COMPDYN 2013
4th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Kos Island, Greece, 12–14 June 2013

DESIGN OF ONE STOREY BUILDING WITH PRECAST CONCRETE SANDWICH PANELS IN EARTHQUAKE REGIONS

Andreas P. Christou[1]

[1] A.P.Christou & Accosiates
9th klm Thessalonikis – Thermis, P.O.Box 8107, GR 57001 Thessaloniki
e-mail: info@apchistou.com

Keywords: Precast building, Seismic design, prefabricated elements connections.

Abstract. *The object of this study is the development of a structural precast system for a supermarket chain in order to have the same quality of product construction all over Greece regardless of its application site and independently of the area seismicity. The dimensions of one typical storey building was approximately 50.0x25.0x0.50 (AxBxH m). The load bearing structure of the building consists of columns restrained in the foundation with special anchors or Koecher – Foundation. Between the columns were placed double-walls (precast Sandwich panels) with insulation and for the earthquake resistance some walls placed in certain positions along the external perimeter. These walls were designed by special connections with the foundations and columns in order to achieve restrain. The panels were connected on the top with beams by hinges (so called Dual Type), define as the combination of structural walls and frames. It is well known that precast concrete structures generally provide poor performance in earthquakes and the existing codes do not provide adequate guidelines for the designing of prefabricated structures so it is very important that the modeling of such structures must be very precise in order to be able to make the design of the connections. The structure was calculated with linear and finite surface elements (3d- modeling) by taking in mind every peculiarity of the building. Slab is acting as diaphragm. The seismic behavior was calculated according to the Dynamic Spectral Method (Norm: EC8). Seismic Behavior Factor q=1.5. Specially calculated and designed connections between the elements (columns- walls, column – beams, column/ wall – foundation, metal structure – concrete elements) is giving the ability to the system for uniform action.*

1 INTRODUCTION

The scope of this paper is the development of an earthquake-resistant [5] prefabriced structural system that may be implemented in all stores of a large food supermarket chain, maintaining the same structural quality regardless of the installation area and its seismic activity.

Due to the particular nature of the structural system, the creation of an accurate calculation model that takes into consideration the method of connecting the different structural elements is a crucial factor in the investigation of an optimum solution. The results of the analysis, in combination with a good knowledge of the features and properties of connecting materials (quality, resistance, etc.) may then make the basis for the proper implementation of the construction.

2 DESCRIPTION OF THE BUILDING AND BEARING STRUCTURE

The aforementioned stores have a typical floor plan measuring 50.00 X 25.00m and have a height of approx. 5.50m; they consist of two main areas: a) the retail area, 18 or 22m wide and b) the storage area with a width of approx. 6.50m. The final dimensions and the configuration of any offsets on the plan are determined based on the architectural requirements and the position of the loading ramp on the site. It is noted that the store entrance is marked with an L-shaped canopy (bottom left of the floor plan in Figure 1).

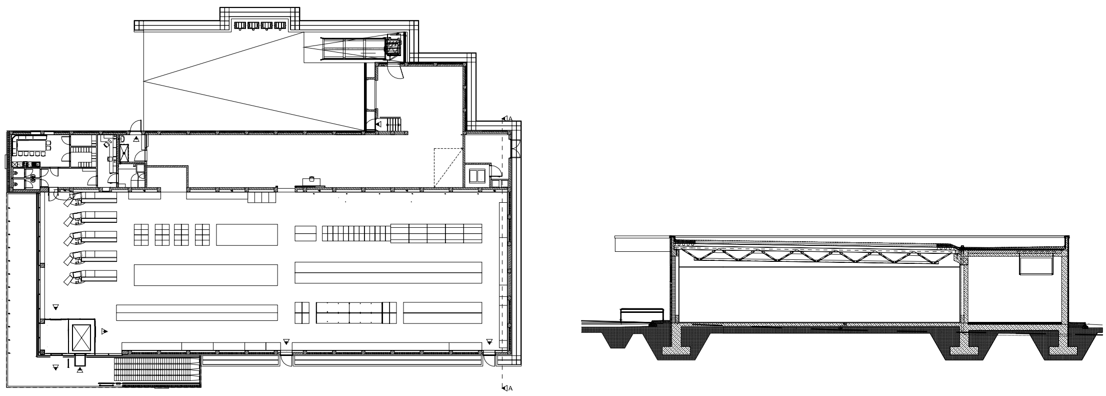

Figure 1: Floor plan (left) and section (right) of a typical store

The load bearing structure of the building consists of prefabricated reinforced concrete columns and beams. Between the columns were placed double-wall (precast Sandwich panels) with insulation and for the earthquake resistance some walls placed in certain positions along the external perimeter. The roof of the retail area is covered by means of large trusses made of structural steel with a span of 18 or 22 m, while the storage area is covered with prefabricated reinforced concrete one-way slabs. The foundation is made of cast strip footings equipped with specially configured sockets where the prefabricated columns are fixed (anchored) or, alternatively, with custom elements where the columns are bolted. The beams are connected to the columns by joints and designed to bear the vertical loads of the steel structure and participate in the transfer of the roof's seismic loads to the columns and walls.

3 SIMULATION MODEL

The simulation of the carrier is performed using a 3D model, where the system's structural elements are simulated as linear and surface finite elements [4] with their exact geometric features. A diaphragm action is simulated on roof level (invariable relative distances of the columns’ top points under horizontal and vertical torsion), which is ensured in the area of the steel roof by the use of a special trapezoid metal sheet specifically bonded to the trusses.

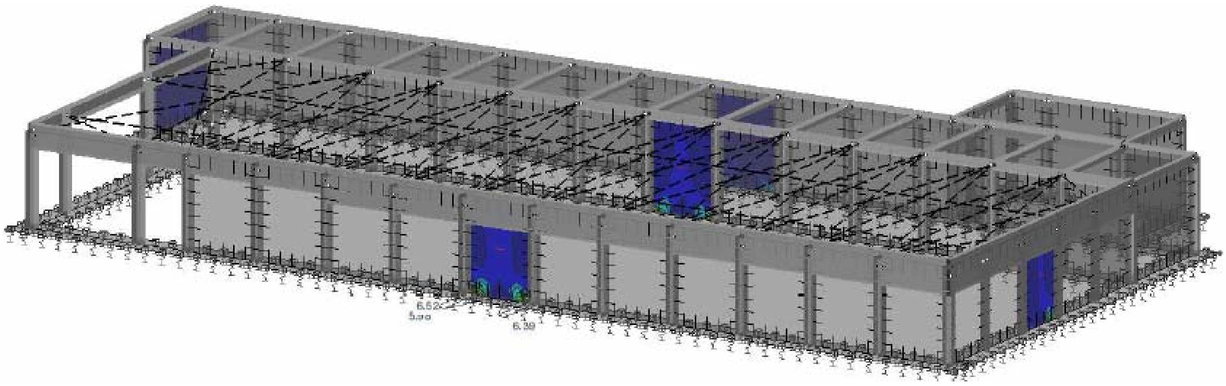

Figure 2: Simulation 3D model

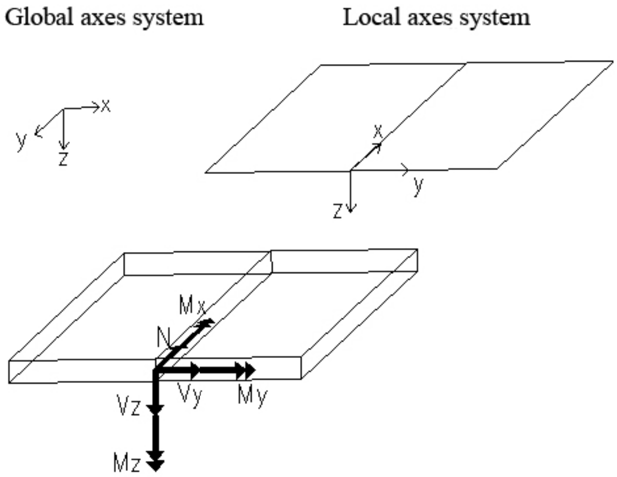

Figure 3: Axes and cross-section loads on the bonding surface of two structural elements

Particularly important are the boundary conditions which are obtained by computer-aided-calculation for the connections of different structural elements. The columns’ bases are considered restrained, while the beam-to-column connections are considered joints.

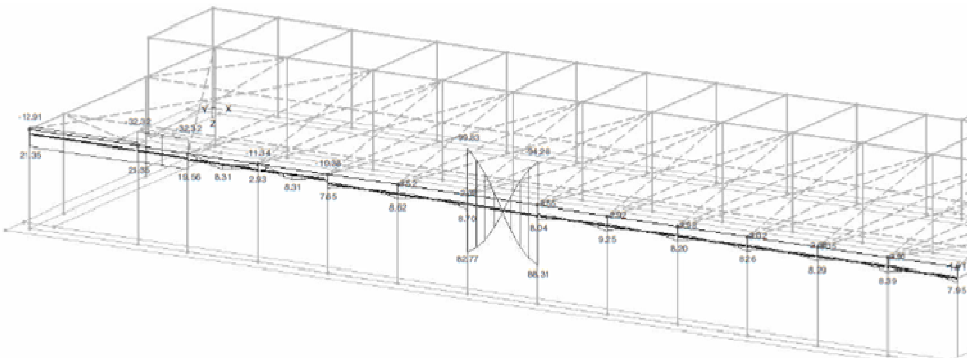

Figure 4: Axial forces of modular beams

The infilled walls are connected to the strip footings, at their bottom, and to the beams, at their top edge, by joints. The simulation of these connections assumes a bound displacement only along the connecting surface of the different structural elements (Vy = Vz = Mx = My = Mz = 0). Moreover, the connection of the wall with the columns is assumed as a joint blocked the displacement only in the direction transversal to the interface of the different elements (N = Vy = Mx = My = Mz = 0). The following diagrams show the envelope results for the cross-sectional loads, where we assume only the loads n-x, D along the connecting surface for the connection of a infilled wall with the foundation, and only the loads n-x transversal to the connecting surface for their connection with the columns.

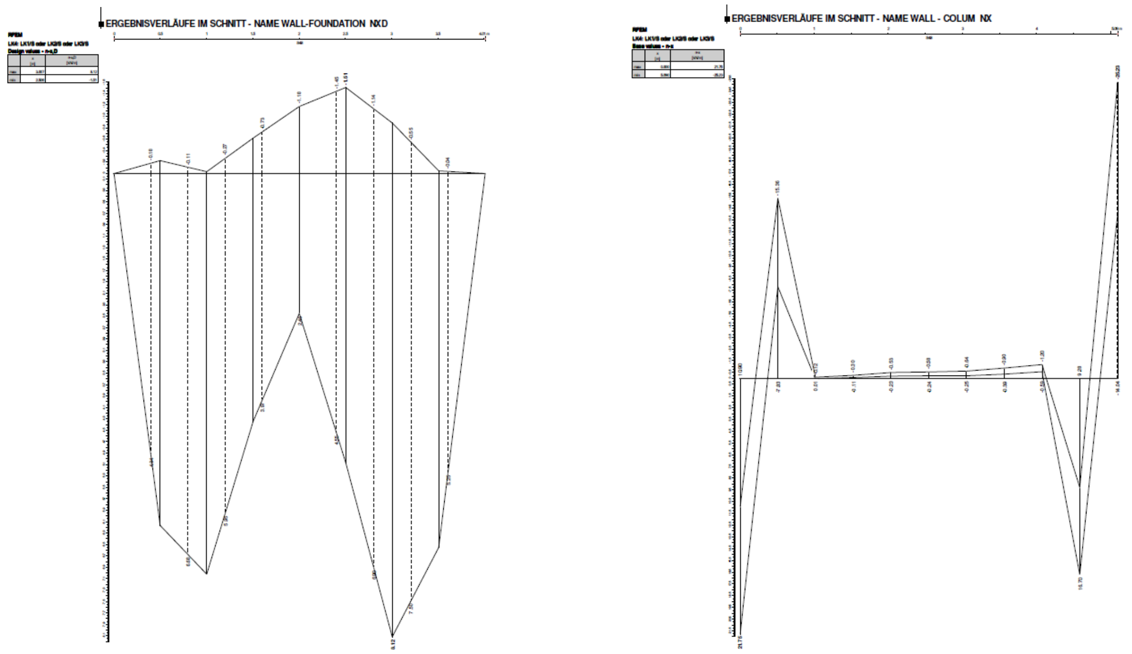

Figure 5: Design envelope for load on the infilled wall-foundation (left) and infilled wall-column (right) connecting surfaces

In relation to the earthquake-resistant (shear) walls (marked blue in Figure 2), the same apply for their connection to the roof beams as in the case of infilled walls, but at their connection to the strip footing, the joint receives only loads in three axes (Mx = My = Mz =0). The joint connections of the earthquake-resistant (shear) walls with the columns vary depending in different site locations, as these depend on the seismic risk zone. For instance, in zone I with a horizontal ground acceleration A=0.16g, the joint must only receive the force that is transversal to the structural elements' interface (N = Vy = Mx = My = Mz = 0), contrary to the other zones where the joint must additionally receive the force parallel to the connecting surface of the different structural elements (Vy = Mx = My = Mz = 0).

The following Figures 6 and 7 show the envelope results of the cross-sectional loads for the connection of the earthquake-resistant (shear) walls with the foundation and the columns, where n-y signifies the loads tending to separate structural elements (i.e. Vy in Figure 3) and n-x signifies the corresponding loads transversal to the connecting surface (i.e. Vz in Figure 3). Figure 8 below shows clearly loads n-y appearing only on the earthquake-resistant wall.

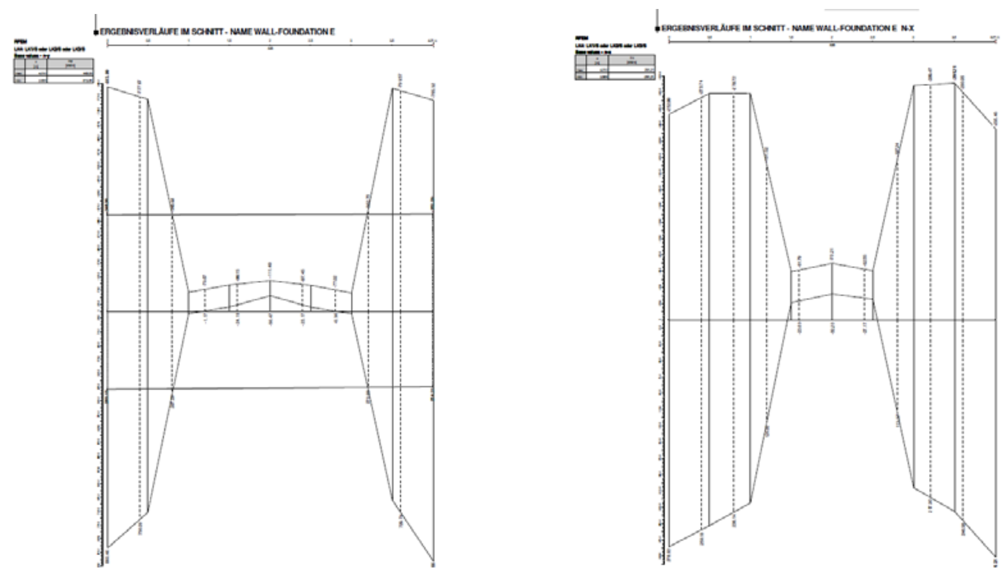

Figure 6: Design envelope for 'n-y' load perpendicular to (left), and 'n-x' load envelope transversal (right) to the connecting surface between earthquake-resistant (shear) wall - foundation

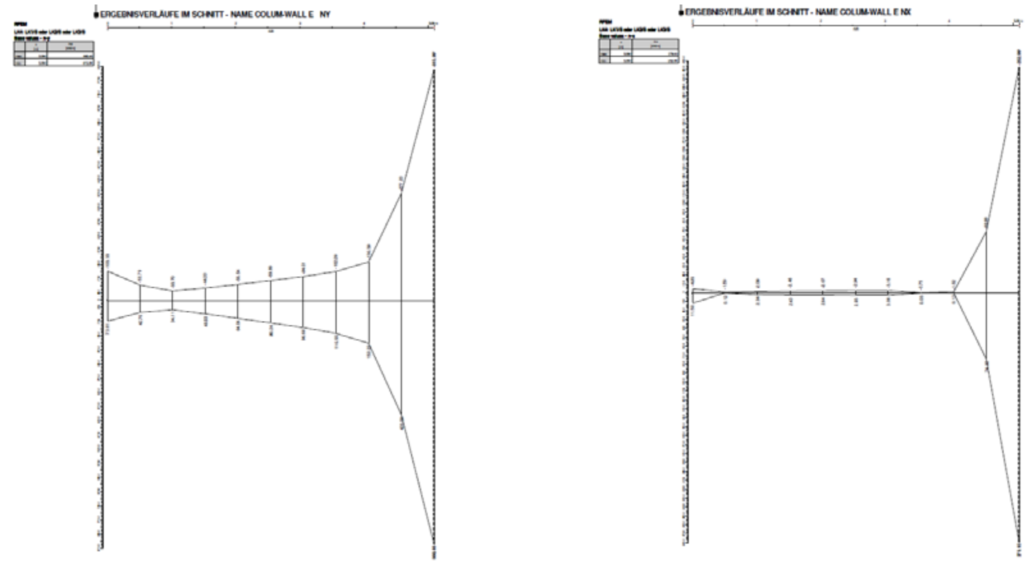

Figure 7: Design envelope for 'n-y' load vertically (left) and 'n-x' transversely (right) of the connecting surface between the (earthquake-resistant) shear wall –column

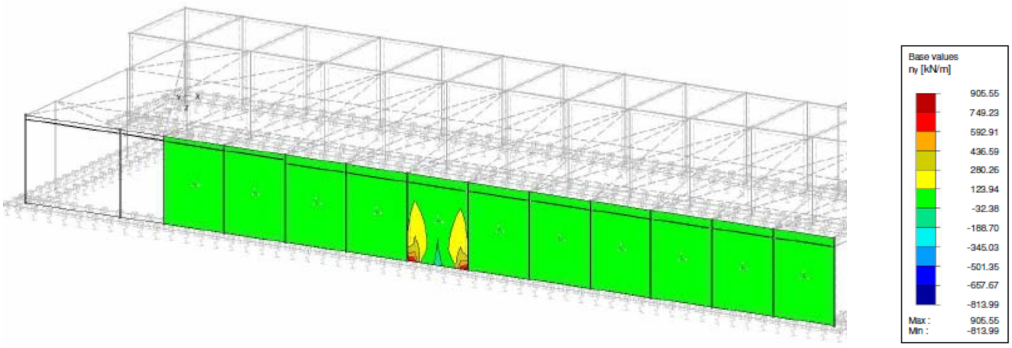

Figure 8: Design envelope for ‘n-y’ load at the connection between earthquake-resistant (shear) wall - foundation

In essence, all the aforementioned calculation results are evaluated before the realization of the connections with materials and reinforcements [2] that can withstand the loads at the connection, as indicated in Figure 9 for the connection between earthquake-resistant (shear) wall and strip footing (see also ‘n-y’ loads of Figures 6 and 8).

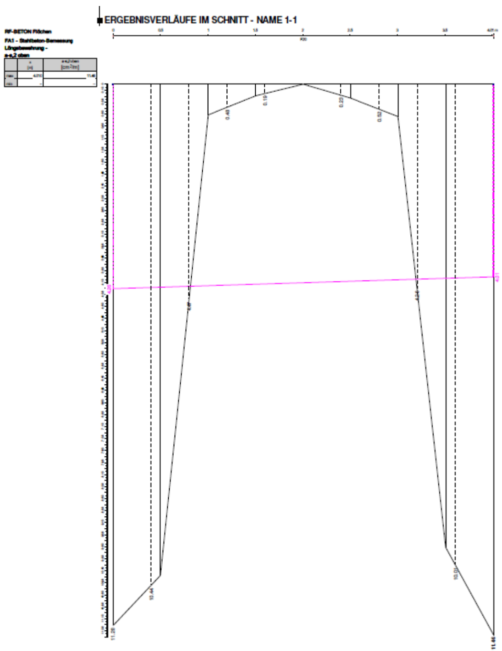

Figure 9: Required reinforcement at the connection between earthquake-resistant (shear) wall and foundation

The last diagram shows the load along the connecting surface between infilled walls and prefabricated beams.

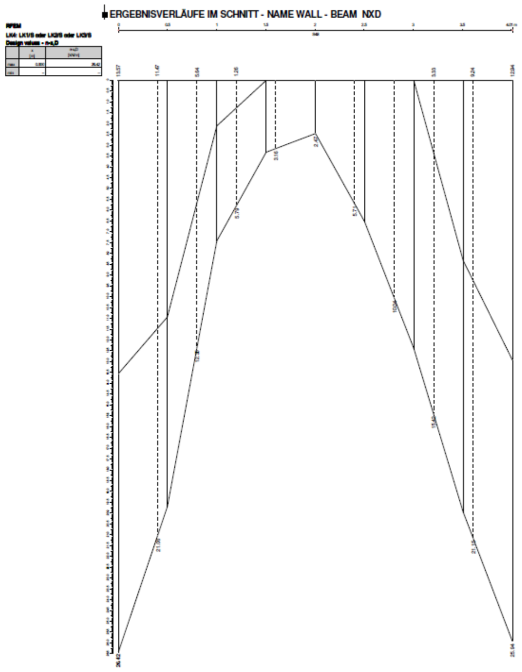

Figure 10: Design envelope for load at the connecting surface between infilled wall and beam

With regard to the loads stressing the structure, vertical dead and live loads are taken as static loads, and the dynamic spectral analysis is applied for seismic loads as per EC8 / National Annex [3]. The dynamic features are determined by modal analysis, and a design spectrum acting in three dimensions (two horizontal and one vertical) is introduced. In the spectrum, the horizontal ground acceleration is A=0.16g or 0.25g or 0.36g, depending on the location of the store; the behavior factor of the structure is taken as q=1.50. The calculation is performed for the modes in which 90% mass participation is achieved in every direction, which requires 23 modes in this particular model, a rather large number resulting from the modular connections of the infilled walls with the columns.

The calculation is performed for load combinations determined in accordance with Eurocodes EC1/EC3, taking into consideration EC8 / National Annex, while the loads cases [1] participating in the combinations are the follows: a) LC1: self weight of the structure, b) LC2: dead load of the slab, c) LC3: additional dead load of the slab (HVAC), d) LC4: dead load of the canopy, e) LC5: dead load of the trusses (point loads on columns), f) LC6: live load of slab, g) LC7: live load of canopy, h) LC8: live load of trusses, i) CA1: seismic load on X-axis, j) CA2: seismic load on Y-axis, and k) CA3: seismic load on Z-axis. The schematics of the three main modes are shown below, as they result from the calculation of the structural model.

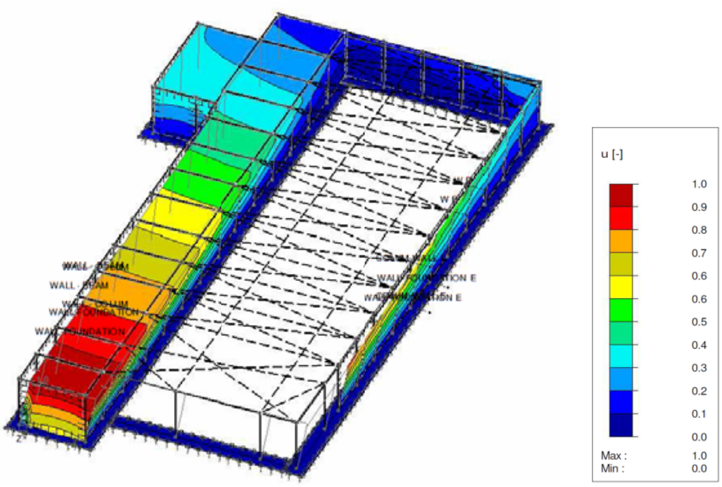

Figure 11: 1st mode (natural frequency 2.76Hz)

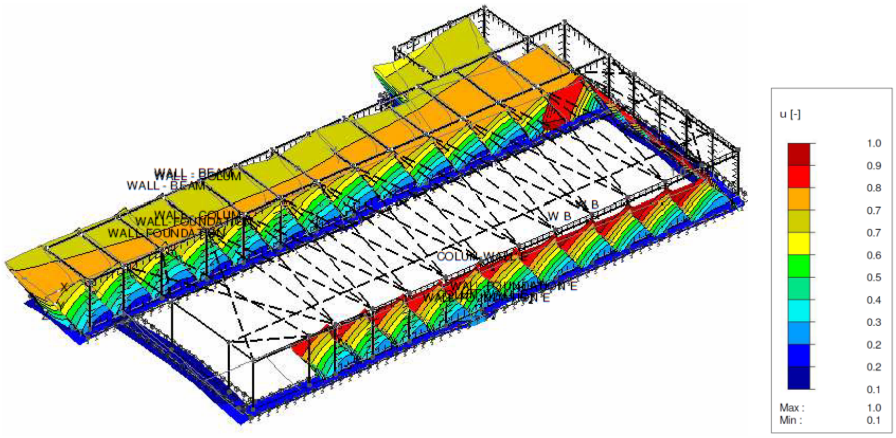

Figure 12: : 2nd mode (natural frequency 4.54Hz)

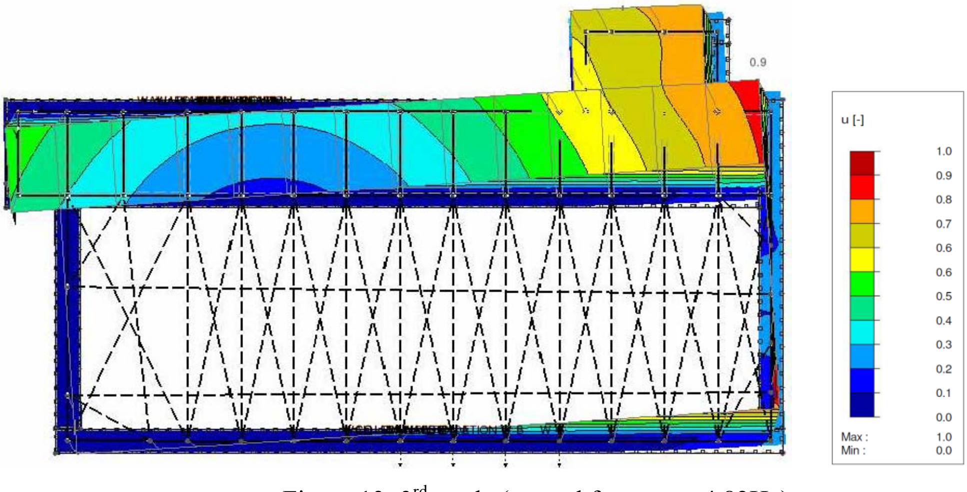

Figure 13: 3rd mode (natural frequency 4.82Hz)

The program RFEM has been used for analysis. The results also have been checked with the program Sap2000.

4 STRUCTURAL DETAILS

The proper implementation of connections [6] is particularly important in prefabrication systems, in order to properly block displacements, according to the calculation model described in detail in chapter 3.

The columns are restrained on the strip footings by use of preconfigured encasement pockets (koecher); wherever this solution is not viable, the columns are restrained using special anchor bolts that are standardized and certified for use to receive specific loads.

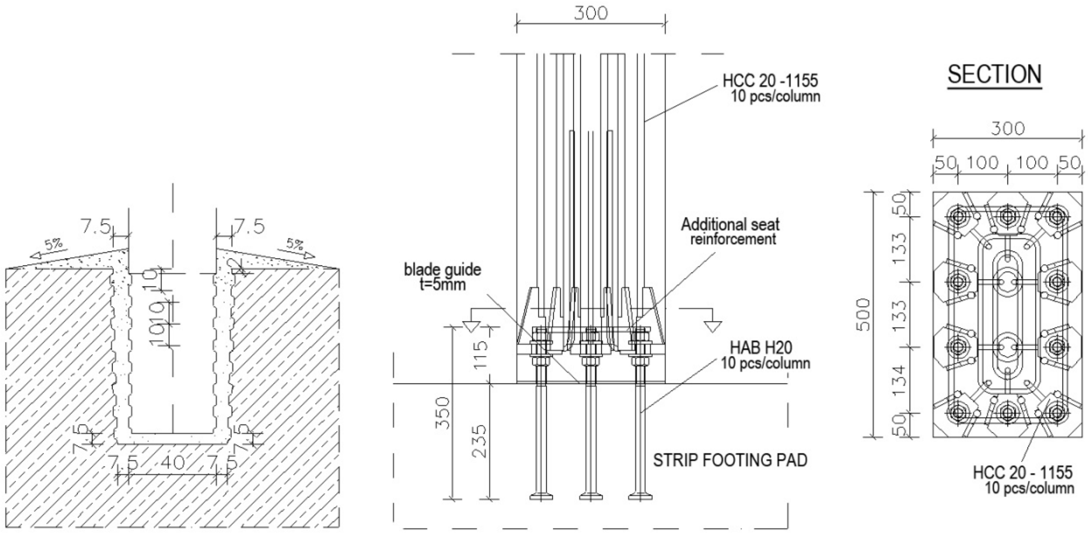

Figure 14: Fixed support of columns by means of pockets (left) and anchor bolts (right)

The sandwich-type walls provide full thermal insulation. They consist of three layers, the outer skin, 7 cm thick with an Ø8/20 steel mesh, the inner skin, 30 cm thick with an Ø12/20 rebar grid, and the 5 cm thick thermal insulation between the two skins. The inner skin is connected with the outer skin by means of special stainless pieces able to transfer their self weight, wind pressure loads and seismic loads to the inner skin.

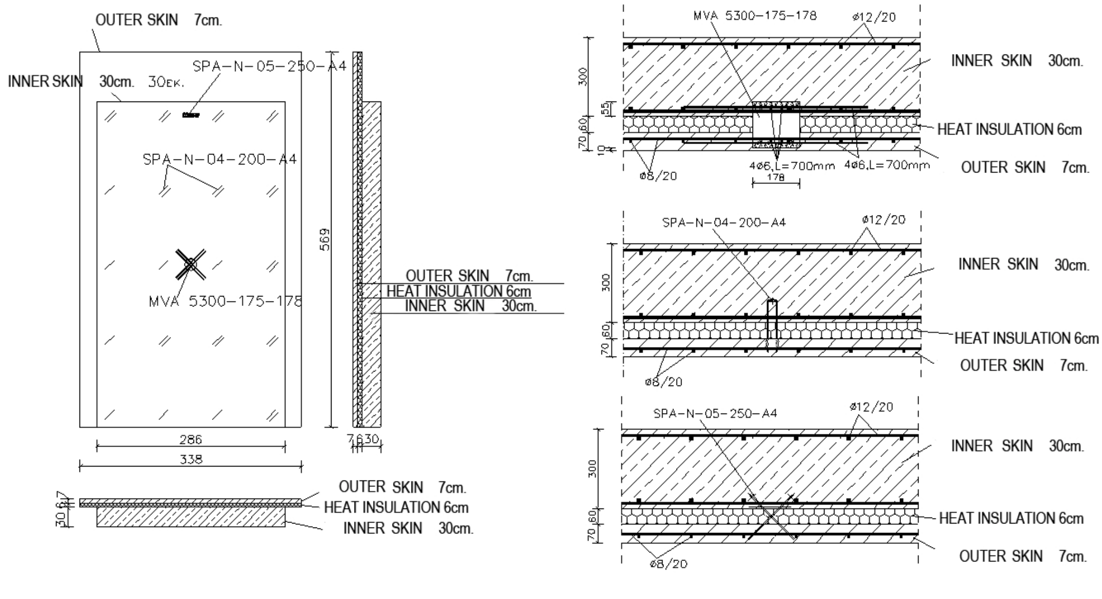

Figure 15: “Sandwich”-type wall: Elevation and typical sections

Depending on their load bearing role, the walls are distinguished as infilled walls and earthquake-resistant (shear) walls; their connections to the remaining structural elements is accordingly arranged. Infilled walls are connected with joints to the strip footings with the use of special reinforced dowel sleeves on the bottom of the walls, which fit in specially configured cavities in the strip footings in order to be able to receive loads point out during the analysis; on the other hand, they are connected with the columns by means of anchoring channels, bolts and L shape steel plates (for the bindings achieved with such connections, see chapter 3).

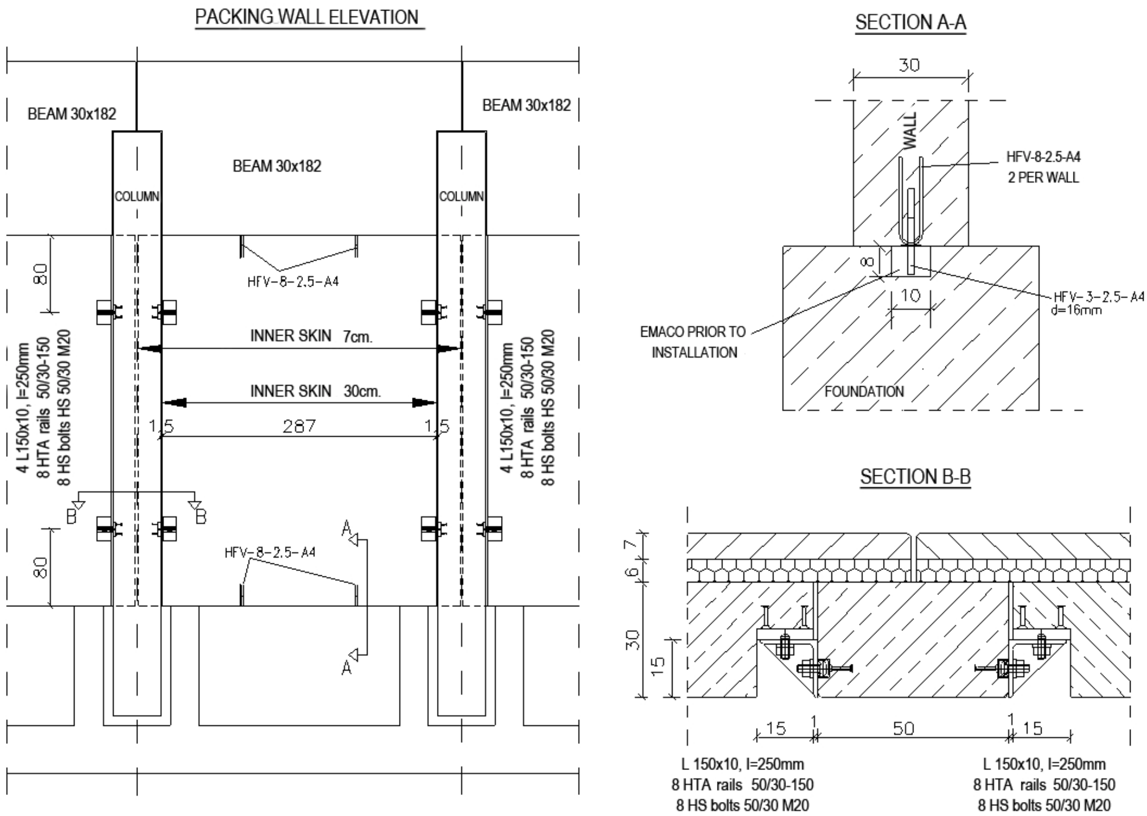

Figure 16: “Sandwich”-type wall: Connections of packing wall with strip footing and column

The connection of earthquake resistant (shear) walls to the foundation is provided by special anchor bolts at 2 points of the walls’ bottom, which are placed in the strip footing before the concrete is poured. This type of connection is dimensioned for compression and tensile forces resulting from seismic combinations (Figure 6). The connection of earthquake (shear) walls with columns for seismic risk zone I (A=0.16g), as mentioned in chapter 3, matches the connection implemented on infilled walls. On the contrary, for the other connections, the columns are equipped with special casings with rebend starters, toothing in transverse direction for optimal force transmission and for exposure to longitudinal shear forces parallel to the joint (Figure 19) in order to achieve connection and cooperation between walls and columns in receiving the loads.

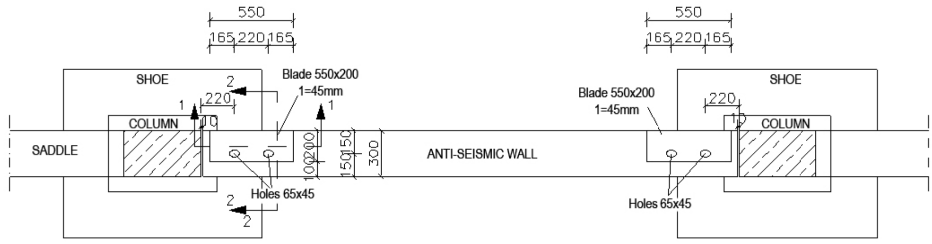

Figure 17: Sandwich”-type wall: Connection between earthquake-resistant (shear) wall and strip footing (floor plan)

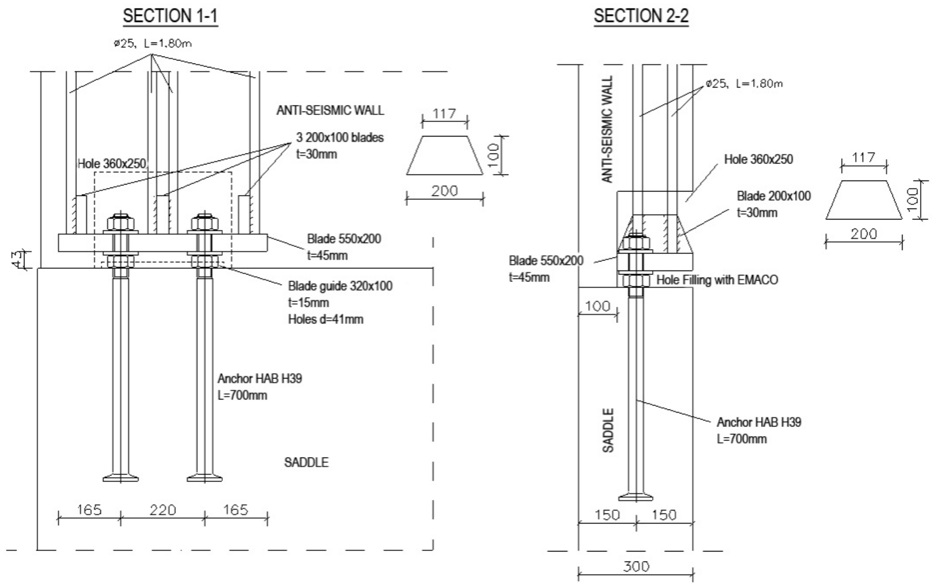

Figure 18: “Sandwich”-type wall: Connection between earthquake –resistant (shear) wall and strip footing (sections, see Figure 17)

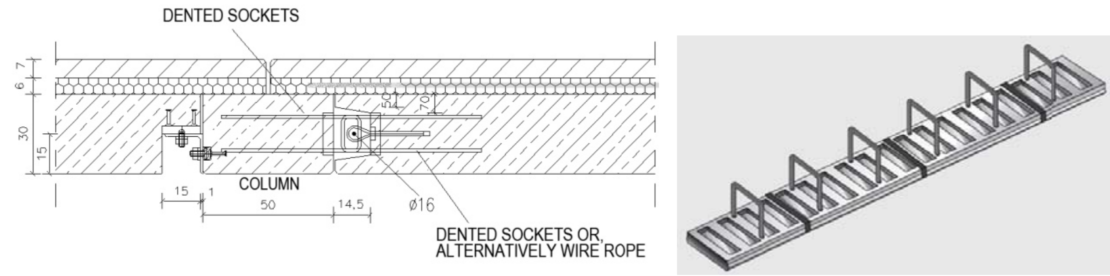

Figure 19: Connection between shear wall and columns using special casing rebend starters (right)

Upon completion of the connections of vertical structural elements, they are connected with the horizontal elements of the structure, i.e. with beams and slabs. At positions of beam-column joints, pins are implemented on the columns to fit in holes inside the beams in order to receive the cross-sectional loads of the joint. Moreover, the bottom side of the beams is connected to the columns by use of special incorporated cast-in channels.

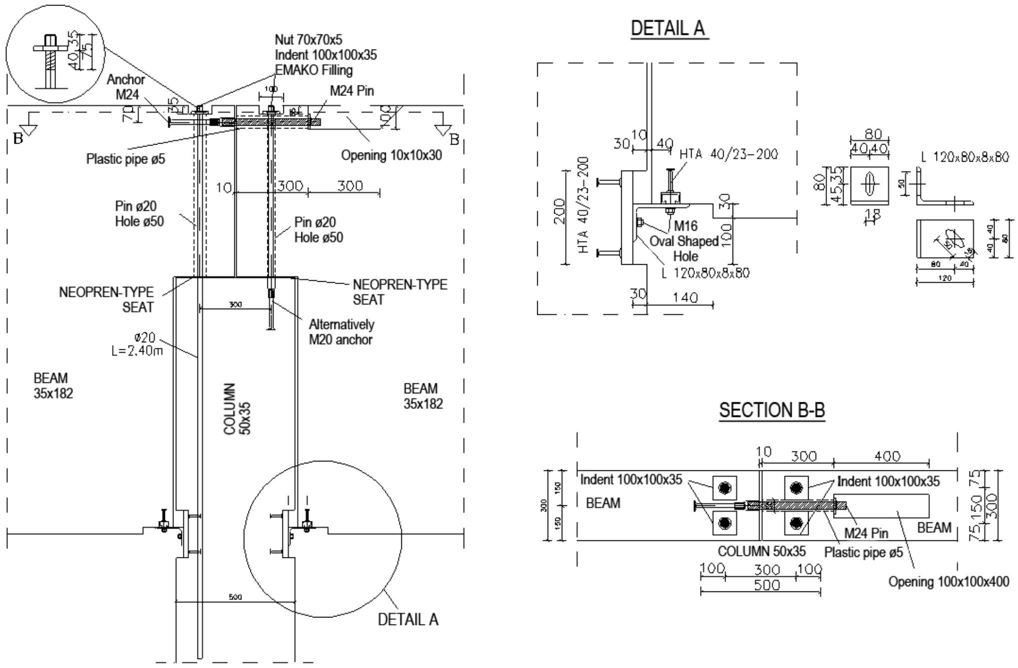

Figure 20: Beam-column joint connection

The storage area roof is laid with 7 cm thick one-way preslabs; during the assembly, these slabs rest on a 4 cm wide support zone on the wall of each side, while their starter bars are anchored through the entire width of the beam. Apart from the rebar mesh, latticed girders as well as connector bars are factory incorporated wherever it is deemed necessary (in order to create hidden beams within the storage roof slab, additional reinforcement areas around slab holes etc.). A top rebar mesh is added on-site and an 18 cm thick layer of concrete is poured to achieve a final slab thickness of 25 cm. The connection between preslab-wall (with hidden beam)-column in the storage area is considered monolithic, due to the on-site concrete pouring procedure. The beam-column connection near the aforementioned slab is implemented using special stud connectors placed at the system points where concrete is poured in order to achieve monolithic connection.

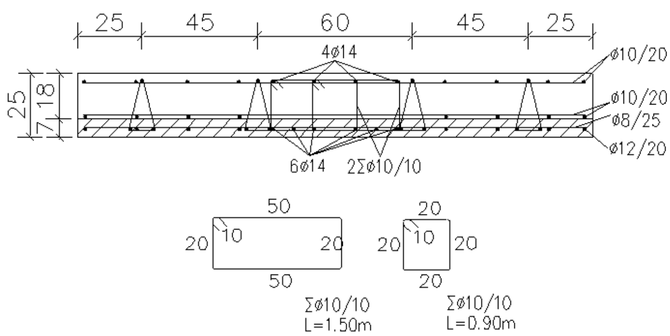

Figure 21: Formation of preslab near the hidden beam

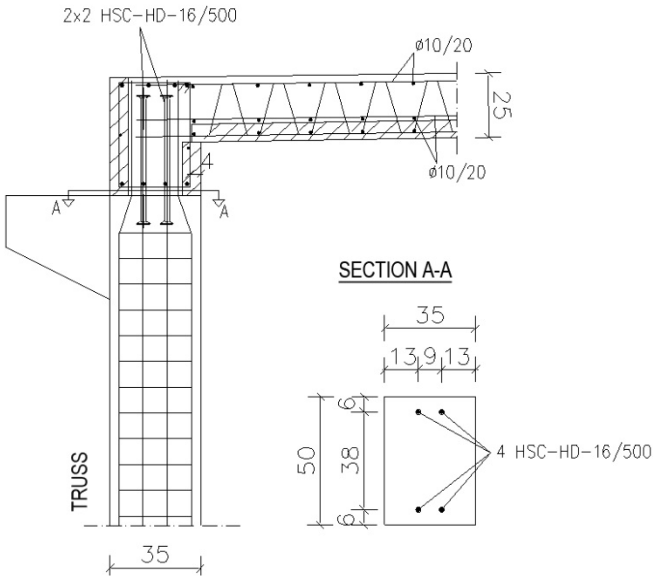

Figure 22: Beam-column monolithic connection near the slab

5 CONCLUSIONS

- Except for linear, surface elements may also be implemented in prefabrication structural systems.
- Modeling the structure model and particularly the connections between structural elements, as well as matching the results to the construction are the determining factors for a complete construction design of prefabrication projects.
- Due to the particularity of the construction, numerous different structural elements and variety of connection types and materials, the creation of a reliable calculation model is a quite strenuous task.
- The prefabrication method may be the ideal solution for mass construction of standard buildings in any location, irrespective of the seismic activity of the area.
- Prefabricated walls can be applicable in strengthening existing buildings.