.

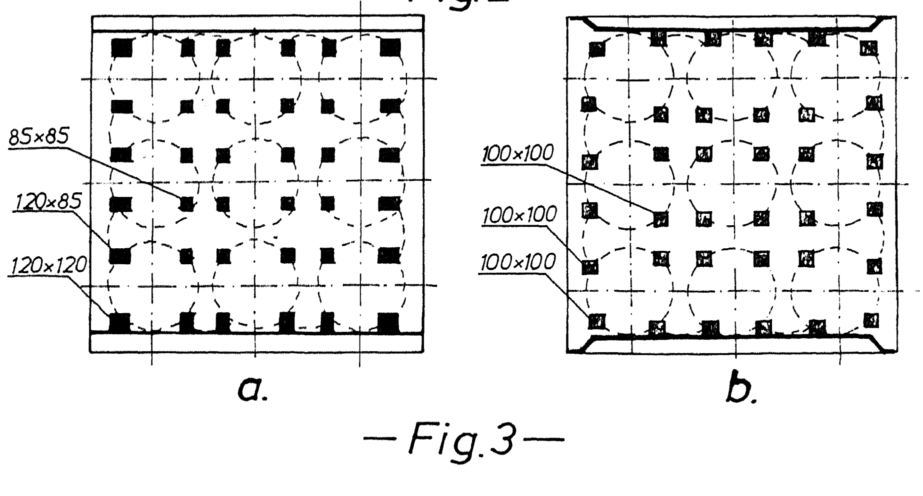
The bottom structure was realized in some cases by flat slab floor supported on columns with capitals (Fig. 2.a) and in the others by the silo walls themselves directly supported on the raft foundation. Both systems were known and also used for silos in various industries (Ref. 2).

The variant with rigid, vertically homogeneous structure made by the silo walls supported on the raft foundation did not rise special problems of aseismic conformation of the assembly cells-substructure. For silos with cells supported by columns, there was a permanent concern to stiffen the bottom structure elements (i.e. raft foundation, columns, flat slab floor) in order to avoid the occurence of a bottom level with much lower stiffness than the cells (soft ground level).

In that period the design pressures beneath the foundation resulted from the assumption of an elastical soil response. As a result, pressure distribution with important concentrations over the perimeter area of the raft foundation were considered in design. That lead to much larger column dimensions in the perimetric area as compared to the interior (Fig. 3.a). Although the proportions of bottom structure columns placed them in what


ROOF STOREY
2%
+37.85
+35.00
-1.10
-5.00
BOTTOM
STRUCTURE
a.
7.50
7.50
7.50
7.50
18
b.
6.50
c.

— Fig. 2 —


85×85
120×85
120×120
a.
100×100
100×100
100×100
b.

— Fig. 3 —

is now called the "short" range, the design could not benefit at that time from what became later known on short columns seismic behaviour. Consequently the shear design of those columns, made in accordance with the general rules applied to all columns, lead to a small amount of transverse reinforcement (four legged ties Ø 8 mm/3oo mm).

The roof storey structure, currently supported on columns, was made of either steel or reinforced concrete. In certain rare cases the supports of the roof were realized by slip-formed parts of the silo walls.

FINDINGS CONCERNING THE PERFORMANCE OF SILOS DURING THE 1977 EARTHQUAKE

The old silos performed rather differently from those designed and built after 195o (Ref.1,3). The damages produced to the old silos were more severe. Since the elevator tower was not separated by joints from the cell groups, damages occured in the zone of abrupt change of rigidity of the assembly cells-tower. Major cracks in the structural elements as well as severe cracking and even expulsions of the infilled walls of the tower were recorded (Fig. 4). Some columns of bottom structure were also damaged in the locations of maximum bending moment (Fig. 5). The causes are atributed to both the lack of any aseismic design principles and the fact that old silos had already undergone the action of another major earthquake in 194o followed by no effective strengthening.

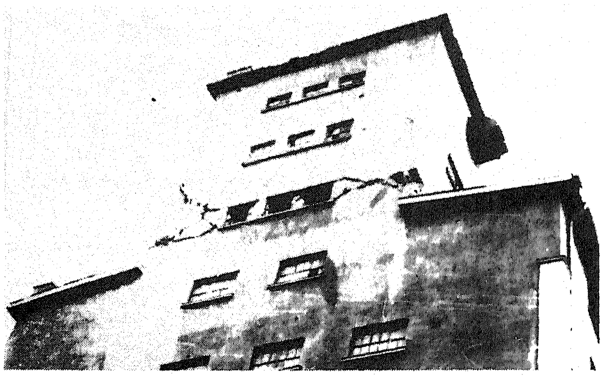


Fig. 4. Old silo. Damages in the zone of abrupt change of stiffness

Fig. 5. Old silo. Damages of capitals in the columns of bottom structure

The silos designed after 195o had a good overall behaviour. The main structure remained unaffected in all cases. The only part that was in some cases damaged was the roof-storey structure when it was made of heavy roof elements supported on R.C. columns. Such damages went from column failure (Figs. 6, 7) to local or total collapse of the roof of one group of cells (Fig. 8). The causes that lead to the unfavourable behaviour of this roof system are related on the one hand to the design philosophy and structural setting and on the other to the way in which lateral loading was considered. Thus :

- The flexible structure of the heavy precast R.C. roof placed on top of a rigid building displayed an amplified dynamic response, usually called "whip"-effect. That increased considerably the lateral seismic forces at the roof level. Though the effect had already been known and analysed in design, the consequences of the earthquake showed that it had been underestimated.

- The connections between the R.C. columns and the cells body proved to be weak points. Since the connections between precast roof and columns were not designed to transmit bending moments, the columns had to resist the lateral seismic forces as a cantilever. In such conditions, due to an insufficient anchorage of the column reinforcement into the concrete cells,

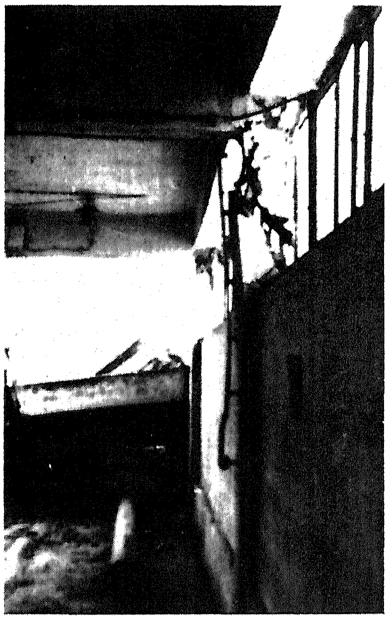


Fig. 6. Column extremity failures at roof-storey structure

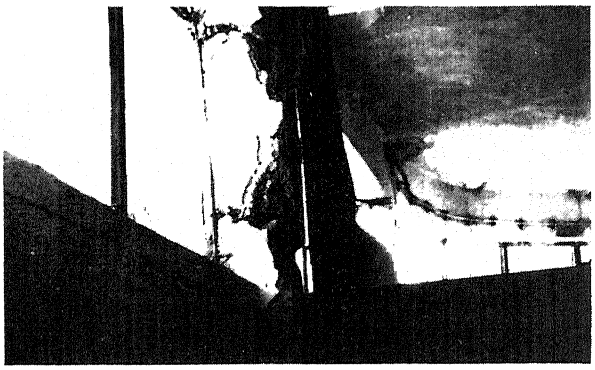


Fig. 7. Characteristic short column failure at roof-storey structure

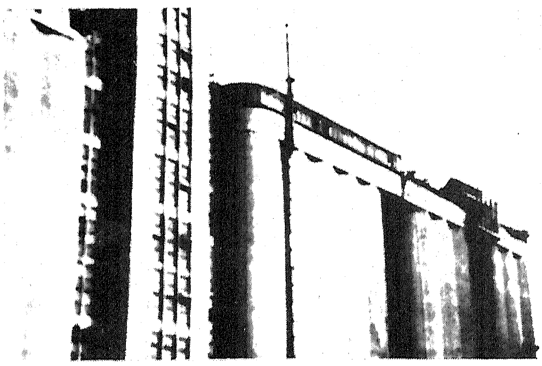


Fig. 8. Partial collapse of a silo roof-storey structure

the base column sections were affected by anchorage breatdowns and witnessed large rotational displacements.

- The infilled masonry walls of the roof storey limited the deforming length of columns to the height of the window openings. At a result, damages characteristic to the short column type of behaviour were exhibited by many perimetric columns (Fig. 7).

No damages were found in the cell walls, that confirmed the fact that overpressures of the stored material due to the dynamic effect of the seismic action do not exceed overpressures allowed for in design in order to consider the unfavourable effects by withdrawal.

IMPROVEMENTS OF THE ASEISMIC DESIGN PHILOSOPHY AND ANALYSIS OF SILOS AFTER THE 1977 EARTHQUAKE

As the most frequently adopted structural system remained that with cells supported on columns and flexible roof storey, the improvements discussed here refer to this system.

The bottom structure elements of the high-rise silos will always have massive proportions due to the important vertical loading. Consequently they can hardly be atributed with post-elastic deformation capacity to dissipate the energy induced by earthquake and, as a result, the provided strength capacity should ensume an elastic response of the silos structure with the assumption that the largest amount of the energy induced by earthquake would be absorbed by the inelastic deformations of the foundation soil. The findings from the 1977 earthquake confirmed that this was the actual behaviour of the assembly structure-soil in the case of high-rise silos. The silo design subsequent to 1977 aimed at as closely as possible reflecting this behaviour mechanism by appropriate proportioning and detailing of elements (Ref. 4).

The consideration of the post-elastic behaviour of the foundation soil lead to the admission in design of a more realistic pressure distribution on the foundation (i.e. devoid of large contour concentrations) and allowed the levelling of the cross-sections of the bottom supporting columns. Advantages resulted in both transmitting reactions from the raft-foundation to the cells and the more uniform distribution of lateral seismic forces to columns.

The bottom structure columns were designed and reinforced in accordance with the provisions for short columns. The provided transverse reinforcement was stronger and better distributed across the concrete section (Fig. 9).

By increasing the cross-sections of columns in the roof-storey structure the difference in fundamental vibration period to the rest of the silo structure was diminished. For a better account of the "whip"-effect greater values of seismic forces were considered for the roof-storey structure. According to the new Romanian aseismic design provisions (Ref. 5) the dynamic amplifying factor in such cases is up to 2.5 times greater than for the rest of the structure.

The perimetric walls of the roof-storey were separated from the columns, to ensure a free vibration of the two elements and thus avoid the above mentioned damaging effects.

CURRENT CONCERN FOR FURTHER IMPROVEMENT OF DESIGN METHODS AND STANDARDS

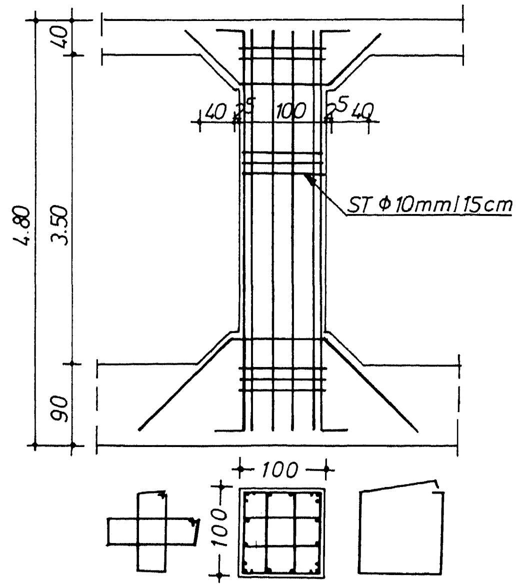


Fig. 9. Detailing of a bottom structure column

Comprehensive computer programs were made available in Romania in recent years to analyse the elastic seismic response of silos. Analysis of response to conventional code loadings (Ref. 6) as well as complex time-history analysis (Ref. 7) can be undertaken with due account to the soil-structure interaction. Experimental investigations were made on existing silos to determin the vibration periods corresponding to various storing levels. The data thus obtained were confronted with analytical results.

The new Romanian code of practice for the aseismic design of buildings (Ref. 5, 9) contains specific references to silos. Amongst these specific aspects mention should be made on the necessity to analyse effects of the dissymetry of masses generated by partial dissymetrical charge of the silo. Due account must be given to the general torsion that may result. Aseismic design provisions are also contained in the draft standard for the design of cereal silos now in its final stage (Ref. 8, 9).

REFERENCES

(1) M. LUPAN : The Behaviour of Cereal Silos. In "The Earthquake of March the 4th 1977 in Romania" (edited by St. Bălan, V. Cristescu, I. Cornea) (in Romanian), Ed. Acad. RSR, Bucharest, 1982, pp. 327-33o.

(2) R. AGENT and N. BUCUR : Structural Solutions Specific to the Silos within the Cement Factories in Romania, Proceedings of International Symposium on Silos of the I.A.S.S. Committee of Pipes and Tanks, Wroclaw, June 1973, pp. 163-166.

(3) C. IACOB, T. DINESCU and N. DIN : Considérations sur le comportement des silos de céréales sous l'action des tremblements de terre importants. Proceedings of the F.I.P. Symposia on Partial Prestressing and Practical Constructions in Prestressed and Reinforced Concrete, Bucharest, Sept. 198o, Part 2, pp. 513-533.

(4) C.PAVEL, D.STANESCU and others : Study on the Development of Cereal Silos. Aseismic Design of the Bottom Structure. IPCT Study N° 57o3, Bucharest, 1981 (in Romanian).

(5) P.1oo-81. Provisions for the Aseismic Design of Civil and Industrial Buildings (in Romanian). Buletinul Construcţiilor nr.11, Bucharest, 1981.

(6) H.SANDI and I.S.BORCIA : Utilizer's Guide of the Programs "SILOTURN" and "TEREN". INCERC, Bucharest, 198o (in Romanian).

(7) I.S.BORCIA : The Computer Program SILOBIO. Proceedings of the National Conference on Aseismic Design, Jassy, May 1983, vol.2, pp. 237-241 (in Romanian).

(8) C.PAVEL : Cereal Silos. Structural Design Provisions (draft), Bucharest, Dec. 1981 (in Romanian).

(9) INCERC : Recommendations for the Aseismic Design of Cereal Silos (draft), Bucharest, 1979 (in Romanian).