EARTHQUAKE PROTECTION OF A BUILDING CONTAINING RADIOACTIVE WASTE BY MEANS OF BASE ISOLATION SYSTEM

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SUMMARY

This paper describes a 3-story building containing radioactive waste and designed to resist an earthquake with a maximum peak ground acceleration of 0.3g. The structural system is a double box system with the inner box installed into the outer box by means of a base isolation system designed to carry the vertical load and to withstand the earthquake forces. A three-dimensional dynamic analysis was performed showing that the building moves horizontally very much like a rigid body inside the outer box with a maximum acceleration of 0.33g and a maximum relative displacement of 4.8 cm.

INTRODUCTION

Storing radioactive waste is a serious problem in countries using nuclear fuel. A solution is to store these materials in tanks located in the basement of buildings specially designed to stop radioactive waves and to resist earthquakes, when they are located in seismic zones. The requirement of protection against earthquakes is unduly severe when the foundation soil is saturated with sea water; in this case, indeed, the smallest crack in the concrete walls of the basement can let the sea water come in contact with the radioactive tanks and pollute the surrounding sea water.

BASICS OF THE PROJECT

The structure is a 3 story reinforced concrete building measuring 24m x 13m in plan (Fig. 1). The first story is a basement where tanks containing radioactive waste are confined. The second floor supports another set of tanks and the third floor is a service floor with a heavy workshop. The project was built around five main requirements arising from the destination and location of the building. These are: (1) the heavy load on floors; (2) the protection against radiations (3) the waterproofing of the basement; (4) the earthquake protection; (5) the foundation soil.

We will briefly review these five points. The design live load was 2500 kg/m^2 (512 pounds/sq. foot) for the first and second floors and 1000 kg/m^2 (205 pounds/sq. foot) for the third floor. The tanks can be filled in a random manner on the floors and five different loadings were considered corresponding to different areas of the loaded floors. The highest static and dynamic stresses are obtained when the tanks are filled in

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the area shaded on Fig. 1a. The protection of the environment against radiations was an imperious must and imposed a thickness of 50cm for the concrete slab of the second floor and 40cm for the shear walls of the basement. Due to the proximity of the sea, the soil surrounding the basement is saturated by sea water up to 2m under the ground level. In case of an earthquake, if the walls of the basement were to be cracked, the sea water would infiltrate into the basement, come in contact with the tanks or even the radioactive waste and would become radioactive itself on a wide spread. To assure the waterproofing of the basement in all circumstances, the building itself with its basement is built inside of a reinforced concrete box (Fig. 1b); the first floor of the building is supported on isolators and a 22cm gap is provided between the walls of the basement and the walls of the outer box.

The building is located in a moderate seismic area with an expected maximum ground acceleration of 0.2g; due to the high safety required by the project, this value was increased by 50% and Fig. 2a shows the design acceleration response spectrum scaled at 0.3g; Fig. 2b shows the corresponding displacement response spectrum. As the structural materials are compelled to work in the elastic range only, spectra of Fig. 2 are elastic spectra. The damping comes mainly from the isolators with a damping ratio equal to 5% of critical.

The foundation soil is made of 2m deep recent alluvial filling material set on a more compact sand gravel layer. The soil was reinforced by local injections of rammed gravel columns to meet the working dynamics stress of 2.7 bars (39 psi).

THE STRUCTURAL SYSTEM

The whole building is made of reinforced concrete. The exterior walls are designed as shear walls, while the inner part of the structural system is composed of moment resisting frames. The floors and roof are reinforced concrete beam-slab systems, except the second floor which is a plain reinforced concrete slab with a thickness of 50cm (19.7") as said previously. The building is installed on a base isolation system comprising 52 Gapec isolators located at the crossings of frames and shear walls. Each isolator consists of laminated layers of rubber and steel plates strongly bonded during the rubber vulcanization process. The rubber is natural rubber specially compounded to resist oxidation; the whole body of the isolator is protected by a 0.3 cm thick layer of rubber and the end steel plates are covered by highly rust resistant paint (Fig. 3). The isolators have a life expectancy of at least as long as that of the building. The 52 isolators are not all of the same diameter - 32 isolators have a diameter of 40cm (15.7") and are made of eight 0.6cm thick layers of rubber separated by five 0.5cm thick steel plates; these isolators are fitted with two 1.4cm thick end steel plates strongly anchored to the structure by means of 16 threaded steel rods of 1.6cm in diameter; the height of an isolator is 10.4cm (4.1"). The other 20 isolators have a diameter of 50cm (19.7") and are composed of five 1cm thick layers of rubber bonded to four 0.5cm thick intermediate steel plates; the end steel plates have a thickness of 1.6cm and are anchored to the structure by means of 16 threaded steel rods of 1.8cm in diameter; the height of an isolator is 10.5cm (4.1"). Despite the strength of their attachment to the structure, provisions have been made to allow the removal of the isolators without great difficulty.

Table 1 gives static and dynamic characteristics of the isolators. We can see from this table that the vertical stiffness of isolators is about 360 times higher than the horizontal stiffness. This is a constant feature of Gapec isolators, which is intended to prevent any rocking motion of the building.

The cost of the isolators was about $43,400 (1981 value.)

DYNAMIC ANALYSIS

A three dimensional dynamic analysis was performed with 3 degrees of freedom at each floor, namely two horizontal displacements and one rotation around the vertical axis (torsion) for a total of 12 degrees of freedom (Fig. 4). The load disposition is shown on Fig. 1a. Fig. 5 shows the first four natural periods and the corresponding natural modes shapes. The first two modes are nearly straight lines indicating that the building behaves like a quasi rigid body; this is a constant characteristic of buildings on GAPEC isolators as previously mentioned and is due to the high ratio between vertical and horizontal stiffnesses. The third mode has the highest torsional component; the shape of mode 4 is just shown for information, for it can be seen from Table 2 that this mode has a very low participation factor and makes no contribution to the total response. Table 2 also shows that when the seismic component is parallel to OX, mode 2 makes the largest contribution; on the contrary, when the seismic component is parallel to OY, the second and third mode make also substantial contributions to the total response.

Tables 3 and 4 show the horizontal response accelerations, shears and overturning moments for the seismic component parallel respectively to OX and OY. The main feature which appears from these tables is the nearly constant acceleration over the height of the building. This is a direct consequence of the shape of the natural modes. It is to be emphasized that, due to the loading considered for the dynamic analysis, displacement takes place in both horizontal directions and, despite this torsional effect, the building undergoes a quasi rigid body motion. We can also observe that the response is higher in the OY direction than in the OX direction, as a consequence of the higher stiffness in the OY idrection. The maximum horizontal relative displacement was 4.8cm giving a maximum shear strain of 100% for the isolators. Static shear testings currently performed on isolators show that they can sustain a strain of 200% without failure. As the building behaves like a rigid body, the fundamental natural period can be evaluated accordingly as the natural period of a one-degree-of-freedom system. From Table 1, the total stiffness of isolators can be calculated as $17206\mathrm{x}10^4$ N/M; from Tables 3 or 4, the total mass is $2346\mathrm{x}10^3$ kg and the approximate first natural period comes to:

$$T_o=2\pi\left(\frac{2346.10^3}{17206.10^4}\right)^{\frac{1}{2}}=o.73s,$$

which is very close to the exact value of o.76s. A preliminary design showed that the fundamental natural period of the building without base isolation system was o.30s and the maximum response acceleration was 0.61 g for materials working in the elastic field only. Thus, the ratio between the response with and without Gapec isolators appears to be o.61/0.33=1.85; this means that the seismic forces applied to the building have been divided by a factor of nearly 2 by using a base isolation system. In addition of the savings made in the structural materials, we have also to remind that the solution comprising a base isolation system brings a much higher safety due to the double protective base shell.

CONCLUSION

A three-story building was designed and built to contain radioactive waste and to resist an earthquake shock with a maximum ground acceleration of 0.3g. The double box and the base isolation system provide a high degree of safety and initiate substantial savings compared to a classical design. This building is part of a set of buildings erected in France on a base isolation system. These buildings include a nuclear power plant, a 600 pupils school and several dwelling houses.

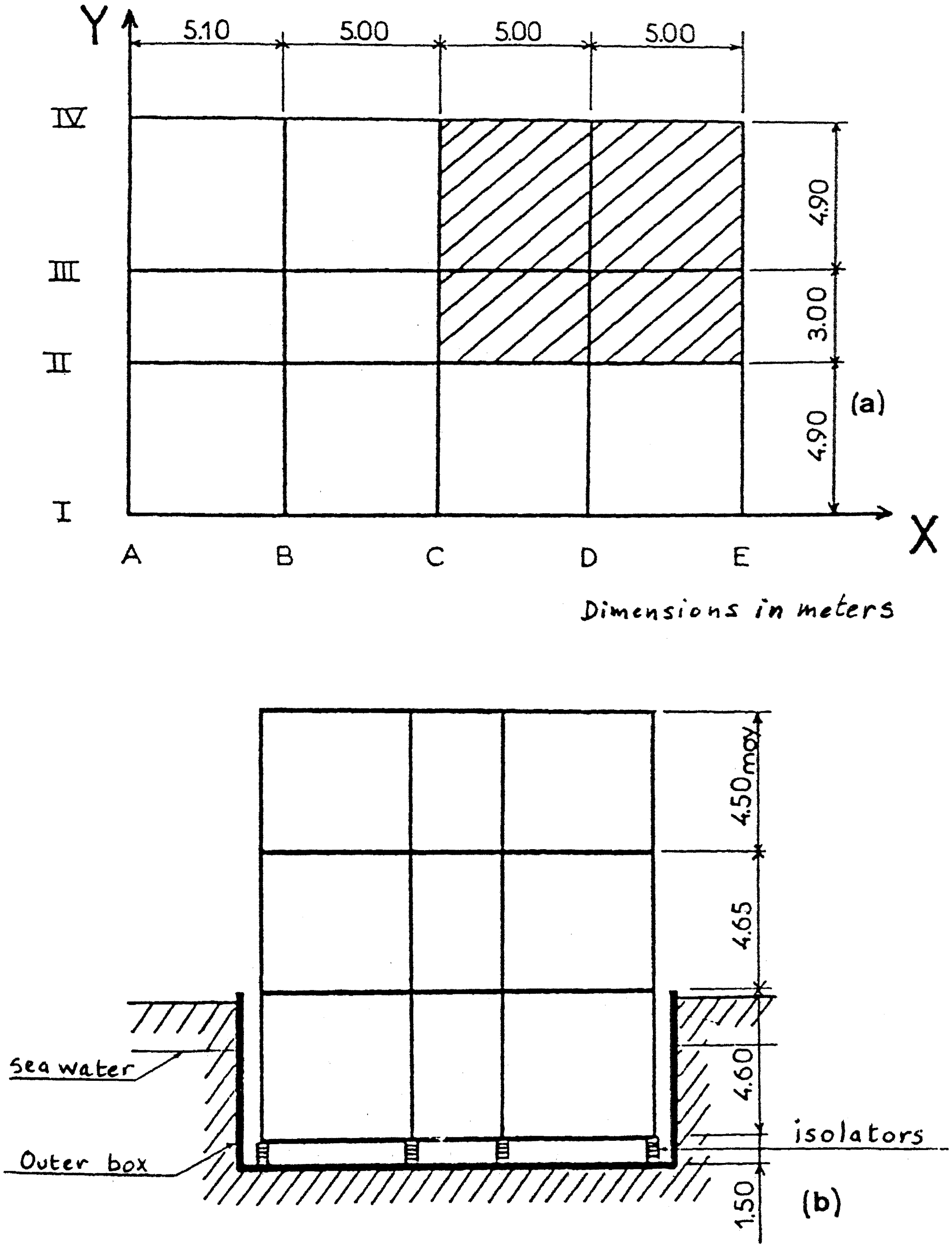

Figure 1 (a) Schematic plan view of the building;
(b) Schematic vertical cross-section

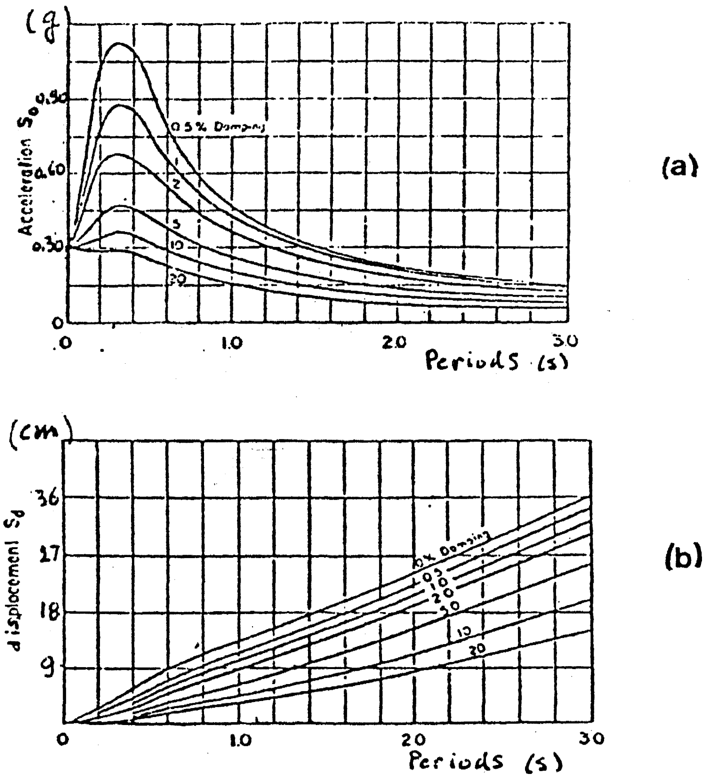

Figure 2 Design response spectrum
(a) acceleration
(b) relative displacement

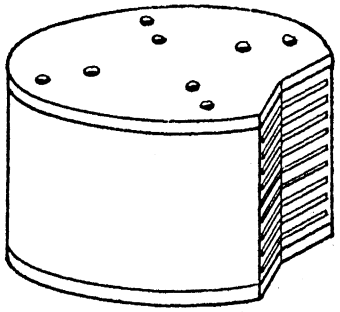

Figure 3 A typical GAPEC isolator

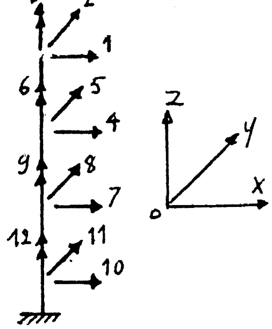

Figure 4 Dynamic model of the building

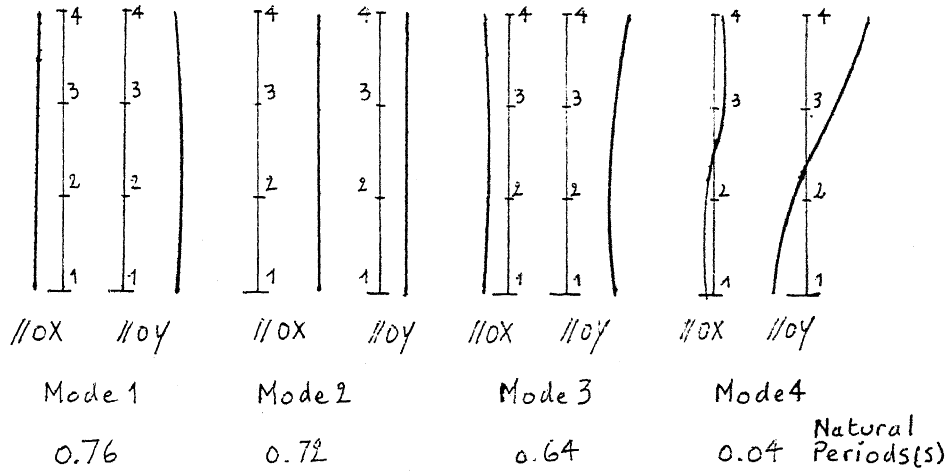

Figure 5 Natural periods and mode shapes of the building

CHARACTERISTICS OF RUBBER LAYERS	Bearing $\phi 40$	Bearing $\phi 50$
Rubber Shear modulus (daN/cm^2)	10.6	10.6
Bulk modulus (daN/cm^2)	10,000	10,000
Shape factor	12.313	12.350
Compression modulus of the bearing (daNcm^2)	6,428	6,467
Vertical stiffness (daN/cm)	993,696	1,505,707
Max, static vertical load (daN)	70,796	92,592
Max static compression stress (daN/cm^2)	58.1	48.3
Max static vertical deflection (cm)	0.07	0.06
Horizontal stiffness (daN/cm)	2,775	4,163
Max shear stress under seismic load (daN/cm^2)	10.6	10.2
Max shear strain under seismic load	1.00	0.96

Table 1 Static and dynamic characteristics of GAPEC isolators used in the building

Seismic Component	Mode 1	Mode 2	Mode 3	Mode 4
Parallel to OX	0.264	0.854	0.154	0.000045
Parallel to OY	0.596	0.374	0.339	0.0068

Table 2 Participation factors

Floor level	Lumped mass (tons)	Displacement //OX			Displacement //OY		
		Acceleration(g)	Shear (KN)	Overturning moment (KN.M)	Acceleration(g)	Shear (KN)	Overturning moment (KN.M)
4(roof)	322	0.30		/	0.14		/
			947			442	
3	527	0.30		4262	0.14		1989
			2497			1166	
2	804	0.30		15873	0.14		7411
			4862			2270	
1	693	0.30		38238	0.14		17853
			6901			3221	
0 (ground)	/	/		48589	/		22864

Table 3 Seismic component parallel to OX. Horizontal response accelerations, shears and overturning moments.

Floor level	Lumped mass (tons)	Displacement //OX			Displacement //OY		
		Acceleration(g)	Shear (KN)	Overturning moment (KN.M)	Acceleration(g)	Shear (KN)	Overturning moment (KN.M)
4(roof)	322	0.12		/	0.28		/
			379			884	
3	527	0.15		1706	0.32		3978
			1154			2538	
2	804	0.14		7072	0.33		15780
			2258			5140	
1	693	0.14		17458	0.31		39424
			3209			7247	
0 (ground)	/	/		22272	/		50294

Table 4 Seismic component parallel to OY. Horizontal response accelerations, shears and overturning moments.