Seismic evaluation of the Pancyprian Insurance Company building

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Scope

In January 2004, the technical services department of the *Hellenic Bank Group* assigned to *J.A. Theophilou Consulting Engineers* the seismic evaluation of the *Pancyprian Insurance Company* building. The purpose was to assess whether the building, which was constructed around 1986-89 before the application of the Cyprus seismic code, complied with the major provisions of the current Cyprus seismic code and to recommend, if required, seismic retrofit measures.

Figure 1. Picture of the building.

History

The design phase of the building commenced in 1986 and the construction was completed around 1988-89. The Consulting Civil and Structural Engineer was the consultancy *J.A. Theophilou Consuting Engineers* and the Architect was the consultancy *Zembylas Associates*.

Structural System

The structural system is classified as Dual System according to the Uniform Building Code 1997 (Ref. 3.) It is comprised of an essentially complete space frame that provides support for gravity loads and shear walls that provide resistance to lateral loads. The entire structure is made of reinforced concrete, cast on site.

The building is 9 levels high and has a one-level basement. The space frame is supported on six circular columns and on two shear wall systems. The slabs are flat with a few overhanging beams. In the middle of the bay, the flat slab is of waffle type.

In the longitudinal direction, the columns of the space frame are connected with slab beams at all levels. These slab beams have dimensions 900 mm width and 420 mm depth. In the transverse direction, the columns of the space frame are connected between them with waffle slab, beams and slab-beams. The ribs of the waffle slab have dimensions 225 mm width and 420 mm depth.

The shear walls are spanning in both directions, providing a large lateral load resistance. They are located at the two opposite faces of the building, providing a large torsional stiffness and resistance.

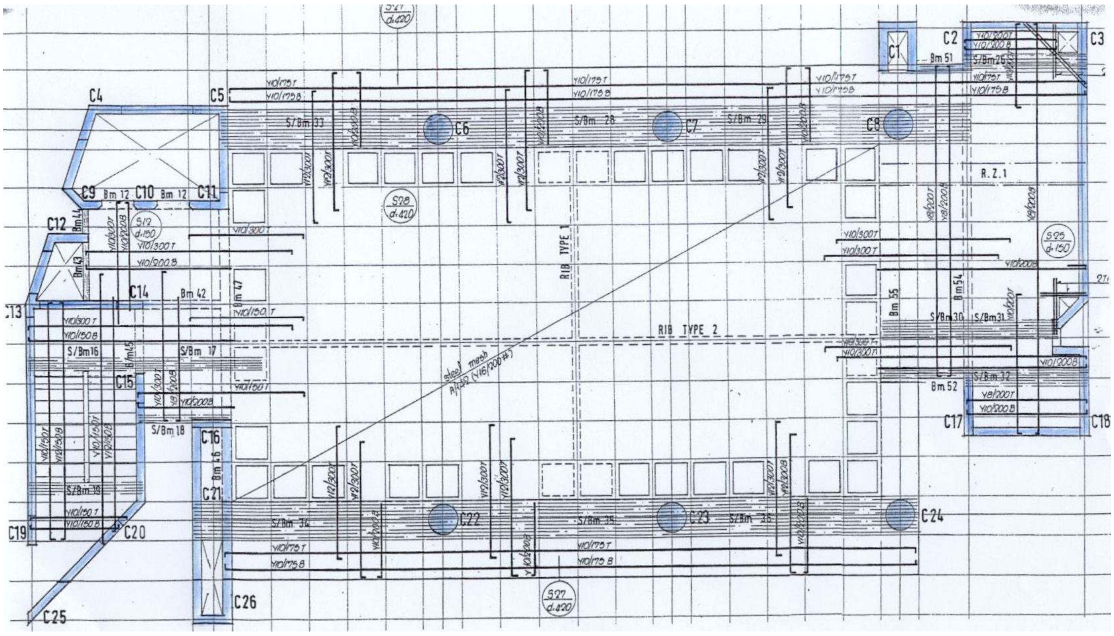

Figure 2. Plan of the building.

Inspection

Optical

The optical inspection was limited to the easily accessible areas, both inside and outside the building. The scope of the inspection was to assess the overall condition of the structure and identify factors that would possibly need to be considered in the present study. No signs of damage due to earthquake events were discovered. Some of the defects could be attributed to physical deterioration of the structure due to the surrounding environment.

Material Testing

Tests were conducted in order to determine the strength of the concrete of the structure. The type of test was the rebound hammer non-destructive test. The test was conducted only on the columns. One column was tested on each floor.

By statistical analysis of the results the measured characteristic strength of concrete was found, with a probability not to be exceeded of 5%. It is expected that the true characteristic strength of concrete is higher because the rebound hammer was not applied directly on the concrete, but on a thin layer of plaster. It was deemed that the measured actual strength was within the allowable range. The uncertainty for the concrete strength has been allowed for by the factor of safety for concrete.

Structural Analysis / Check

Mathematical Models

In order to check whether the structure has the capacity to resist the design earthquake two mathematical models were created:

1. *Model A*: Model of the space frame. The purpose of this model is to check the provision in UBC97 (Ref. 3), clause 1629.6.5 which states that the space frame shall independently have the capacity resist 25% of the design earthquake load.

2. *Model B*: Model of the complete building system. The purpose of this model is to check that the shear walls have the capacity to resist 100% of the design earthquake load, that there are no second-order effect problems and that the interstorey drifts are within the allowable.

Software

The analysis of the structure was performed using the computer software SAP2000 Nonlinear, which uses the finite element method. The Dynamic Analysis was performed using the Response Spectrum Method, in which a number of eigenmodes are superimposed using the SRSS method. The number of eigenmodes taken was such that the Mass Participation Ratio achieved was at least 90%.

Earthquake Load

The structure was found to have the capacity to resist an earthquake ground motion of magnitude 0.15g. This magnitude is 50% higher than that required by the Cyprus Seismic Code (Ref. 2), which is 0.10g for the area of Nicosia. The seismic load was applied in both the X and Y-axes (horizontal) directions. No earthquake load was applied in the Z-axis (vertical) direction.

The bedrock is found at a depth of about 15 - 20 m. Above the bedrock there is a layer of gravel, which extends to the surface. This information was provided empirically by experienced geologists, geotechnical and civil engineers. This soil profile is classified as type S2 in CySC (Ref.2) Clause 6.4.2.1, or equivalently as type S_C in UBC97 (Ref.3), table 16-J.

Building Codes

The structure was checked for compliance to Cyprus Code for the Design and Construction of Concrete Structures (CYS 159: Part 1, Ref 1.) and the Seismic Code for Reinforced Concrete Structures in Cyprus (Ref. 2)

In addition to the provisions of the above codes, on the discretion of the structural engineer, provisions of other widely accepted codes have been used. These codes are the UBC97 (Ref. 3) (which refers to ACI318 (Ref. 5)), CP110 (Ref. 4), ACI 318-95 (Ref. 5) and NEAK95 (Ref. 6).

Quality Assurance

To ensure the correctness of the structural analysis, all computer analysis results were compared and verified with hand calculations with various other analysis methods.

Mathematical Model A – Space Frame

Scope

The scope of Model A is to determine whether the space frame has the capacity to resist 25% of the design earthquake load, so as to comply with the provision in UBC97 (Ref. 3), clause 1629.6.5. The criterion set forth is that, due to its very small ductility, the space frame must resist the applied load elastically.

Description

The model represents the space frame part of the structure. The space frame is supported on eight columns; six circular columns and two columns which constitute part of shear wall systems. The slabs are flat with waffle construction sections and a small number of overhanging beams.

The structure is deemed to have a very small ductility capacity. This is because the slab-beams and the ribs have very small cross-sections.

Assumptions

1. The supports of the columns were assumed to be fully fixed.
2. The stiffness of the in-fill components was neglected.

Elements

The mathematical model of the structure is comprised of both 1D (frame) elements which represent the beams, slab-beams and the columns and 2D (shell) elements which represent the slabs.

The waffle slab has been represented using 2D elements, which have uniform thickness and equivalent stiffness.

Mesh Discretization

The mesh discretization for the beam/slab-beam and the slab elements was selected to be sufficiently dense so that an acceptable convergence of the resulting forces is achieved. An indication of the density is that each beam was discretized to at least 8 elements.

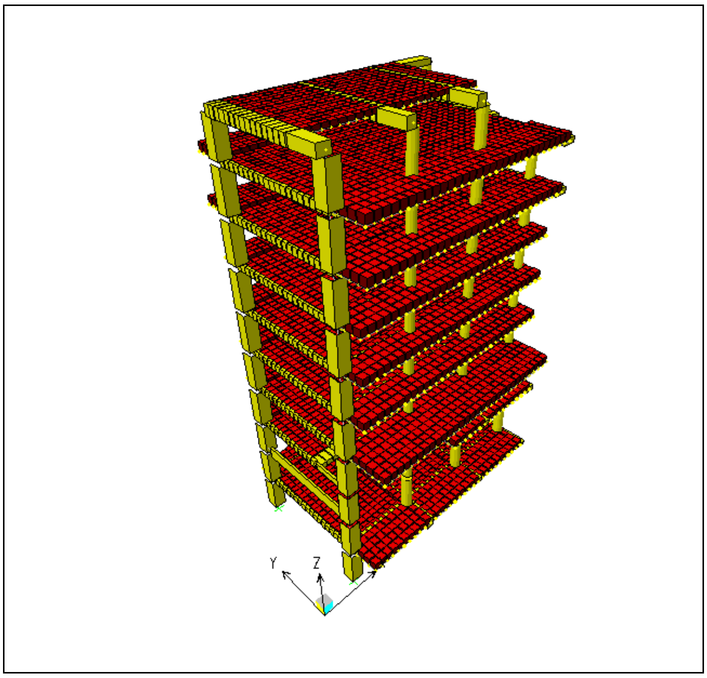

Figure 3. 3D Rendering of Model A.

Joint Restraints

The columns at the base of Level 1 have been fully fixed. To model the effect of the underground basement, the column joints at the top of Level 1 have been restrained for translation in the X and Y-directions.

Joint Constraints

To reduce the size of the stiffness matrix a number of nodal degrees of freedom were eliminated. At levels 2-10 all nodes were assigned a 'Diaphragm' constraint for rotation about the Z-axis. The 'Diaphragm' constraint was the same for all nodes of the same level and different for each level. This type of constraint prohibits any differential translation of the joints in the X and Y-axes direction.

Mass

The mass participating in the seismic forces is taken to be the Dead Load and the Superimposed Dead Load. In addition, 30% of the Live Load was added, as required by NEAK (Ref. 6), Clause 3.2.2.

Earthquake Load

The earthquake load was applied to the structure as static loads at the column joints. The static force procedure was used, as defined in UBC97 (Ref.3) Clause 1630.2. The modal period used in the calculations for the base shear is that found from the dynamic analysis of Model B. The reason for the usage of the static force procedure is because the dynamic analysis procedure was not applicable due to the reduced stiffness of the model.

Column Check

The circular columns were checked for their bending strength using the computer software *CADS RC Column Designer*, by *Computer And Design Services Ltd, UK*. The program, when at 'Check' mode, checks the design bending moment strength of the column under a given axial load. The calculations are based on the charts included in CP110 (Ref. 4.)

The circular columns were checked for their shear strength using the provisions of UBC97 (Ref. 3) (which refers to ACI318 (Ref. 4)). It has been assumed that the section is square with equal cross-sectional area. In the calculation of the total shear strength, both the contribution of the concrete and the shear reinforcement were considered.

The spacing of the spiral reinforcement of the circular columns was found to comply with CySC (Ref. 2), Clause 5.2.3.2.

Flat Slab Check

Diagrams were created with the bending moment contours of the flat slabs. It was found that at a small number of regions localized yielding occurs, which does not however cause any concern on the stability of the structure.

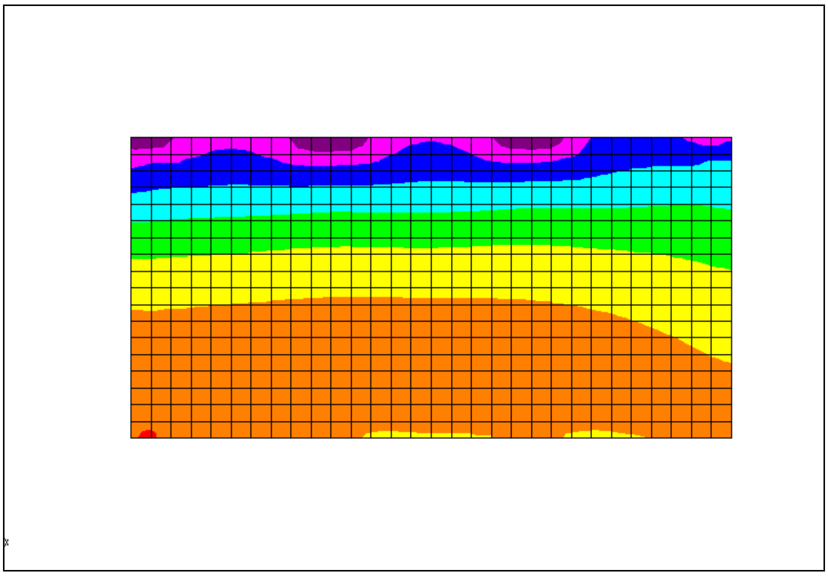

Figure 4. Level 6 – Bending moments on flat slab.

Mathematical Model B – Complete Building System

Scope

The scope of Model B is:

1. To determine whether the complete structural system has the capacity to resist the design earthquake forces.
2. To calculate the fundamental periods of the structure in the X and Y-axis direction.
3. To determine whether the second-order effects can be ignored.
4. To determine whether the interstorey drifts are within the allowable range.

Description of Model

Model B is comprised of the entire Model A to which the shear wall systems were added. The earthquake load is calculated with a Dynamic Analysis.

The shear wall systems are modelled as frame elements with equivalent stiffness properties. They are located at the stiffness centroid of the shear wall systems and they are connected to the space frame with the same 'Diaphragm' constraints at each level.

Shear Wall Strength

The structure has sufficient capacity to resist the lateral loads, since the total shear wall strength capacity at Level 2 (the ground level) is higher than the design earthquake base shear.

Dynamic Analysis – Modes

The fundamental periods of the structure were found to be:

X-Translation T_x = 0.919 seconds
Y-Translation T_y = 0.743 seconds
Z-Rotation T_z = 0.312 seconds

Figure 6, Figure 7 and Figure 8 and show the respective modes.

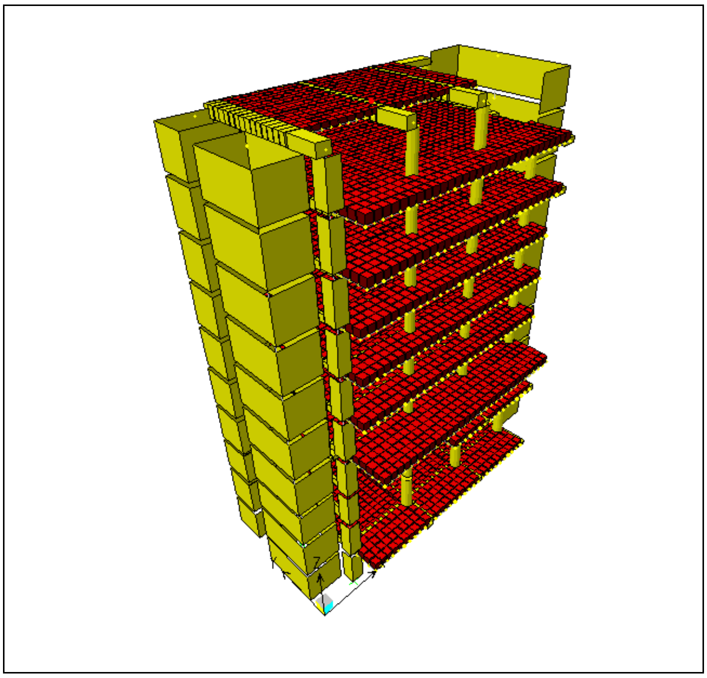

Figure 5. 3D Rendering of Model B.

Earthquake Loads

The earthquake loads have been evaluated with a Dynamic Analysis.

Design spectrum characteristics:

T_1 = 0.12 seconds
T_2 = 0.58 seconds

These periods were taken from the UBC'97 (Ref.3), and correspond to a design spectrum with a soil profile Type S_C according to the Cyprus Seismic Code (Ref. 2).

Allowable Interstorey Drift

The elastic interstorey drifts were found not to exceed the allowable as defined in CySC (Ref. 2), Clause 4.5.4.

Second-Order Effects

The Deformability Index (θ) was calculated and found to be smaller than 0.10 for all levels. Therefore, the second-order effects were ignored, as allowed in CySC (Ref. 2), Clause

4.2.4.3. In the calculation of the interstorey drift the average storey displacements were used for the loadcases EQX and EQY. To check the long columns at Levels 2 and 3, the entire length between the bottom of Level 2 and the top of Level 3 has been assumed to be totally unsupported.

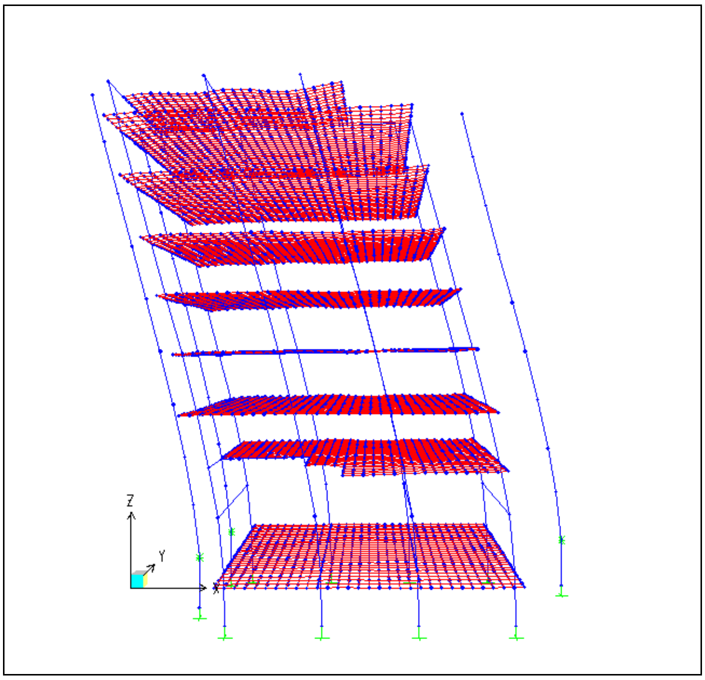

Figure 6. Mode 1 – Period 0.919 sec. X-Translation.

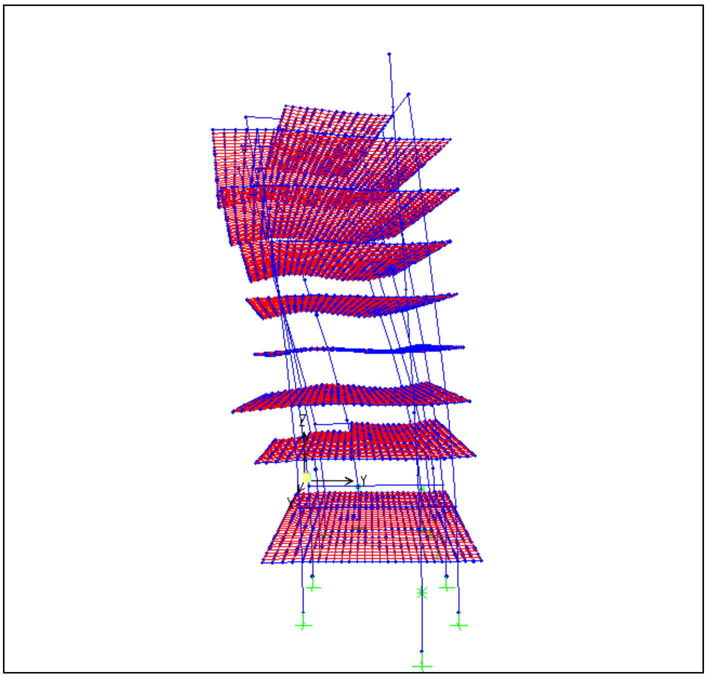

Figure 7. Mode 2 – Period 0.743 sec. Y-Translation.

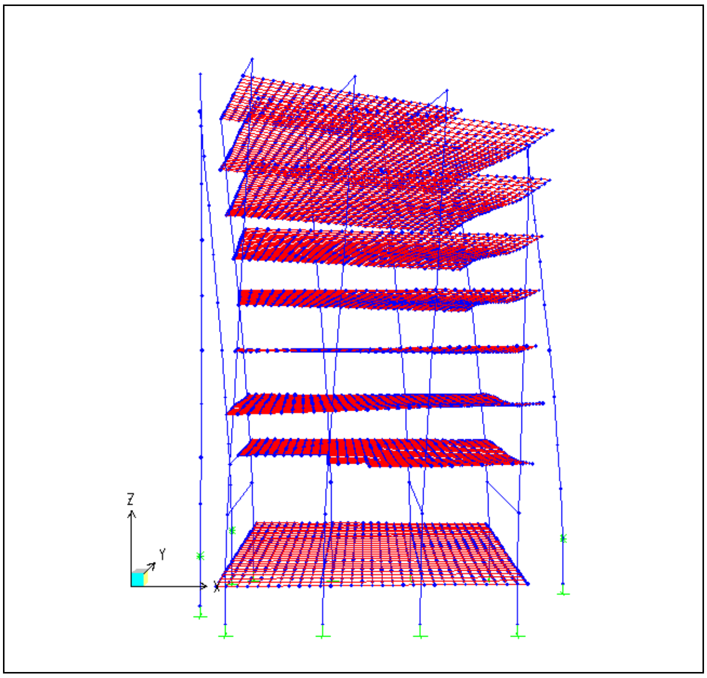

Figure 8. Mode 3 – Period 0.312 sec. Z-Rotation.

Foundations

Bearing Capacity

The foundation is of cellular raft type. The worst loading condition for the vertical reactions at the base of a number of columns were found to be those under the combination for gravity loading (1.5 DL + 1.5 LL), therefore it has been concluded that the foundations bearing capacity is adequate.

Overturning

The structure was checked for overturning about its base.

Conclusions

1. The structure has the capacity to resist an earthquake ground motion of magnitude 0.15g. This magnitude is 50% higher than that required by the Cyprus Seismic Code (Ref. 2), which is 0.10g for the area of Nicosia.
2. The structure was found to comply with the most important provisions of the Cyprus Code for the Design and Construction of Concrete Structures (CYS 159: Part 1, Ref 1.) and the Seismic Code for Reinforced Concrete Structures in Cyprus (Ref. 2)

References

1. Code for the Design and Construction of Concrete Structures, Cyprus Standard 159: Part 1, Cyprus Organisation for Standards and Control of Quality, 1991.
2. Seismic Code for Reinforced Concrete Structures in Cyprus, Cyprus Organisation for Standards and Control of Quality, October 1992.
3. 1997 Uniform Building Code, International Conference of Building Officials.
4. Code of Practice 110: Part 1: November 1972, British Standards Institution.
5. American Concrete Institute Committee 318, Building Code Requirements for Structural Concrete, 1999.
6. New Greek Seismic Code (NEAK'95), 1995.