

EFFECTS OF VRANCHEA EARTHQUAKE, MARCH 1977

ON THE TERRITORY OF BULGARIA

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Summary

The Vrancea earthquake of 4 March 1977 had very strong effects on the old and modern buildings located at 200-500 km from the epicentre.

The effects of the earthquake on different types of buildings (masonry, tall reinforced concrete, industrial, etc.) are analysed.

Conclusions for improving the design and construction taking into consideration the long distance effect, spectral characteristics, joints and others are drawn up.

INTRODUCTION

The earthquake of 4 March 1977 with epicentre Vrancea, Romania, focal depth of 110 km and magnitude 7,3 had an effect on the territory of Bulgaria of intensity up to VIII according to the MSK scale. The isoseismal map is influenced significantly by the geological conditions - especially on alluvial deposits at the river valleys. The earthquake damaged not only old buildings but also some new ones (modern reinforced concrete structures) non-designed for seismic excitation and located up to 500 km from the epicentre. This is the reason the effects of the earthquake to be analysed and conclusions for improvement of the earthquake resistant design to be suggested.

SPECIFIC SPECTRAL CHARACTERISTICS OF VRANCHEA

EARTHQUAKE

The specific mechanism of Vrancea earthquake [1] generates surface seismic waves similar to a sinusoidal excitation [2] with long predominant periods 1-2,4 sec. The response spectrum of Vrancea earthquake has a maximum at $T \approx 2$ sec and it is very different from the response spectra of other earthquakes. The size of the ground displacement during the earthquake can be seen from the shifting of the upper part of a tomb stone (Fig. 1). The specific spectral characteristics of Vrancea earthquake were the main cause the flexible structures with natural period $T > 0,8$ sec to

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be effected significantly. There are some regions on the territory of Bulgaria in which short period motions could be generated and small buildings of one-two storey had been heavily damaged.

LONG DISTANCE EFFECT OF VRANCHEA EARTHQUAKE

The most surprising result of this earthquake was the strong effect on the tall buildings in Sofia located at 450 km from the epicentre. Many multi-storey reinforced concrete buildings with infilling masonry walls were cracked and had to be repaired. A few tall buildings built with reinforced concrete shear walls located on alluvial deposits were cracked from shear forces (Fig.2) and bending (Fig.3).

The long distance effect of Vrancea earthquake can be explained by the specific mechanism and unusual attenuation law. The graphs in Fig.4 show the change of the maximum acceleration of Vrancea Earthquake ($M=7,3$) depending on the epicentral distance using formulae of different authors. From the comparison of the different curves it is obvious that the corresponding maximum accelerations differ considerably one from another. The attenuation formulae have been drawn from an analysis of accelerograms of earthquakes with seismic foci in the earth crust for given regions. These relations do not reflect the peculiarities of the deep focal earthquakes like Vrancea earthquake of March 4, 1977. The maximum acceleration depending on the epicentral distance was determined for this earthquake [3] by the relation

$$a = a_0 \exp(-5,7 \cdot 10^{-3} R) \quad (1)$$

where: a_0 - acceleration in the epicentre for this particular earthquake in function of the magnitude;
R - epicentral distance.

The curve No 7 in Fig.4 calculated according relation (1) demonstrates the big difference with other expressions. This specific attenuation law for the acceleration and specific spectral characteristics of Vrancea earthquake shown in 2 can explain the long distance effect and damages up to 500 km.

Other examples for long distance effect of Vrancea earthquake on three R.C. frame buildings with flexible first storey, located in Svishtov (240 km from the epicentre) are shown in Figs.5-7.

Six-storey residential building (Fig.5) was completely collapsed. The basement of the building constructed with shear R.C. walls and columns did not get any cracks.

As a result of the existing two shear walls of the stairs in a five-storey R.C. office building additional

rotational effects have been developed. Only part of the first two storeys near the stairs were reserved (Fig.6).

A nine-storey apartment building with shops (without shear walls in the first storey) was collapsed (Fig.7) as the above two buildings. Other two nine-storey buildings with the same structure but with masonry shear walls in all storeys (including first storey) have survived the earthquake.

The collapse of the three mentioned buildings can be explained by the specific response spectra, sinusoidal excitation in the both directions, rotational effects, large horizontal displacements and additional influence of P- Δ effect on the bending moments in the columns. The earthquake resistance of the buildings can be improved significantly by shear walls or R.C. diagonals (Fig.8).

EFFECTS ON THE MASONRY BUILDINGS

The three-storey building shown in Fig.9 had R.C. columns and shear walls only in the first storey and got heavy damages in the second storey (without R.C. columns).

Many two-storey school brick buildings got damages in the corners (Fig.10). Another school building was damaged in the conference room (Fig.11) and also at the connections between masonry walls and timber roof structure.

In some places like Svishtov one-storey brick buildings did not get any damages although some tall buildings (Figs.5-7) were destroyed. In some other places only small buildings were damaged (Fig.12). A few old churches were seriously damaged (Fig.13). Many damages occurred in some industrial buildings of the cause of the bad connection between the roof trusses and columns (Fig.14) and also between the walls and columns (Fig.15).

CONCLUSION

From the analysis of the spectral characteristics of Vrancea earthquake and damages in the different type of buildings the following conclusions and recommendations can be proposed.

- The earthquake resistance design of buildings located in northern parts of Bulgaria, near to Danub river, has to take into consideration the long distance effect of Vrancea earthquake by a respective spectrum (Fig.16).

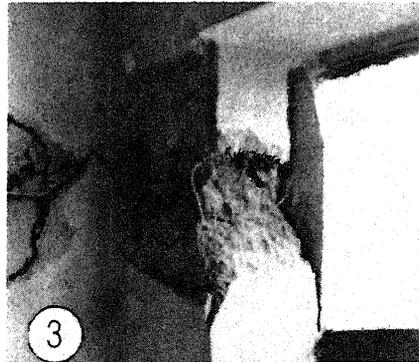
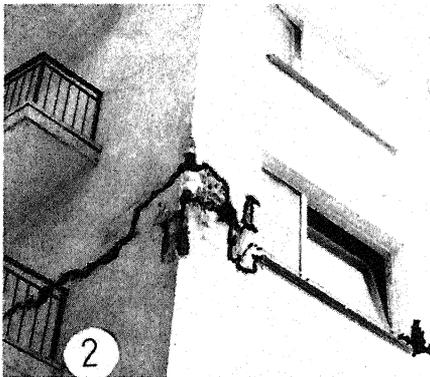
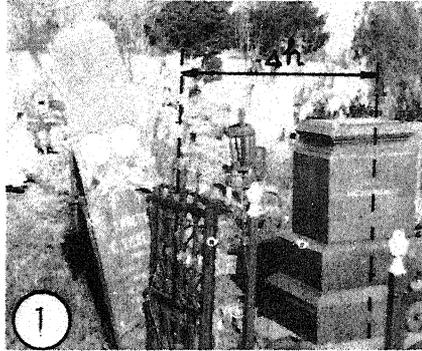
- The planing of buildings with flexible first storey must be avoided in regions strongly effected from Vrancea earthquake.

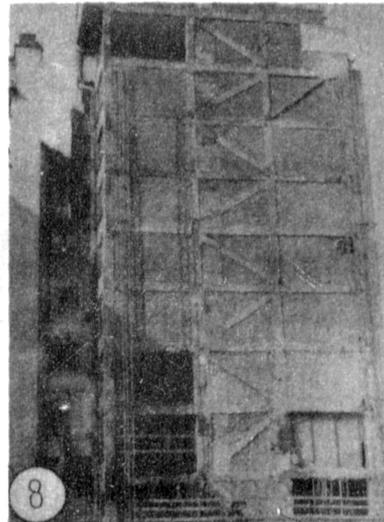
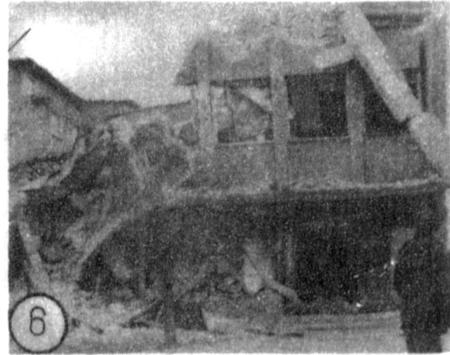
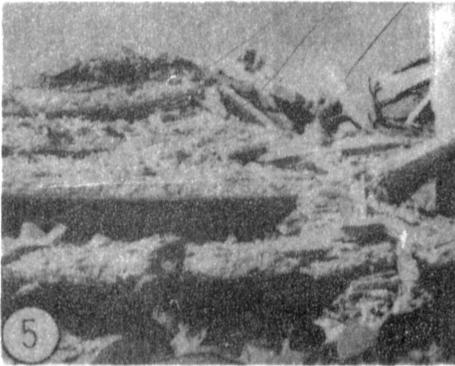
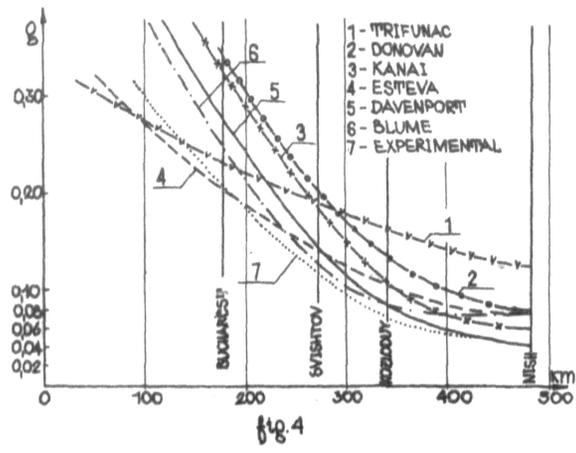
- The maximum horizontal deformations in flexible buildings must be limited in order to decrease P- Δ effect and avoid the total collapse of the buildings.

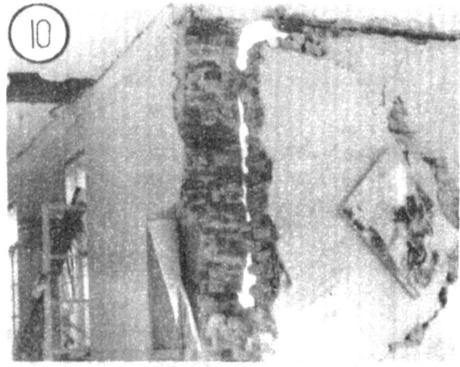
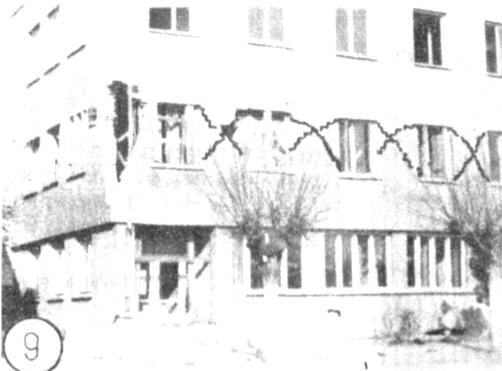
- The earthquake rotational effects on buildings have to be taken into consideration in the design.
- Special attention has to be paid to the quality of the joints between separate prefabricated elements.

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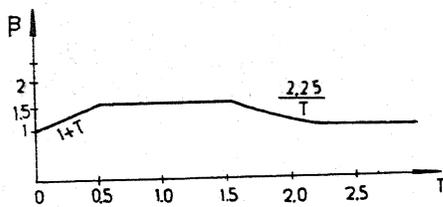
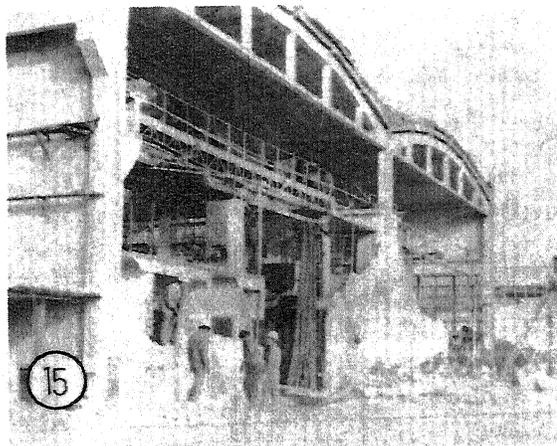
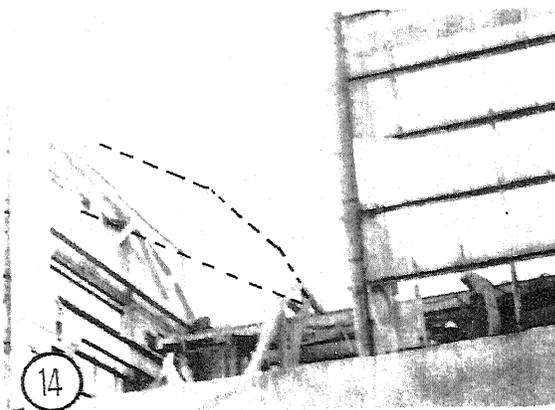


fig. 16