European Commission

Research Programme of the Research Fund for Coal and Steel

STEEL-EARTH

STEEL-BASED APPLICATIONS IN EARTHQUAKE-PRONE AREAS

PRECASTEEL

PREFABRI**CA**TED **ST**EEL STRUCTUR**E**S FOR LOW-RIS**E** BUI**L**DINGS IN SEISMIC AREAS

SUGGESTIONS and CRITICAL COMMENTS

FERRIERE NORD SpA CONTRIBUTION

Authors: **dr. Loris Bianco**

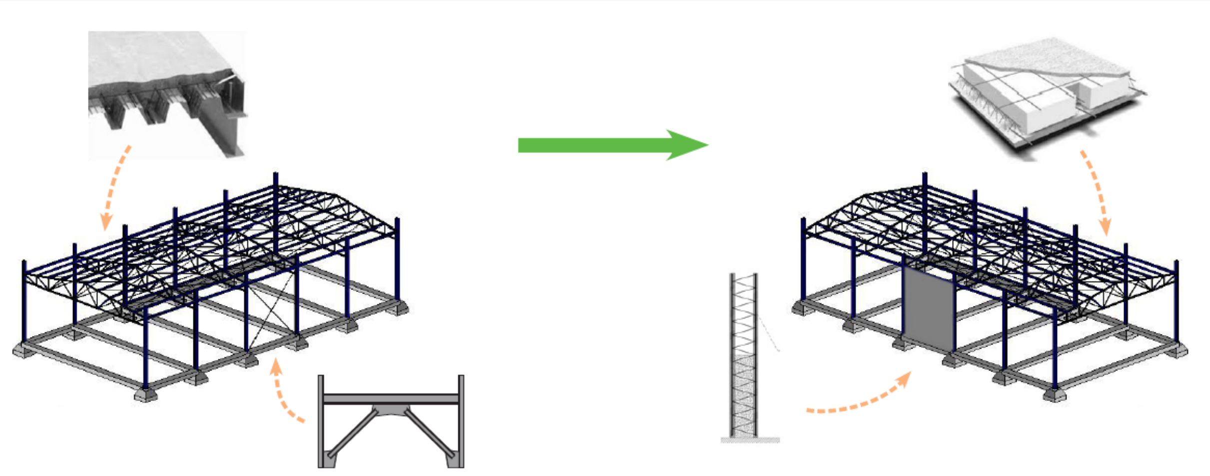
ing. Roberta Mallardo

ing. Pietro Filipuzzi

In STEEL EARTH research we have collected the results obtained thank to two other European Research: PRECIOUS (Prefabricated composite beam to concrete filled tube or partially reinforced concrete encased column connection for severe seismic and fire loadings) and PRECASTEEL (Prefabricated steel structures for low-rise building in seismic areas) about **electrowelded steel reinforcements for precast slabs and double slabs used respectively as an alternative of steel sheeting with concrete for floor and of steel bracing system in low-rise steel commercial or industrial buildings in seismic areas.**

During *Precasteel* research **a simplified design approach for steel industrial and commercial buildings** was developed with the aim to accelerate and make easier all the decisions that has to be taken about feasibility of a project **both in structural and economical terms**.

This simplified design approach include some innovative solutions as the one **with double-slab walls as bracing system and lightweight lattice girder slab for floor.**



Moreover a software, **Precasteel web 2.0**, was implemented: on the basis of a preliminary statistical data analysis, structural configurations were defined fixing geometries (bays length, storey number, floor configuration or roof slope) in order to be consistent with housed activities, industrial or commercial, and to be competitive with concrete market shares. The selected structural solutions for commercial building activities were iteratively designed varying geometrical parameters and resisting static schemes in order to define the optimum steel and steel-concrete composite solutions.
The iterative design of many structures, integrated with the cost analysis, was transformed in a complete performance analysis where structural performance (assessed applying Eurocode design framework) were harmonized with construction costs

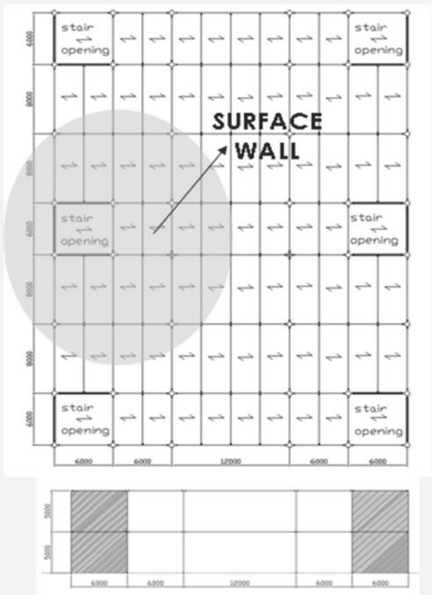
For low-rise commercial buildings, using the results from the *Precasteel* database implemented by FENO (for r.c.wall bracing system) and UNICAM (for steel bracing system), it was possible **a comparison both in terms of seismic influence area and in terms of total and unit cost, between reinforced concrete walls solutions towards concentric and eccentric steel bracing systems.**

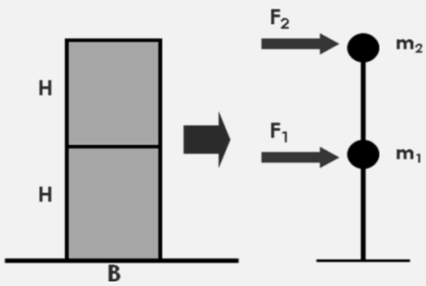
Suggestions and critical comments for designers

1. The definition of the **simplified pre-design method is based on some hypothesis** concerning the idealization of the structural behavior:
    a. simplified static schemes, obtained by extracting substructures with lower complexity but still able to describe the behavior of the whole structure;
    b. substructures are regular in plant and in elevation, in terms both of the distribution of seismic masses and stiffness;
    c. floor systems are supposed as rigid diaphragms;
    d. foundation structures are considered and modeled as ideal rigid constraints;
    e. linear elastic analyses;
    f. static seismic analyses to pre-design ductile walls (ULS), simplified dynamic seismic analyses to give an estimation about influence area/wall (considering lumped masses for each storey);
    g. the first vibration mode is assumed to be linear.
    h. overturning vibration modes are avoided by technical joints and a symmetrical disposition of the braces;

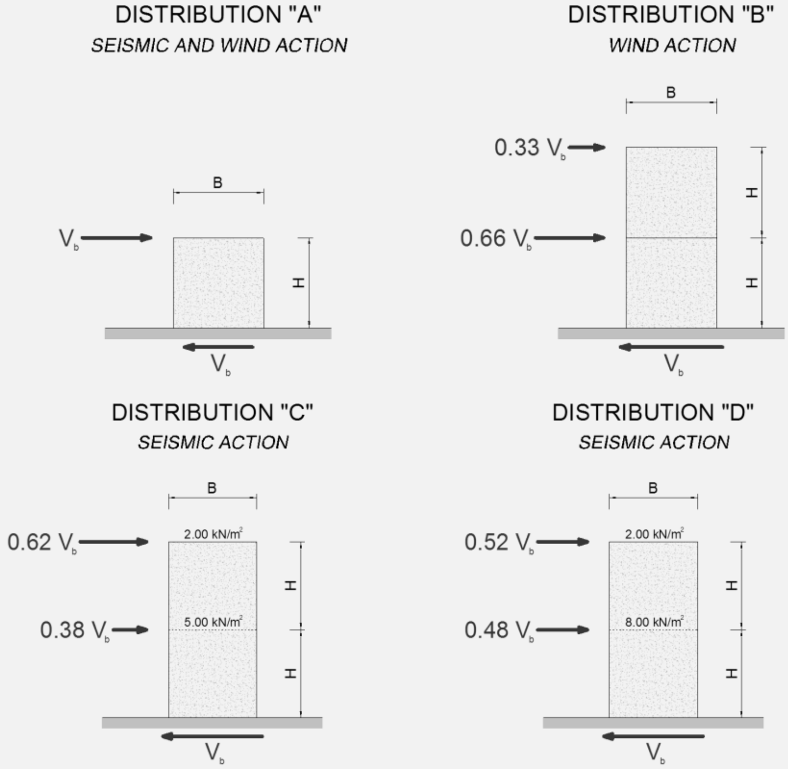
In particular **for what concern the r.c.walls:**
    i. shear wall deformation is taken into account through a refined wall stiffness model (**Timoshenko model**);
    j. **ductile walls are uncoupled** (i.e. C or L plan shapes for staircases);
    k. for steel braces the main hypothesis of decupling vertical and horizontal loads must be strictly respected especially for the eccentric one because vertical loads can compromise the behavior of the seismic link. **With double-slab wall it's possible to avoid this decoupling** and this bring down the total estimation building costs.

2. **Pre-design method**
   In order to obtain the minimum number of seismic-resistant walls, able to withstand assigned base shears V_b and given a specific commercial building area, the following procedure is adopted.





R.c. walls are designed to resist both seismic and wind actions, assuming four different distributions of the storey forces (distributions A, B, C, D).



In the case of wind, the base shear was distributed so that the force applied at the first storey is twice the one applied at the roof level; in the case of seismic actions, by assuming the first vibration mode to be linear, the base shear was distributed according to the following formulas (where *M* represents storey seismic mass):

$$F_1 = V_b \left(\frac{M_1 \cdot H}{M_1 \cdot H + 2 \cdot M_2 \cdot H} \right)$$

$$F_2 = V_b \left(\frac{2 \cdot M_2 \cdot H}{M_1 \cdot H + 2 \cdot M_2 \cdot H} \right)$$

Being *K* the translational stiffness matrix of the walls (Tomoshenko model) and *M* the mass matrix corresponding to a unit area, the fundamental period *T* of the system can be estimated from the expression:

$$T = 2\pi \cdot \sqrt{\frac{a \cdot Ma}{a \cdot Ka}} \cdot \sqrt{A}$$

where *A* is the unknown wall influence area.

The influence area *A* of the single wall may be evaluated by solving the following nonlinear equation, obtained by equating the assigned V_b to the base shear expected:

$$V_b = A \cdot \frac{(a \cdot Mr)^2}{a \cdot Ma} \cdot S_d(T)$$

where S_d is the design spectrum.

INPUT:

INPUT								
Number of storeys	Storey height H [m]	Width B [m]	Thickness s [m]	Base shear Vb [kN]	Distribution type	Seismic/Wind action	Ductility class	Behaviour factor
2	4.00	4.00	0.20	500	C	0.16 g	DCH	4.00
2	4.00	4.00	0.20	500	C	0.16 g	DCM	3.00
2	4.00	4.00	0.20	500	C	0.16 g	DCL	1.00

and **material characteristics** (concrete class, concrete compressive resistance at 28 days, design value of modulus of elasticity of concrete), **loads** (dead, super-dead and live loads) and **partial factors for actions**.

OUTPUT: **seismic-resistant area / wall**

Improving the model with costs, the final output are the following:

OUTPUT						
Surface/ Wall [m^2]	Vertical rebars As,bending [cm^2]	Horizontal rebars As,shear [cm^2/m]	Steel weight [kg]	Concrete weight [kg]	Concrete volume [m^3]	Precast DL wall surface [m^2]
374	52	6	553	15360	6.40	32
307	52	6	553	15360	6.40	32
156	52	6	553	15360	6.40	32

3. **This approach has been validated** implementing a finite element model for an existing steel two-storey building with r.c.walls as bracing system, for which a complete three dimensional seismic analysis was carried out.

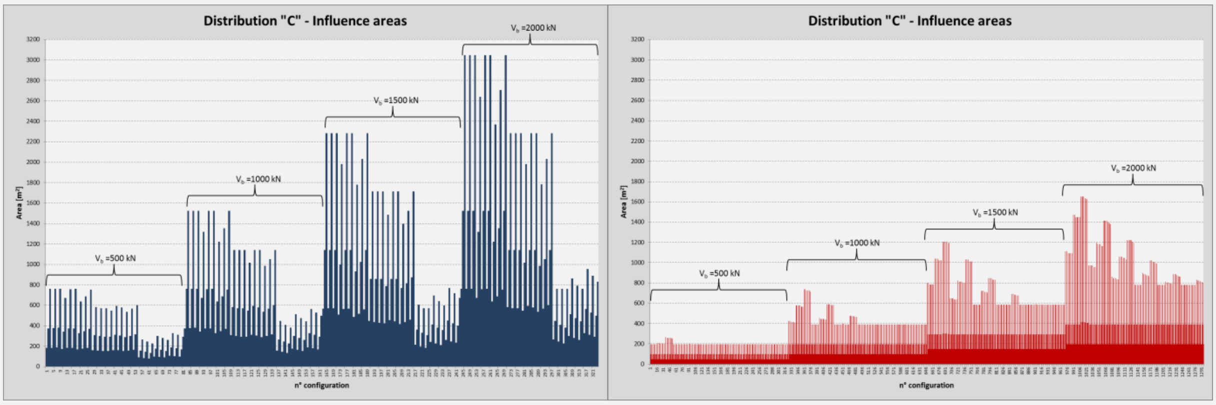
   The error estimation following the pre-design Precasteel procedure does not reach 15%, value that includes all the simplifications in terms of structural hypothesis (i.e. the assumption of the first vibration mode as the representative; in the three dimensional analysis an accidental torsion effect has been taken into account etc…).

4. During *Precasteel* research some suitable solutions for selected structural configurations were studied. So a considerable database was created (about 1.000 cases).

   Using this database, some comparisons between the steel and precast solutions for floor and bracing system were carried out in technical (seismic area) and economical terms.

   Comparing the solutions of the database, in steel and composite steel-concrete low-rise commercial buildings **double-slab precast walls are more convenient toward steel bracing system**; actually steel bracing system are potentially more dissipative then walls but, due to the normative lateral deflection limits and stiffness requirements, double-slab walls become more competitive.

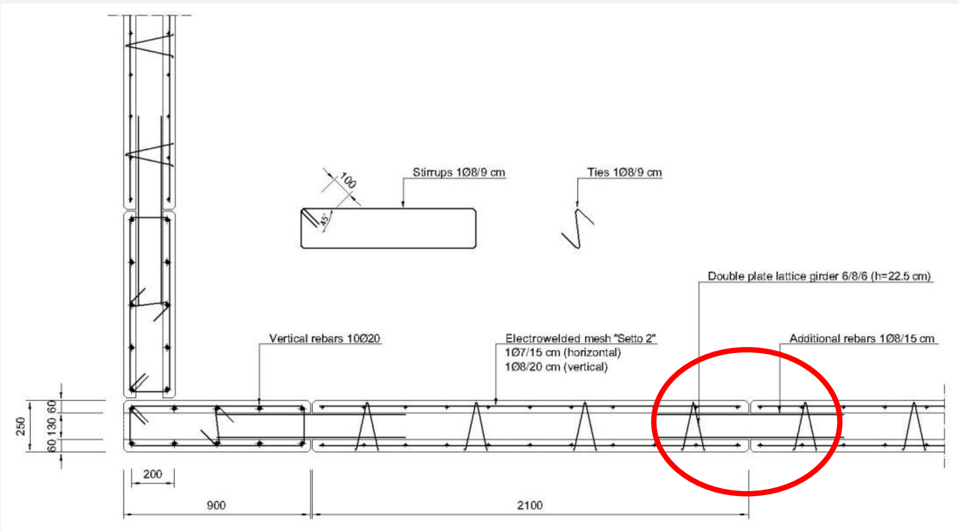
   In particular **double-slab walls in DCM and DCH are more competitive** towards the other bracing systems



Comparison in terms of influence area - r.c. bracing system (left) vs. steel concentric bracing system (right).

5. The seismic behavior of the steel commercial building could be improved if we consider even the **"box" behavior of walls** (edge and staircase).

6. Instead of using double-slab as formworks, in order to exploit all the thickness of the wall cross section (in verifications) and to reduce the cost of erection of double-slab, it could be useful **to put steel reinforcements inside the slabs** during operations in the factory.



The width of the wall can be greater than the slab one, which depends on the track transport standard limits. Subsequently a wall could be composed by more slabs; so in correspondence of the joint between them, it's necessary to pay attention to the "reduced" section and verify:

$V_{rds} < V_{rdc}$ – in order to avoid that the collapse of the complete section occurs for concrete crack

$V_{rds,red} < V_{rdc,red}$ – in order to avoid that the collapse of the reduced section occurs for the concrete crack

$V_{rds,red} > V_{rds}$ – in order to avoid that the collapse of the reduced section occurs before the complete one

In some cases, in DCH, due to these considerations, the solution with the reinforcements inside the slab was less competitive then the one with the slabs used as formwork.

We can avoid the problem with mechanical joints.

7. **Detail - «Cantiliver effect»**: We have to pay attention to the part of the slab near the corner that can't be reinforced by lattice girder in order to have the space to put reinforcements needed in the critical zone. In order to avoid cracks the slab must be reinforced with an opportune electrowelded mesh or it's necessary to put ouside the corrner a mechanical joint in order to avoid the cantiliver effect.

8. *Precious* numerical analyses and experimental test have shown that floors made with lightweight prefabricated lattice girder slabs can be **more ductile under seismic actions and fire resistant towards to steel sheeting** with cast in situ floors.

   Moreover they have a **greater self-bearing capacity** that means less secondary steel beams and so an economical advantage.