Superior Council of Public Works

Central Technical Service

GUIDELINES FOR THE DESIGN AND CALCULATION OF STRESSED-SKIN PANELS BUILDING SYSTEMS BASED ON HEAT-INSULATED BLOCKS AND CAST-IN-PLACE LIGHTLY REINFORCED CONCRETE

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Table of Contents

1. OBJECT

These Guidelines have the purpose of providing to designers, technicians in the field and to competent control bodies, according to Chapter 12 of the Technical Standards, the theoretic and test references as well as design and construction specifications, for the design and calculation of buildings achieved by means of stressed-skin panels building systems based on the use of heat-insulated blocks and cast-in-place lightly reinforced concrete.

These systems have to be characterized by a length extended to abt. the entire perimeter of the structural plan besides being equipped with suitable measures meant to ensure the structural continuity, so as to generate an effective box action.

The project criteria contained in these guidelines cannot be applied to building systems based on reinforced concrete sandwich panels insulation with material interposed between the layers of concrete.

For every building system, including particular panel types, it has to be studied and proposed a safety verification procedure under several limit conditions, based on established criteria and specific tests results. In the first case, it has to be considered as a reference, for instance, CNR 10025/98, in the matter of cast-in-place panels, after having applied the necessary adjustments for the compliance with NTC 08. Additionally, design details specific to the system have to be presented along with engineering methods, based on the indications given in the present Guidelines.

2. EXPERIMENTAL CHARACTERIZATION

The building system must be characterized from a structural viewpoint through the suitable number of tests, according to the Technical Standards in force, so as to demonstrate an effective behaviour of bearing elements subjected to cyclic vertical and horizontal actions.

The main experimental tests for the building system are indicated in Table 1 given hereafter.

Tests Type	Features of prototypes		Purpose of the tests	Application of loads	Test Protocol	Number of prototypes
1	Panel section (abt. 1,0 m x 1,0 m) (Figure 10-1)		Evaluation of the elastic modulus	Centred axial compression	Pseudo-static, monotone	2
				Diagonal compression	Pseudo-static, monotone	2
2	Panels with no aperture h = storey height, b≥1,0 m (Figure 10-2)		Evaluation of the collapse load for local and global instability of the panel	Centred axial compression	Pseudo-static, monotone	2
3	Panels in full scale h = storey height b≥3.0 m (Figure 10-3)	With no aperture b:h =1:1 and b:h = 4:3	Evaluation of: • resistance • displacement capacity • dissipation	Constant axial compression and horizontal load in the panel plane	Pseudo- static, cyclic (horizontal)	2 per each shape ratio
		With door b:h =1:1 or b:h=4:3				2
		With window b:h =1:1 or b:h=4:3				2
4	Connections sections (at least one meter of linear connection length) (Figure 10-4)	L-shaped	Assessment of constrains effectiveness	Constant axial compression and moment applied to the connection	Pseudo- static, cyclic (horizontal)	2
		T-shape				2

5	Option Additional panels in full scale h = storey height, b>3.0 m b:h =1:1 o b:h=4:3 (Figure 10-5)	Assessment of out of the panel plane resistance. Interaction of in-plane and out-of-plane collapse	Constant axial compression and loads combination in-plane and out-of-plane	Pseudo- static, cyclic (horizontal)	2 per each shape ratio
6	Option Building or building section on large or full scale	Assembly and project hypotheses verification	Building or building section with 2 or more floors	Pseudo - static Pseudo- dynamic Cyclic or Dynamic (vibrating table)	1 or 2

Table 1: Experimental program type for the study of a building system (h = storey height type, b=base of test panel)

The experimental tests have to be carried out according to the following methods:

Tests type 1: carried out on panels of suitable size (abt.1,0 m x 1,0 m) under pseudo-static regime by applying normal and diagonal monotone compression load, see **Figure 10-1**. The tests are meant to determine the relationship between the secant stiffness assessed at the maximum load and secant stiffness at 30% of the maximum load.

Tests type 2: carried out on panel sections (the height of the sections is to be considered equal to the height of the storey type while the base is b> 1.0 m) under pseudo-static regime by applying monotonous axial load, see Figure 10-2. The tests aim at determining panels' behaviour under local and global instability.

Tests type 3: carried out on full scale panels under pseudo-static regime by applying a monotone axial load and horizontal actions in cyclic plan. The tests have to be carried out on panels with and without aperture, subjected to at least two different axial loads having the minimum and maximum value to be found in real cases. The panels must be built with a shape ratio b:h=1:1 by assuming the height as being equal to the storey height type; the panels with no aperture must also be built with shape ratio 4:3, see Figure 10-3.

The tests are carried out by applying first a monotone axial load, followed by in-plane horizontal displacement of collapse, increased in steps; perform at least three cycles for each increment. The increments will allow assessing the elastic stiffness of the panel and the transitions due to cracks caused by the bending and cutting, to yielding of the reinforcement bars and to other degradation phenomena (crushing of concrete, local instability of bars, fracture of vertical bars, fracture of horizontal bars, panel-foundation and panel-spandrel beam sliding, etc.). The cycles of movement must be applied symmetrically (pull and push) with respect to the starting position.

The vertical load must be kept constant during the entire test; the constraint at the top of the panel can allow or prevent rotation.

Tests type 4: carried out on sections of the panel-panel, panel-floor and panel-foundation connections by applying a monotone axial load and a cyclic action up to the collapse on the joint. The geometries of the specimens and the methods of loads application are indicated in Table 1.

The test must be conducted under movement control until bringing the connection to collapse. The displacement has to be increased in steps by performing at least three cycles for each increment. The increments will allow assessing the elastic stiffness of the connection, the transitions due to cracks caused by the bending and cutting, to yielding of the reinforcement bars and other degradation phenomena (crushing of concrete, local instability of bars, fracture of longitudinal cross-bars, sliding, etc.). The cycles must be applied symmetrically (pull and push) with respect to the starting position.

The vertical load must be kept constant during the whole duration of the test.

Tests type 5: (option) carried out on full scale panels under pseudo-static regime by applying a monotone axial load and in-plan and out - of - plane cyclic horizontal actions. The tests have to be carried out on panels with no apertures, subjected to at least two different axial loads having the minimum and maximum value to be found in real cases. The panels must be built with a shape ratio b:h=1:1 by assuming the test panel height as being equal to storey height type, see Figure 10-5.

The tests are carried out by applying first a monotone axial load, followed by in-plane horizontal displacement of collapse, increased in steps; perform at least three cycles for each increment. At the end of this phase it is applied an out - of - plane cyclic displacement increased in steps. The increments will allow assessing the collapse load. The cycles of movement must be applied symmetrically (pull and push) with respect to the starting position.

The vertical load must be kept constant during the whole duration of the test.

Tests type 6 (option): pseudo-static, pseudo-dynamic or dynamic experimental tests within which there are applied cyclic vertical and horizontal actions on a building or a section of it in large or full scale. The tests have are meant to verify the behaviour of the whole and the project hypothesis.

All experimental tests will be carried out until bringing to collapse conditions the element or elements assembly. The reaching of collapse is identified when registered a load decrease equal to 20% of the maximum value recorded during test.

Loads or displacements applied during pseudo-static experimental tests have to be applied quasistatically or using a rate of increase such as not to induce high dynamic effects on the test panel. For this purpose there can be considered as being acceptable rate of increase lower than 2 mm/sec for displacement control test or (Nr/ 500) /sec (N_r equal the estimated breaking load) in the case of load control.

Further experimental tests such as type 5 ones, test on large scale structures (type 6), on high complexity subsets or building sections carried out under cyclic pseudo-static or pseudo-dynamic regime or on vibrating table can be used to obtain more details as regards the behaviour of the building system besides being used for fine tuning in calculation and design.

The experimental tests described in the previous paragraphs have to be performed on panels suitable to the materials and the construction methods prescribed in the design, building and installation manual supplied by the Manufacturer; moreover there must also be certified by a Laboratory referred to in art.59 of Presidential Decree N 380/2001 provided with the suitable competencies, organization and equipment appropriate to the execution of the tests described. On the basis of the results obtained out of the experimental tests, and the consequent numeric processing, the Manufacturer shall identify the mechanical quantities required to define the main strength and deformability features per each panel, the dissipation capacity of the building system, as well as checking the structure coefficient hypothesis provided.

The Manufacturer of the building system under examination has to prepare, with the support of a technician, a report interpretation of the experimental data obtained.

The Superintendent and the Inspector, within their competence level, will acquire copies of test certificates for the building system employed; they will also verify the compliance of the material used upon indications of the designer. This certification will represent integral part of the executive project filed at the territorial office responsible.

If in the numerical evaluation referred to in Chapter 6, there are used models which refer to continuous equivalent panel systems, and the equivalence has not been proven by the numbers, it will be demonstrated in an experimental way, by repeating a suitable number of the test indicated herein also on continuous equivalent panels.

3. Mechanical features of the materials used and approval of the components

The materials and the components used to manufacture the panels are:

- heat-insulated blocks as envisaged for by building system;
- cast-in-place concrete;
- reinforcing steel;

As regards the mechanical properties of the concrete and of the steel, the qualification methods and approval tests at the building site for these components, apply the indications given in the relevant paragraphs of the Technical Standards in force.

The heat-insulated blocks have to match the requirements meant to ensure a suitable quality level in assembly phase, particularly as regards the absence of unacceptable out of plumb of panels, the absence of void spaces in the concrete and the proper overlapping of the vertical and horizontal steel reinforcements.

In particular, the elements have to be provided with EC marking in compliance with the harmonized European Standards EN 15435:2008[1] or EN 15498:2008[2], or in accordance with a European Technical Assessment (ETA) issued on the basis of the Guidelines EOTA ETAG 009[3]. In addition, the manufacturer must provide an assembly manual that illustrates in detail the assembly steps of the blocks, the laying of the steel reinforcement and the casting of concrete along with the procedures and controls necessary for the verification of final assembly quality. For further details on the manual, see chapter 8.

[1] EN 15435:2008: Pre-cast concrete products - Heat-insulated blocks made from standard or lightly reinforced concrete - Properties and performance of products

[2] EN 15498:2008: Pre-cast concrete products - Heat-insulated blocks with wood chips - Properties and performance of the products

[3] ETAG 009: *Guideline for European Technical Approval of Non load-bearing permanent shuttering kits/systems based on hollow blocks or panels of insulating materials and sometimes concrete.* Edition June 2002.

4. Implementation rules

In order to ensure an adequate construction quality level of the panel, the maximum diameter of the concrete inert must be limited to 16 mm. The concrete must also have suitable workability in order to compensate any lack of vibration; to this purpose, there will not be accepted classes lower than S4.

As regards steel reinforcements, the overlapping length value prescribed by the Technical Standards in force must be increased by at least 50 %.

The details regarding the implementation rules will be provided within the technical documentation of the building system particularly in relation to the overlapping of bars and their deviations; see also the indications given at chapter 8.

5. Safety verification criteria

The approach to the safety inspections of the structures concerned is provided by the Technical Standards in force as regards structures made from reinforced concrete; explicitly, consider the procedures which ensure safety against collapse, in duty performance and durability in rated life.

Apply fully the limit conditions calculation rules and criteria with particular reference to:

- calculations actions
- combinations of actions
- partial coefficients of safety

6. Structural analysis and calculation models

The calculation of design stresses must be performed with a suitable model so as to properly represent the distribution of building structural rigidities and masses according to the box action of the whole and the results of experimental tests carried out for the design system to be used. There can be used, for instance, two-dimensional finite elements models or, as an alternative, one-dimensional model with equivalent frame.

All analysis methods provided in the Technical Standards in force can be employed.

The uses of analytical techniques such as push-over or non-linear dynamics are accepted only in the presence of an appropriate and comprehensive preliminary study of constitutive models.

In the modelling of the structures concerned, besides aspects related to conventional structures there have to be assessed the effects of:

- void spaces or interposition of material having a lower resistance (such as the cross walls of heat-insulated blocks);

- type and constraint degree between the elements in the wall - wall (T-shaped, L-shapes and crossed), wall-ceiling and wall-foundation connections.

The use of templates that refer to continuous equivalent panels systems must be based on experimental validation of the equivalence, as indicated in chapter 2, unless demonstrated in numbers.

7. Recommendations for the structural design in seismic regions

The structural design must ensure effective box action. Since the collapse mechanisms of the structures concerned are primarily related to the breaking mechanisms due to shearing or shearing-bending, these structures must be considered as pertaining to a low ductility class.

7.1 Structure Factor

For the building systems concerned, the coefficient of basic structure q_0 is assumed no higher than 2.0.

The end structure coefficient, according to the Technical Standards in force, will be expressed as follows:

$q = q_0 K_s K_r$

$K = \alpha_u / \alpha_1$ is the over-strength design factor which, in the absence of specific analytical determinations, can be assumed equal to 1.2 for plan regular structures and 1.1 for the irregular ones.

Kr represents the reduction factor related to elevation irregularities conditions as determined by the Technical Standards in force, and is assumed to be equal to 1 in the case of regular height structures and 0.8 in case of irregular structures.

Higher coefficient values of basic structure q_0 are allowed only if sustained by experimental results obtained by experimental studies and supported by suitable numerical analysis. However, the basic structure coefficient value q_0 cannot be higher than 3.

7.2 Thickness of walls for the calculation of project-related stresses

To nominal thickness of cast-in-place concrete apply the same limitations provided by the Technical Standards in force as per reinforced concrete.

The equivalent thickness of the panel can be calculated, first by spreading throughout the length of base b of the panel the cast-in-place areas of ACI concrete, i.e. with relation $t = (A_{c,eff} / b)$ being $A_{c,eff} = \sum A_{ci}$ equal to the total area of cast-in-place concrete in the cross-section.

The Manufacturer shall however indicate in its design, building and installation manual the possible modelling for the verification of serviceability limit state and of end limit state through the results obtained in the necessary experimental tests, which will provide the exact measurement of stress-strain behaviour of the panel in a specific building system (the lowering of fatigue cracking, for instance).

7.3 Verification of walls Bending and Buckling

BENDING AND BUCKLING

For the verification of walls there shall be use the methods provided in the Technical Standards in force for walls having low ductility class.

For these elements, the normal compression force does not exceed 40% of the limit load for simple compression f_{cd} $A_{c,eff}$, being $A_{c,eff} = \sum A_{ci}$ (the sum of cast-in-place concrete areas in cross section). This limitation (40 %) has to be lowered to 25 % for reinforcements arranged on a single layer in the section thickness.

SHEAR

The verification of shear strength will be carried out in accordance with the Technical Standards in force on the basis of various breaking mode:

- ✓ by shear-compression;
- ✓ by shear-tensile stress;
- ✓ by shear-sliding.

In the calculation of the shear strength refer to the equivalent thickness as defined at point 7.2.

However, the local resistance of ribs has to be verified using the formulas given within the Technical Standards in force.

INSTABILITY

In order to prevent instability phenomena of out-of-plane walls, firstly follow with the limits given below:

$\lambda \leq \lambda_{lim}$

being

$\lambda_{lim} = 15{,}4 \frac{C}{\sqrt{\nu}}$

where

- $v = N_{ed} / (A_{c,eff,}\ f_{cd})$ represents the axial dimensionless load and N_{ed} represents the axial load achieved by combining a more fatiguing and comprehensive seismic action;
- $C = l.\ 7 - r_m$ depends on the moments distribution ($0.7 = C < 2.7$).
- $r_m = M_{01}/M_{02}$ is the relationship between first order bending moments at the wall end

The slenderness value is given by the ratio between the free inflection length and the inertia given by the radius of gyration of the actual panel section $i_{eff} = (J_{eff}/A_{c,eff})^{0.5}$, where J_{eff} is the minimum inertia moment of cats-in-place concrete section. Therefore

$$\lambda_{lim} = l_0/i_{eff}$$

within which l_0 equals 0.7 *h* for two-layers reinforcement and *h* in case of single layer reinforcement where h represents the storey height.

7.4 Verification of wall connection elements

For this verification, the calculation models have to reflect the mechanical behaviour postulated for the connection element. However, only the manufacturer instructions, contained in its manual, can give the exact measure of the verification through the results obtained after the necessary experimental tests.

If there are envisaged connection elements that transmit shearing forces, the verification will be carried according to the Technical Standards in force for the connection beams of wall systems. In case the building system does not allow X-shaped reinforcement, carry out a local shear check of elements ribs.

In the case the elements cannot fulfil the coupling function, they will only have the function of connecting rods between walls. This function can also be undertaken by a suitably sized spandrel beam.

7.5 Verification at serviceability limit status

The storey height displacements obtained by means of structural analysis in the presence of designed seismic action in relation to SLD have to satisfy the following limitation:

$d_r < 0,002\ h$

where:

d_r, represents the storey height displacement, i.e. the difference between the displacement to top and bottom slab and *h* represents the plane height.

7.6 Durability

In order to ensure a suitable building durability all panel reinforcement armatures of panels should in any case have a layer of cast-in-place concrete according to the Technical Standards in force. In the installation and operating instructions manual, the manufacturers have to indicate the procedures meant to ensure compliance to these limits and the procedures for the verification of finished panels.

7.7 Design details

In order to ensure the assembly box action, the designer has to specify those details which ensure an effective connection between elements.

For every detail there have to be defined position, bending and anchor length of the reinforcement bars.

7.8 Reinforcements limitations

The diameter of the reinforcements, both horizontal and vertical, must not exceed 1/10 of wall thickness; they can be arranged on both sides of the wall or on the centre of a single layer, on the thickness of the cast-in-place concrete. However, the distance between bars (pitch) must not exceed 30 cm in both directions.

To ensure a correct behaviour as regards serviceability and end limit as well as local and global instability there have to be followed the reinforcement limits given below:

$\rho_v \geq 0.20\%$

$\rho_0 \geq 0.20\%$

$\phi_v, \phi_0 \geq 8$ mm

where

- ρ_v represents the geometric percentage of vertical reinforcement obtained by dividing the area of the vertical reinforcement bars by the horizontal cross-section area of cast in place concrete;
- $\rho 0$ represents the geometric percentage of horizontal reinforcement obtained by dividing the area of the horizontal reinforcement bars by the vertical cross-section area of cast in place concrete;
- φ_v, $\varphi 0$ represent the horizontal and vertical bars diameters.

For the beams, which are determined above and below possible apertures, the reinforcements shall comply with walls- related limitations, where from the calculations it is found that these elements have not coupling function. However, these beams must be provided with minimum reinforcement, suitably anchored, not lower than 2ϕ 12 at the lower edge and 2ϕ 12 to the upper section of the connecting element.

Conversely, if the beams have a walls connecting structural function, as described in the paragraph 7.4, follow the limitations provided within the Technical Standards in force as regards connecting beams.

8. Technical documentation

The Manufacturer is in charge with writing and providing the following documentation:

- Technical sheet;
- Design details;
- Testing certification;
- Interpretative Reporting;

- Calculation examples;
- Design, construction and assembly manual.

8.1 Technical sheet

The technical sheet must contain at least:

1. physic and chemical features of the specific components (e.g. the heat-insulated blocks) of the building system;
2. mechanical features of system specific components;
3. mechanical features required for structure modelling and structural elements verification.

8.2 Design details

The Design details shall be described within suitable illustrations.

These illustrations have to contain at least information related to the following aspects:

- position of the wall reinforcements (horizontal and vertical);
- wall - foundation connection;
- wall - floor spandrel beam connection;
- cornered walls connections (L-shaped connection);
- orthogonal walls connections (L-shaped and cross shaped connection);
- lintels;
- design details near apertures;
- coupling elements between walls.

8.3 Certifications

The certifications must be related to the experimental tests envisaged in chapter 2 and to the qualification of components.

8.4 Calculation examples

The manufacturer shall provide comprehensive calculation examples, representative of the structural type as regards modelling and verification.

8.5 Design, construction and assembly manual

The installation and operating instructions manual should include at least:

1) description of the system and its components;
2) implementation method of the building system;
   a) building verification methods (verticality and horizontality, flatness, etc.)
   b) reinforcements verification methods (proper overlapping, steel rods protection, etc.)
   c) carrying out of concrete casting, including minimum resistance and consistency class;

9. Quality control of the final product

As regards construction materials, in addition to approval tests provided in the Technical Standards in force, there will be carried out, under the responsibility of the Superintendent, a protocol for the verification at the building site, meant to determine the final quality of the construction.

Particularly, perform the following checks:

- verification of cast-in-place concrete compactness by removing of the of the structural wall (heat-insulated blocks) on a 0.1 square meters area for every 50 square meters of the total wall surface with possible addition of drill cores;
- overlapping of bars: they have to be checked by means of suitable techniques (local demolition, coring, cover meter and georadar) at the connections with the foundations or at new on old concrete bonding;
- alignment of vertical joints: the control has the purpose of verifying the geometric regularity of forms and therefore of concrete prisms; to this aim the vertical joints must not differ from the vertical ones of over 10 mm on the storey height.
- verification of the reinforcement protection.

10. Prototypes and test set-up

Hereafter there are given a number of diagrams related to prototypes and tests set-up referred to within section 2.

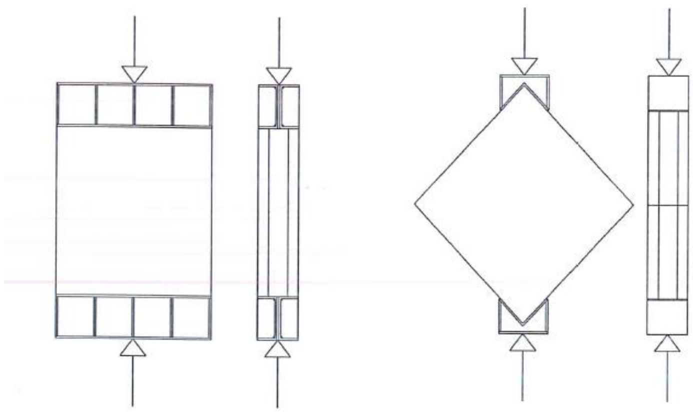

Figure 10-1: Type 1 tests - small size prototypes (abt. 1.0 m x 1.0 m), calculation of the modulus of elasticity

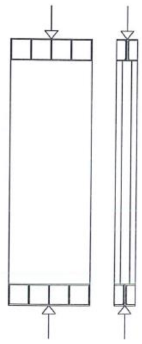

Figure 10-2: Type 2 tests - full scale panel prototypes (abt. h= storey height type, b>1.0 m), evaluation of collapse load for local and global panel instability

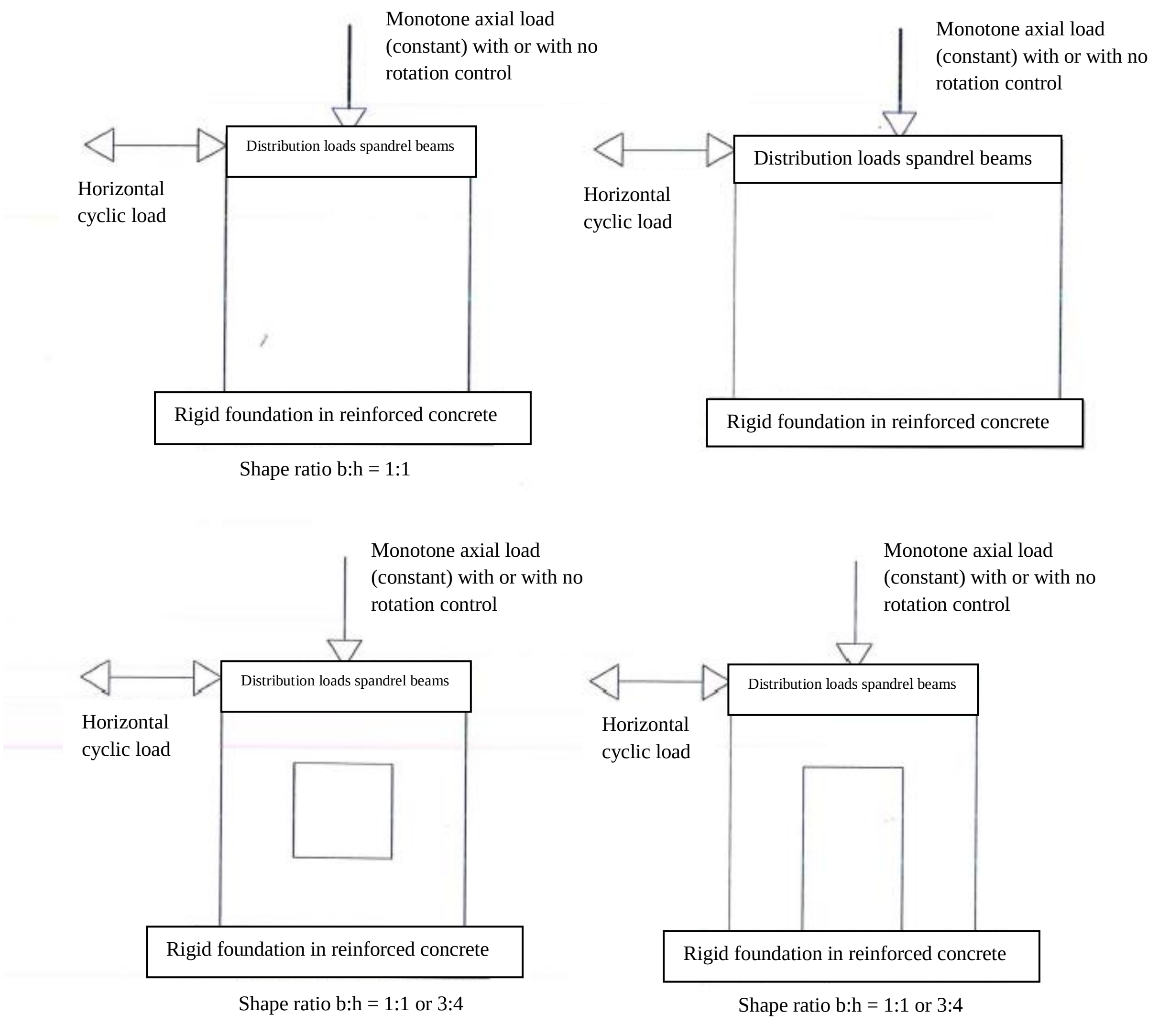

Figure 10-3: Type 3 tests - prototypes for experimental tests on full scale panels, on panels with no apertures (b:h=l:l e 4:3) with apertures (b:h=l: 1), h = storey height type, evaluation of strength, displacement capacity, dissipation. Note that in the figure, the spandrel beams and the foundation elements have the only purpose of allowing the application of the load in testing phase; they are not an integral part of the structural element object of study.

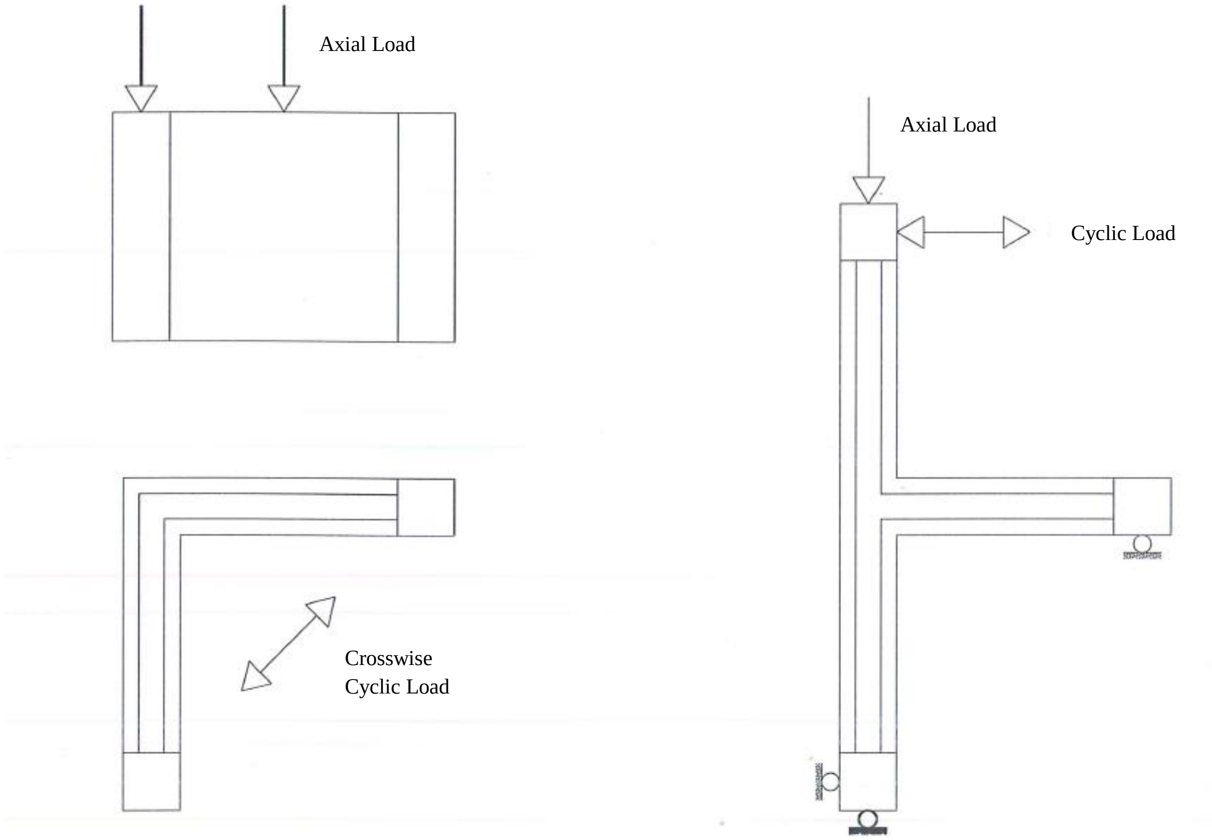

Figure 10-4: Tests type 4 - Prototypes for experimental tests on L and T shaped connections.

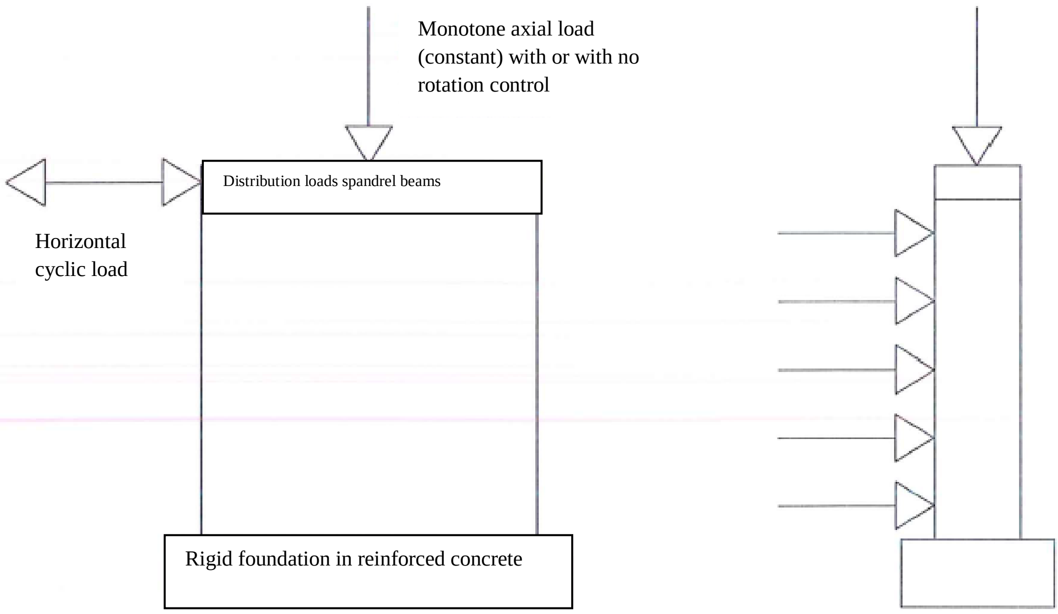

Figure 10-5: Tests type 5 (option) - Prototypes for experimental tests with combined application of actions in-plane and out-of-plane. Note that in the figure, the spandrel beams and the foundation elements have the only purpose of allowing the application of the load in testing phase; they are not an integral part of the structural element object of study