This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

RE4 Project

REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

D3.3 Structural modelling	
Author(s)[1]:	ITC-CNR (STRESS linked third party)
Date:	15/05/2019
Work package:	WP3 - Innovative concept for modular/easy installation and disassembly of eco-friendly prefabricated elements
Distribution[2]	PU
Status[3]:	Final
Abstract:	D3.3 reports the structural modelling which supports the design development with regards to seismic performance of primary elements installed in the building context with particular reference to the mockup for seismic test to be performed within WP6.
File Name	Re4_D3.3_Structural modelling_ITC-CNR_Version V0

Version	Date	Description	Written By	Approved by
V0	15/05/2019	Final draft version	ITC-CNR (STRESS linked party)	

[1] Just mention the partner(s) responsible for the Deliverable
[2] PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.
[3] Draft, Revised, Final

TABLE OF CONTENTS

Index of figures

Index of tables

1. EXECUTIVE SUMMARY

The document herein reports the activities and results developed in task T3.4- *Numerical modelling to support the prototypes design and to predict the prototypes performance.* STRESS (with its linked third party ITC-CNR) led this task of WP3 with the collaboration of ZRS, RISE, CETMA, QUB.

With inputs mainly from the work developed in WP3 – task 3.2 and 3.3 the prefabricated elements were designed accordingly with the design concept established in T3.2 and 3.3. The prefabricated elements will be assembled in the seismic mock-up to be tested within task 6.2-*Manufacture and testing of the prefabricated elements prototypes, quality control and characterization.*

The following prefabricated elements were designed during T3.3:

- A concrete solid slab
- Two concrete columns
- Two concrete beams
- A concrete shear wall

Deliverable D3.4 reports the modelling assumptions, design procedures and results.

2. INTRODUCTION

The present document is included in the framework of the ongoing RE^4 research project, funded by the European Commission in the context of Horizon 2020 research funding programme, call H2020-EEB-2016.

This deliverable D3.3 summarises the results obtained in the development of T3.4 as mentioned above. The work carried out on this task is focused on the seismic design of selected elements and components from the range of products developed in RE^4 project. The results and the products of this tasks will be incorporated in the seismic mock-up to be test in Naples, Italy (shaking table test) at ITC/CNR facilities. The seismic design follows the Eurocodes requirements for medium-high seismic activity prone areas and for building with members of medium class ductility.

One of the goals of WP3 is to investigate the seismic performance of all selected elements and components which incorporate high levels of recycled CDW. Mutual connections have been designed on order to ensure acceptable seismic performances and to allow disassembly of the concrete member after a seismic event.

2.1 Relevant Work Package input

The activities reported in this deliverable are built mainly on the design concept developed in WP3, T3.2 and 3.3 as in these tasks the building structural layout and all the technological solutions (e.g. for mutual connections) have been selected. The D3.3 contents are linked with knowledge obtained in T3.3 where the design concept for the development of components for the new construction of residential or commercial
buildings is defined. Also, from WP6 comes the knowledge of specific constructive requirements in order to fulfil production and assembly of the prefabricated elements. The CDW concrete mixes, geometry of elements and components were developed also taking into account knowledge coming from WP5.

3. DESCRIPTION OF THE RESULTS

3.1 WP objectives and limitations

The specific objectives of WP3-T3.4 are:

- Structural modelling of the prototypes installed in the building context
- Seismic design of the prefabricated elements
- Seismic design of the mutual connection of prefabricated elements
- Assessment of the mechanical behaviour versus the given requirements

This deliverable D3.3 has the main goals of reporting:

- design procedures and assumptions for the selected prefabricated elements
- the resulting characteristics in terms of geometry and reinforcement of the selected RE^4 elements for seismic test
- investigation of the expected seismic performance (safety factors) of the selected RE^4 elements with respect to European code requirements

T3.4 - Numerical modelling to support the prototypes design and to predict the prototypes performance main limitations are related with scaling of the primary elements with respect to the building context and the achievement of an appropriate structural layout which reflects the building global behaviour.

3.2 Description of work undertaken

3.2.1 Modelling assumptions

The reference structure consists of: a) two square precast columns fixed at the base with bolted connections; b) a precast shear wall; c) two L-shaped precast horizontal beams (the beam ends are connected to the column and to the wall, respectively); d) a horizontal solid slab.
The structural elements are designed and verified according to Eurocodes (CEN 2004; CEN 2005). Parameters and factors to be applied in the design procedure, for which Eurocodes refer to National Annexes, and for the definition of the seismic loads, the Italian building code provisions are taken into account (Circolare 02/02/2009 n. 617 2009; D. M. 14/01/2008 2008).
The geometrical features of the structural elements, as well as the span lengths and the building height reflect the design approach developed within WP3. The span length for beams is assumed equal to 1.8m. The span length of the shear wall is assumed equal to 2.4m. The column and wall height is equal to 3m.
In the following, the adopted materials and the corresponding nominal values of their mechanical properties are reported. The mechanical properties of the precast concrete C40/50, of the reinforcement steel B450C are evaluated according to the Italian building code. In particular, the table in the following refers to the standard concrete properties, implemented in the structural model, according to the assumptions made within WP3. The table shows, in this order, the

characteristic compressive strength (f_{ck}), the average and characteristic tensile strengths (f_{ctm} and f_{ctk}, respectively), the average Young modulus, the design compressive strength and the ultimate strain values. Table 1 refers to the reinforcement steel properties and it shows, in this order, the characteristic yielding strength (f_{yk}), the design yielding strength (f_{yd}), the Young modulus (E_s) and the ultimate strain values (ε_{su}).

Table 1 Adopted materials for structural elements

Element	Concrete	Mild steel
Concrete slab	C40/50	B450C
Columns	C40/50	B450C
Wall	C40/50	B450C
Beams	C40/50	B450C

Table 2 Mechanical properties for C40/50 precast concrete

f_{ck}	f_{ctm}	f_{ctk}	E_{cm}	f_{cd}	ε_{cu}
[N/mm^2]	[N/mm^2]	[N/mm^2]	[N/mm^2]	[N/mm^2]	[-]
40.0	3.51	2.46	35220	22.7	0.35%

Table 3 Mechanical properties for B450C reinforcement steel

f_{yk}	f_{yd}	E_s	ε_{su}
[N/mm^2]	[N/mm^2]	[N/mm^2]	[-]
450.0	391.3	200000	7.50%

3.2.2 Design procedure

The load combinations considered for the structural design are reported in the following:

a) Fundamental combination, applied for the ultimate limit states:

$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \Psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \Psi_{03} \cdot Q_{k3} + \cdots$$

b) Characteristic combination, applied for irreversible service limit states:

$$G_1 + G_2 + P + Q_{k1} + \Psi_{02} \cdot Q_{k2} + \Psi_{03} \cdot Q_{k3} + \cdots$$

c) Frequent combination, applied for reversible service limit states:

$$G_1 + G_2 + P + \Psi_{11} \cdot Q_{k1} + \Psi_{22} \cdot Q_{k2} + \Psi_{23} \cdot Q_{k3} + \cdots$$

d) Quasi permanent combination, applied for long term effects:

$G_1 + G_2 + P + \Psi_{21} \cdot Q_{k1} + \Psi_{22} \cdot Q_{k2} + \Psi_{23} \cdot Q_{k3} + \cdots$

e) Seismic combination, applied for service and ultimate limit states related to the seismic action E:

$E + G_1 + G_2 + P + \Psi_{21} \cdot Q_{k1} + \Psi_{22} \cdot Q_{k2} + \Psi_{23} \cdot Q_{k3} + \cdots$

In the above equations:

- G_1 is the dead load of the structural elements;
- G_2 is the dead load of the non-structural elements;
- P is the prestressing load;
- E is the seismic load;
- Q_{k1} is the characteristic value of the predominant variable load;
- $Q_{k,i}$ is the characteristic value of the non-predominant variable load;
- $\gamma_{G,j}$ is the partial coefficient for the dead load;
- γ_P is the partial coefficient for prestressing load;
- $\gamma_{Q,i}$ is the partial coefficient for the variable load;

ψ_{ij} is the combination coefficient for the variable load.

The effect of the seismic action is computed by means of a dynamic linear analysis. The 32 combinations are due to the possible directions of the seismic action with respect to the building global principal in plane directions, namely x and z direction, (±Ex and ±Ez, both combined with the 30% of the orthogonal direction) and accounting for an accidental eccentricity of the mass centre in both of the principal directions of the buildings ($e_X = 0.05 \cdot L_X$, $e_Z = 0.05 \cdot L_Z$).).

The seismic design of the precast buildings is performed by means of a modal response spectrum analysis. Following the Eurocode requirements, included as well in the Italian building code, the seismic action can be evaluated using response spectra, related to the site hazard and the reference limit state. According to the Italian seismic map, the site hazard is defined by the seismic hazard parameters (a_g, F_0, T_c^*), for damage limit state DLS and life safety limit state (LLS), reported in the Annex B of the Italian building code, depending on the geographical position and on the return periods. In the following, the seismic hazard parameters for the reference sites and for the considered limit states in the design process are reported.

Table 4 Hazard parameters

Site	**Longitude**	**Latitude**	**Limit state**	**a_g**	**F_o**	**T_c^***
				[g]	**[-]**	**[sec]**
Napoli	14.268	40.854	DLS LLS	0.060 0.168	2.335 2.374	0.312 0.338

The response spectrum depends on the soil and topographic category. The soil category can be defined considering the stratigraphic profiles and the average shear wave velocity $v_{s,30}$. For the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

reference case studies, referring to Tab. 3.2.II – NTC, soil type C is considered. Flat ground level is assumed for the case studies (topographic category T_1, according to Tab. 3.2.IV – NTC).
The elastic response spectrum is defined for horizontal acceleration component and vertical acceleration component, referring to the Italian building code. Table 5 to Table 6 show the seismic parameters for the horizontal and vertical spectrum definition, for soil type A and C respectively: the stratigraphic (S_S) and topographic (S_T) soil factor ($S=S_S \cdot S_T$), the characteristic period values (T_B, T_C, T_D) and the damping factor (ξ).
In the following, the horizontal and vertical elastic response spectra for soil type C, for life safety and damage limit state are reported.

Table 5 Horizontal elastic acceleration spectrum parameters for soil type C

Site	Limit state	S_S	S_T	S	C_C	T_C	T_B	T_D	ξ
		[-]	[-]	[-]	[-]	[sec]	[sec]	[sec]	[%]
	LLS	1.33		1.33	1.49	0.517	0.172	2.644	
Napoli	DLS	1.50		1.50	1.54	0.481	0.160	1.840	
	LLS	1.46		1.46	1.50	0.508	0.169	2.272	

Table 6 Vertical elastic acceleration spectrum parameters (LLS)

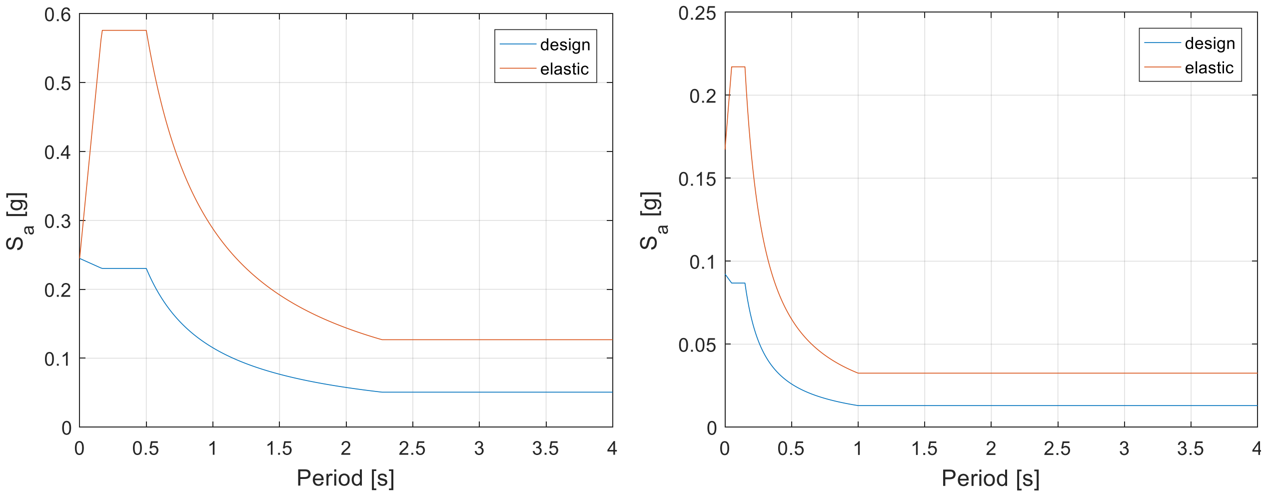
Site	S_S	S_T	S	F_V	T_C	T_B	T_D	ξ
	[-]	[-]	[-]	[-]	[sec]	[sec]	[sec]	[%]
Napoli				1.31				

The design response spectrum can be obtained from the elastic one, changing η with q, i.e. the behaviour factor for precast structures with isostatic columns equal to:

$$q = q_0 \cdot K_R$$

For the considered structural typology, q_0 is equal to 3.5 for high ductility class and equal to 2.5 for low ductility class.
K_R is the regularity coefficient equal to one for regular structures (in plan and elevation). For the case studies (low ductility class and regular plan and elevation), the behaviour factor which should be applied to the seismic horizontal component is equal to 2.5. The behaviour factor for the seismic vertical component is equal to 1.5.
The elastic and design response spectra of horizontal and vertical acceleration component, for the life limit state, corresponding to soil C, is reported in the following.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583



(a) (b)

Figure 1 Horizontal (a) and vertical (b) spectral accelerations LLS

For the structural design of the constitutive elements of the reference buildings, also non seismic loads are considered. In particular, dead loads can be evaluated considering the structural self-weight of the elements. In the following, variable loads are described in detail. Accidental loads can be defined according to CEN (2001) considering characteristic values of imposed loads for residential buildings (q_{acc}=2kN/m^2).

The static snow load can be evaluated as:

$$q_s = \mu_i \cdot q_{sk} \cdot C_E \cdot C_t$$

Where:

- q_s is the snow load on the roof;
- μ_i is the roof shape coefficient [3.4.5 – NTC], assumed to be equal to 0.8;
- q_{sk} is the characteristic value of the ground snow load, with a return period of 50 years [3.4.2 – NTC]. It depends on elevation (as) and on the local climatic and exposition conditions, considering the variability in the snow precipitation.
- C_E is the exposition coefficient [3.4.3 – NTC], assumed equal to 1;
- C_t is the thermal coefficient [3.4.4 – NTC], assumed equal to 1.

Snow load values for the considered site are reported in the following (Table 7).

Table 7 Snow load parameters

Site	Snow zone	a_s	q_{sk}	μ_i	C_E	C_t	q_s
[-]	[-]	[m]	[kN/m^2]	[-]	[-]	[-]	[kN/m^2]
Napoli	III	6	0.60				0.48

The wind load is generally considered as a horizontal load acting along the principal directions of the building. It consists of a dynamic load which can be modeled as equivalent static loads represented by normal forces (on the orthogonal surfaces with respect to the wind direction) and tangential forces (on the parallel surfaces with respect to the wind direction).
The equivalent static loads can be evaluated according to the Italian building code [3.3 - NTC], considering the parameters reported in the following which depend on the specific site. In particular, the reference velocity v_b and the reference kinetic pressure q_b can be evaluated according to equation 3.3.1 and 3.3.4, respectively, of the Italian building code.

Table 8 Wind load parameters

Site	Wind zone	Roughness	Exposition category	a_s	a_0	k_a	$v_{b,0}$	v_b	q_b
[-]	[-]	[-]	[-]	[m]	[m]	[1/s]	[m/s]	[m/s]	[kN/m^2]
Napoli	3	B	III	6	500	0.02	27.00	27.00	0.46

The normal wind pressure can be evaluated as:

$$p = q_b \cdot c_e \cdot c_p \cdot c_d$$

where:

- q_b is the reference kinetic pressure [3.3.6 – NTC];
- c_e is the exposure coefficient [3.3.7 – NTC]. The exposure coefficient depends on the distance from foundation z, on the topography (c_t = 1) and on the exposure category. For the case studies, it is assumed to be constant along the building height and equal to the maximum possible value. The exposure category can be defined depending on the site geographical position and on the site's ground roughness;
- c_p is the shape coefficient, which depends on the structural typology and geometry and on the building orientation with respect to the wind direction [C3.3.10 – Circ. N.617]. It is assumed to be equal to 0.8 for the external windward surfaces, equal to 0.4 for the external leeward surfaces and equal to ±0.2 for the internal surfaces (3.12);
- c_d is the dynamic coefficient, assumed equal to 1, which accounts for the non-contemporary maximum effects related to the static pressures and the dynamic structural response [3.3.8 – NTC].

The normal and tangential wind loads are applied in both directions and the maximum effects in terms of horizontal force at the column top end is finally considered.

For precast structures geometrical imperfections, due to wrong positioning of the column, can be taken into account using global equivalent static forces according to the Italian building code [C4.2.3.5 – Circ. N.617] and Eurocodes [5.2 – EC2].
In particular, considering the total high of the column h, the total imperfection is assumed equal to:

$$\phi = \alpha_h \cdot \alpha_m \cdot \phi_0$$

where:

- ϕ_0 = h/200 is the reference value of the geometrical imperfection for the single column;
- h is the building height;
- α_h is the reduction factor $\alpha_h = 2/\sqrt{1}$ with $2/3 \leq \alpha_h \leq 1$;
- α_m is the reduction factor $\alpha_m = \sqrt{0,5 \cdot \left(1 + 1/m\right)}$ which accounts for the number of elements (m) along the considered direction.

The global equivalent static force at the column top end can be evaluated as:

$$H_i = \phi \cdot N_a$$

In which N_a is the column axial force evaluated for ultimate limit state combination and for the seismic one. The equivalent static force is calculated for the lateral and corner columns.

It is assumed that thermal effects do not induce critical effects for the reference buildings so that it is possible to consider only the constant thermal action obtained from Tab. 3.5.II – NTC:

$$\Delta T_U = T - T_0 = \pm 15°$$

The thermal load is applied to the roof elements introduced in the numerical model.

3.2.3 Structural verifications

In the following, the structural verifications for primary elements are summarized. It can be observed that for the assumed geometry, cross sections and applied loads the safety factors for all the selected elements are higher than 1 (satisfied requirement) and in most cases they assume very high values. This is due to the fact that minimum code requirements rule for the definition of the main reinforcement.

Table 9 Columns verifications at ULS (M-N)

Height	As %	Mx	My	N	MRdx	MRdy	Saf. factor
0	2.6	106272	-106272	-53136	6129421	-6129421	57.677
5	2.6	105834	-105834	-52917	6129421	-6129421	57.915
34	2.6	-103574	-103574	-51787	-6083274	-6083274	58.734
63	1.3	-169656	-101273	-50637	-8919460	-5324328	52.574
92	1.3	-256000	-98973	-49487	-12099520	-4677838	47.264
121	1.3	-342345	96673	-48336	-14399941	4066324	42.063
149	1.3	-428689	94373	-47186	-15921544	3505008	37.14
178	1.3	-515033	92072	-46036	-16920908	3024947	32.854
207	1.3	-601378	104679	-44886	-17349548	3019963	28.85
236	1.3	-687722	132389	-43736	-17155212	3302445	24.945
265	1.3	-772572	159619	-42606	-16657310	3441531	21.561

Table 10 Columns verifications at LLS (M-N)

Height	As %	Mx	My	N	MRdx	MRdy	Saf. factor	Nmin	Nlim
0	2.6	-2195111	361691	-22486	-14032560	2312158	6.393	42150	1872515
5	2.6	-2136011	356067	-22317	-14055830	2343064	6.58	41982	1872515
34	2.6	-1830957	327037	-21448	-13806685	2466089	7.541	41112	1872515
63	1.3	-1520530	297497	-20563	-11517202	2253380	7.574	40228	1872515
92	1.3	-1511774	88049	-39343	-14064111	819121	9.303	39343	1872515
121	1.3	-1511774	88049	-38458	-13959885	813051	9.234	38458	1872515
149	1.3	-1511774	88049	-37574	-13856645	807038	9.166	37574	1872515
178	1.3	-1511774	88049	-36689	-13754920	801113	9.099	36689	1872515
207	1.3	-1511774	88049	-35804	-13646051	794773	9.027	35804	1872515
236	1.3	-1511774	88049	-34919	-13525010	787723	8.946	34919	1872515
265	1.3	-1511774	88049	-34050	-13408137	780916	8.869	34050	1872515

Table 11 Columns shear verifications at ULS

		X direction						Z direction					
Height	Stirrups	V	N	VRd	VRsd	VRcd	Saf. F.	V	N	VRd	VRsd	VRcd	Saf. F.
0	3ø8/11.3	959	-53136	65395	398627	395430	412.26	-2989	-53136	65395	398627	395430	132.3
5	3ø8/11.3	959	-52917	65367	398627	395400	412.22	-2989	-52917	65367	398627	395400	132.29
34	3ø8/11.3	959	-51787	65219	398627	395248	412.07	-2989	-51787	65219	398627	395248	132.24
63	2ø8/17.5	959	-50637	65070	170840	395093	178.11	-2989	-50637	65070	170840	395093	57.16
92	2ø8/17.5	959	-49487	64920	170840	394938	178.11	-2989	-49487	64920	170840	394938	57.16
121	2ø8/17.5	959	-48336	64770	170840	394783	178.11	-2989	-48336	64770	170840	394783	57.16
149	2ø8/17.5	959	-47186	64620	170840	394628	178.11	-2989	-47186	64620	170840	394628	57.16
178	2ø8/17.5	959	-46036	64470	170840	394473	178.11	-2989	-46036	64470	170840	394473	57.16
207	2ø8/17.5	959	-44886	64320	170840	394318	178.11	-2989	-44886	64320	170840	394318	57.16
236	3ø8/11.3	959	-43736	64170	398627	394163	410.93	-2989	-43736	64170	398627	394163	131.88
265	3ø8/11.3	959	-42606	64023	398627	394011	410.78	-2989	-42606	64023	398627	394011	131.83

Table 12 Columns shear verifications LLS

		X direction						Z direction					
Height	Stirrups	V	N	VRd	VRsd	VRcd	Saf. F.	V	N	VRd	VRsd	VRcd	Saf. F.
0	3ø8/11.3	96621	-42150	63964	398627	393949	4.08	96621	-42150	63964	398627	393949	4.08
5	3ø8/11.3	96621	-41982	63942	398627	393927	4.08	96621	-41982	63942	398627	393927	4.08
34	3ø8/11.3	96621	-41112	63829	398627	393809	4.08	96621	-41112	63829	398627	393809	4.08
63	2ø8/17.5	96621	-40228	63713	170840	393690	1.77	96621	-40228	63713	170840	393690	1.77
92	2ø8/17.5	96621	-39343	63598	170840	393571	1.77	96621	-39343	63598	170840	393571	1.77
121	2ø8/17.5	96621	-38458	63483	170840	393452	1.77	96621	-38458	63483	170840	393452	1.77
149	2ø8/17.5	96621	-37574	63368	170840	393332	1.77	96621	-37574	63368	170840	393332	1.77
178	2ø8/17.5	96621	-36689	63252	170840	393213	1.77	96621	-36689	63252	170840	393213	1.77
207	2ø8/17.5	96621	-35804	63137	170840	393094	1.77	96621	-35804	63137	170840	393094	1.77
236	3ø8/11.3	96621	-34919	63022	398627	392975	4.07	96621	-34919	63022	398627	392975	4.07
265	3ø8/11.3	96621	-34050	62908	398627	392857	4.07	96621	-34050	62908	398627	392857	4.07

Table 13 Beams bending verifications ULS

x	A sup.	A inf.	C.b. inf.	M+ela	M+des	M+ult	x/d	M-ela	M-des	M-ult	x/d
0	6.03	6.03	4.6					-878676	-518243	-7371815	0.162
18	6.03	6.03	4.6	-76378	308477	7375749	0.162	-179074	-179074	-7371815	0.162
106	6.03	6.03	4.6	1641176	1647485	7375749	0.162				
203	6.03	6.03	4.6	-16749	428634	7375749	0.162	-39620	-39620	-7371815	0.162
213	6.03	6.03	4.6					-417570	-223621	-7371815	0.162

Table 14 Beams bending verifications LLS

x	A sup.	A inf.	M+ela	M+des	M+ult	x/d	M-ela	M-des	M-ult	x/d
0	6.03	6.03	1028588	1028588	7375749	0.162	-2011969	-1723550	-7371815	0.162
18	6.03	6.03	1248541	1386617	7375749	0.162	-1447896	-1447896	-7371815	0.162
106	6.03	6.03	1393605	1488525	7375749	0.162				
203	6.03	6.03	448935	576323	7375749	0.162	-492904	-492904	-7371815	0.162
213	6.03	6.03	335633	335633	7375749	0.162	-802808	-644997	-7371815	0.162

Table 15 Beams shear verifications ULS

x	A st	A sl	A sag	Vela	Vdes	Vrd	Vrcd	Vrsd	Vult
0	0	6.03	0	41192	41192	52946	402135	0	52946
18	0.151	6.03	0	38762	38762	52946	402135	179335	179335
106	0.093	6.03	0	2302	2302	52946	402135	110094	110094
203	0.151	6.03	0	-36800	-36800	-52946	-402135	-179952	-179952
213	0	6.03	0	-38628	-38628	-52946	-402135	0	-52946

Table 16 Beams shear verifications LLS

x	A st	A sl	A sag	Vela	Vdes	Vrd	Vrcd	Vrsd	Vult
0	0	6.03	0	32963	109604	52946	402135	0	52946
0	0	6.03	0	13298	-65772	-52946	-402135	0	-52946
18	0.151	6.03	0	31503	108145	52946	402135	179335	179335
18	0.151	6.03	0	11839	-67232	-52946	-402135	-179335	-179335
106	0.093	6.03	0	11118	87759	52946	402135	110094	110094
106	0.093	6.03	0	-8547	-87617	-52946	-402135	-110094	-110094
203	0.151	6.03	0	-10754	65651	52946	402135	179952	179952
203	0.151	6.03	0	-30419	-109725	-52946	-402135	-179952	-179952
213	0	6.03	0	-11824	64817	52946	402135	0	52946
213	0	6.03	0	-31489	-110559	-52946	-402135	0	-52946

3.2.4 Resulting structural drawings

In the following the final structural drawings of the primary elements, including devices for mutual connections and lifting devices are reported.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

Slab drawings

In the following structural drawings for the solid slab are reported. They show the main longitudinal and transversal reinforcement following structural calculations and additional devices and reinforcement for lifting and for slab to beams connections. Vertical bolts for slab to beams connections have been designed according to the horizontal design seismic loads, in both the main directions. Supplementary reinforcement is also considered to avoid concrete cover splitting for tensile actions.

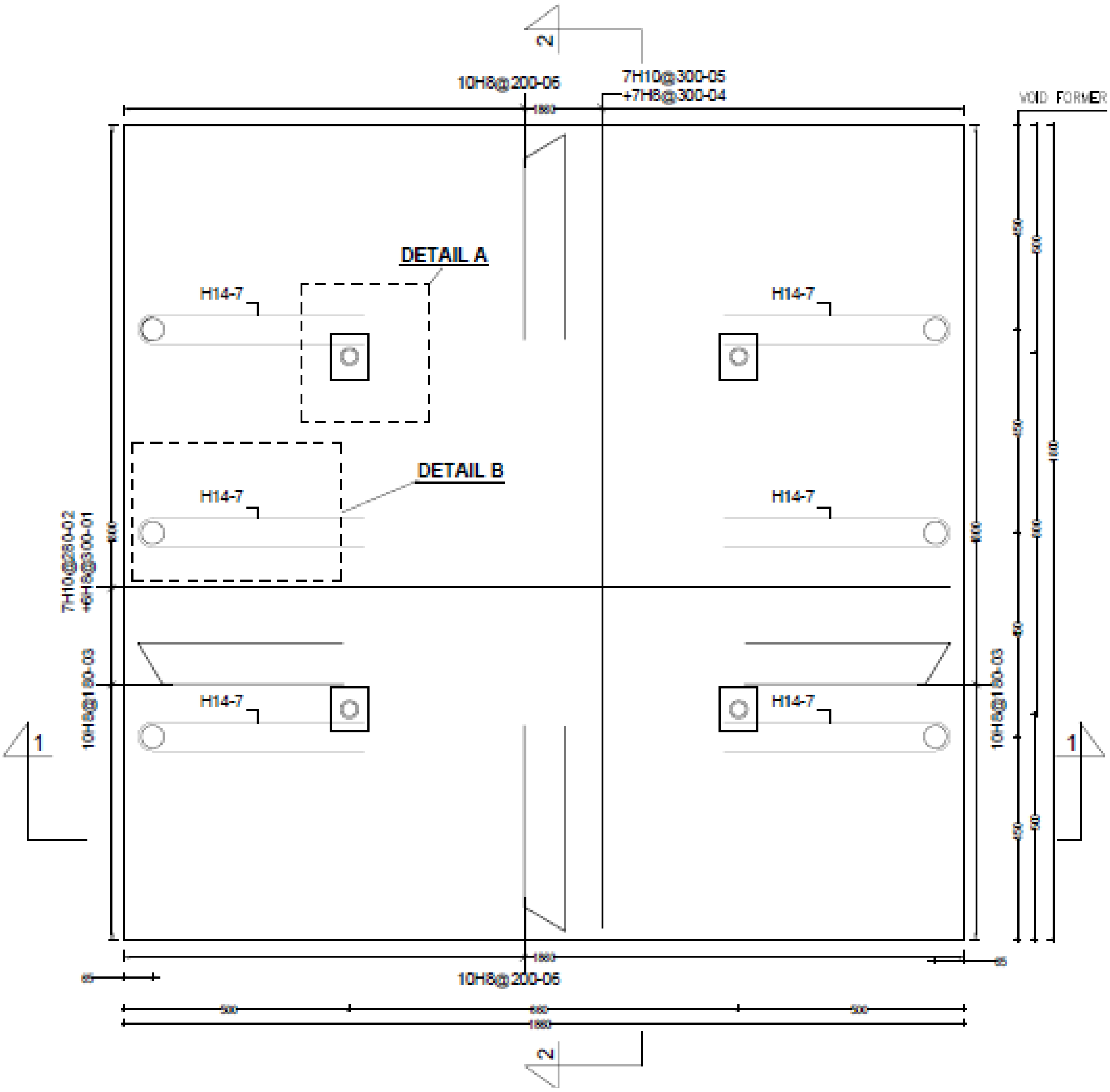


Figure 2 Slab plan view- top reinforcement

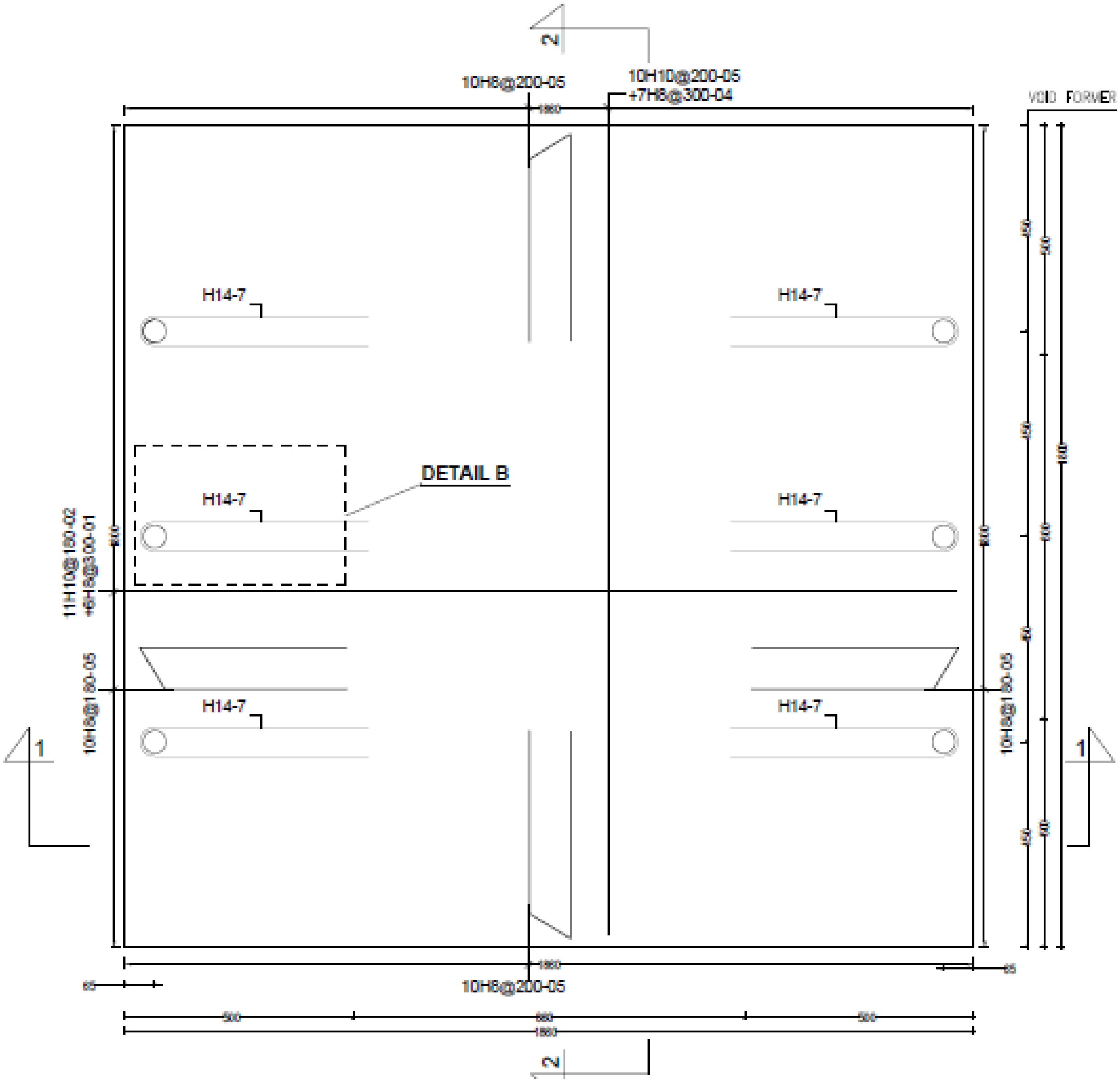


Figure 3 Slab plan view- bottom reinforcement

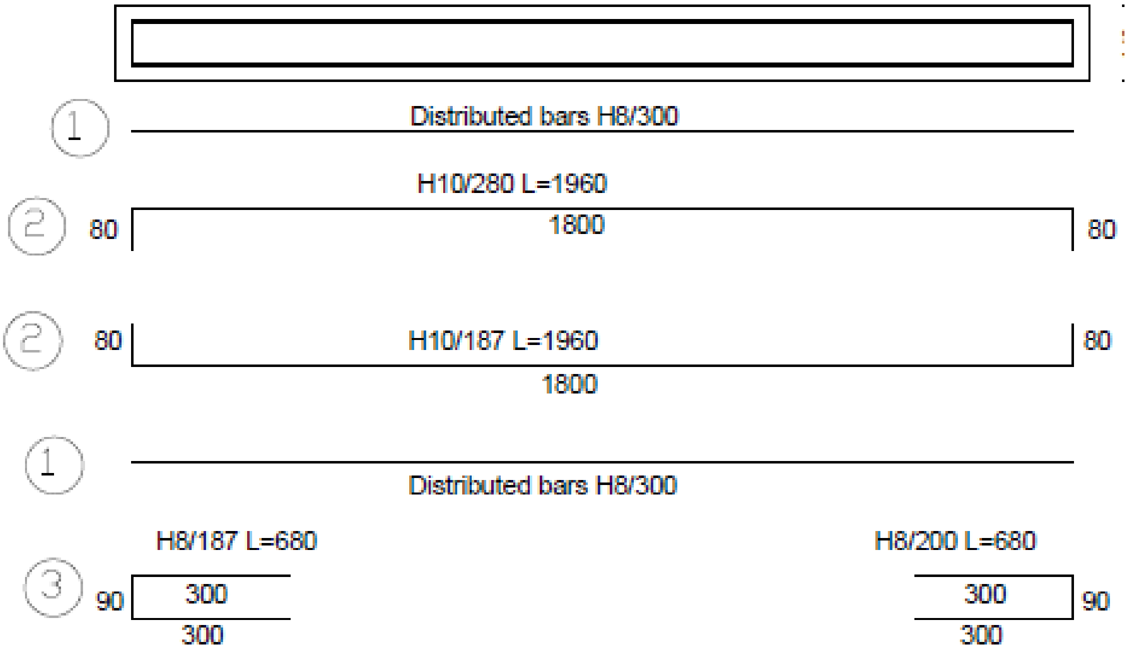


Figure 4 Slab reinforcement detail longitudinal section

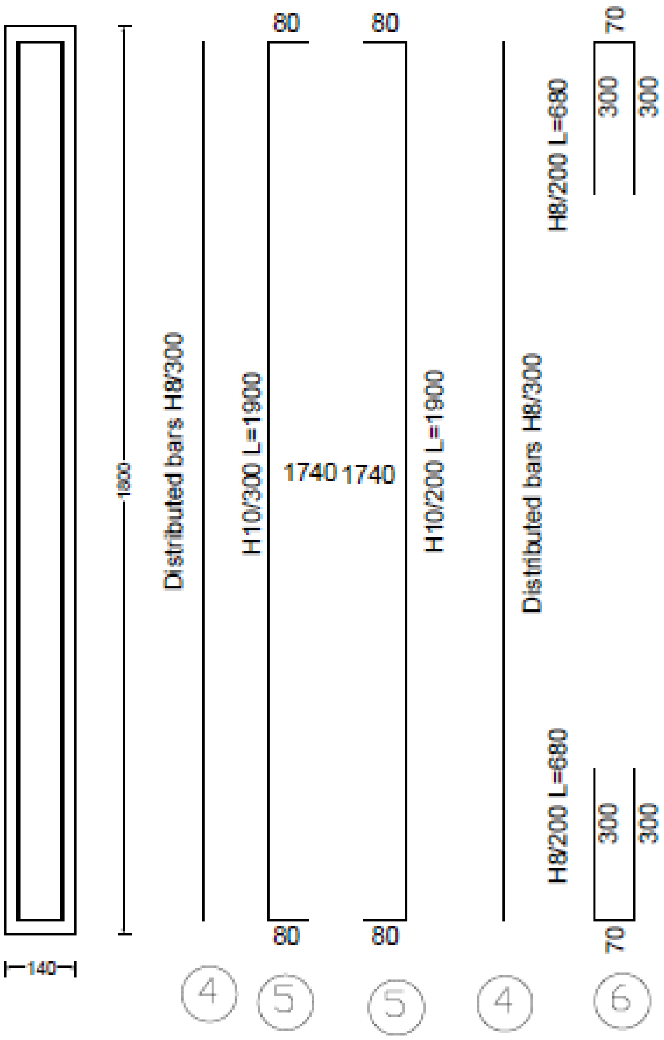


Figure 5 Slab reinforcement detail transversal section

Wall drawings

In the following structural drawings for the shear wall are reported. They show the main longitudinal and transversal reinforcement following structural calculations, additional devices and reinforcement for lifting and for wall to beams connections and foundation devices. The wall to beams connections and foundation devices have been designed in order to absorb the design seismic loads. Supplementary reinforcement is also considered according to the manufacturer technical manual.

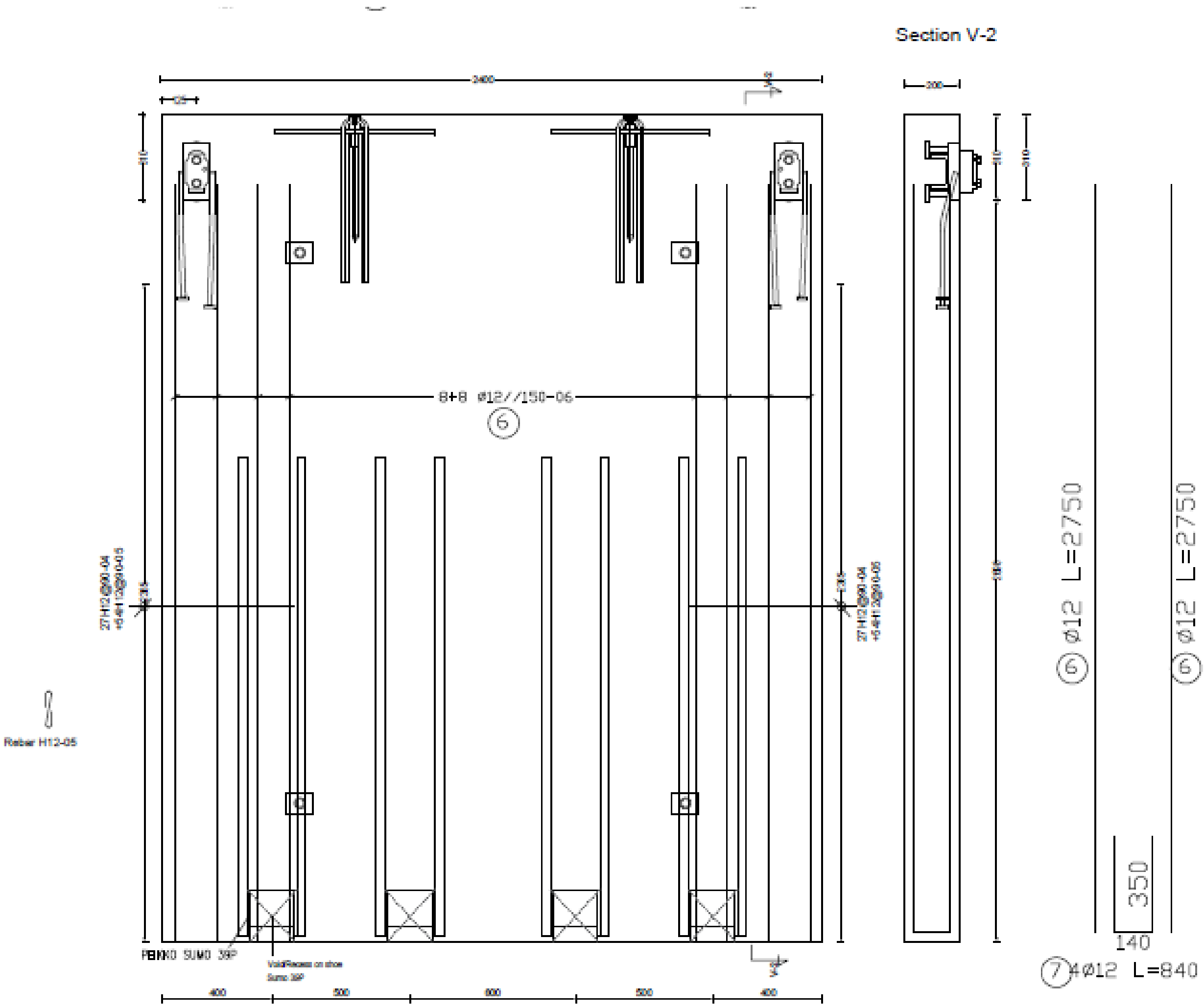


Figure 6 Wall primary reinforcement

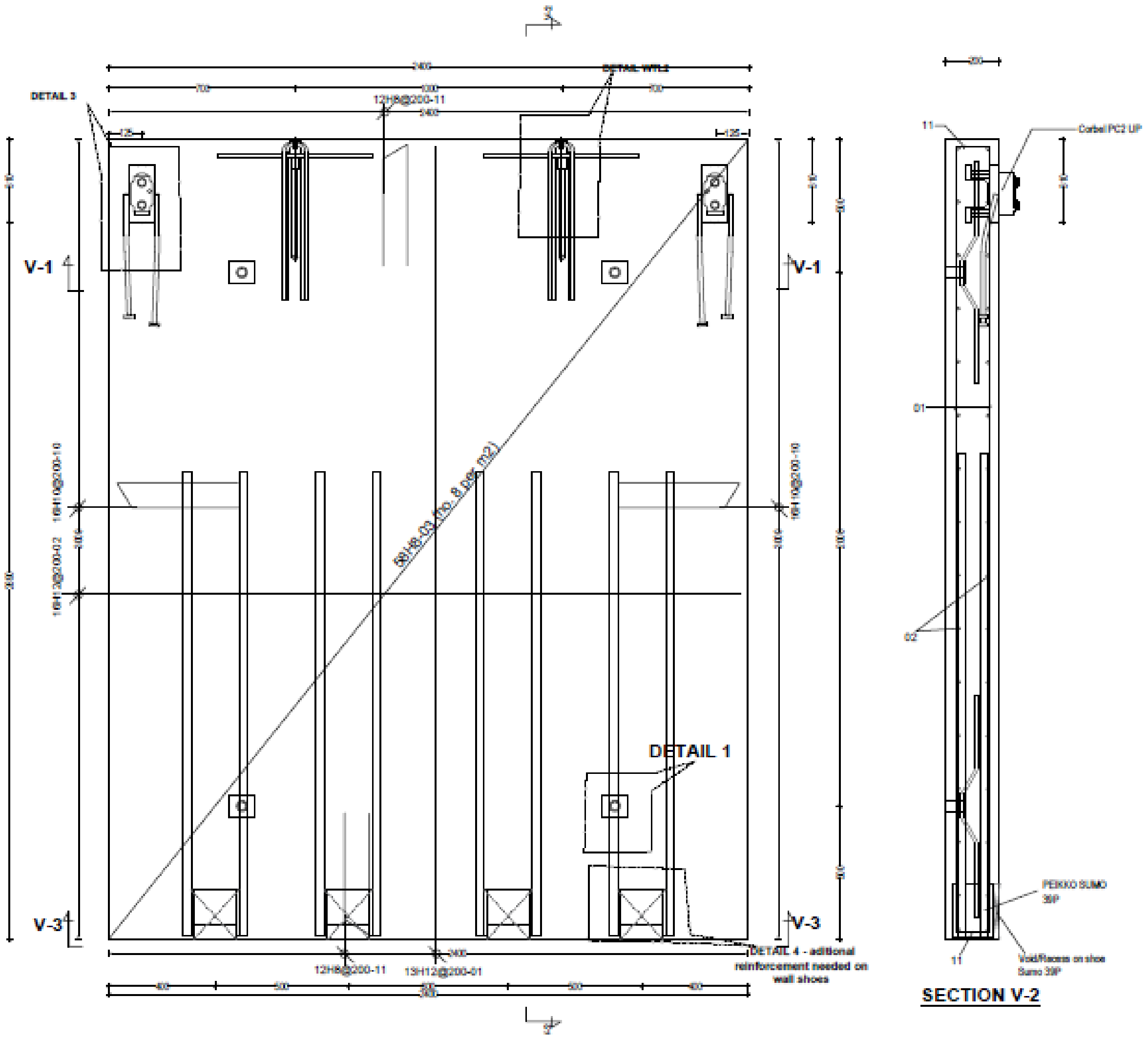


Figure 7 Wall lifting devices

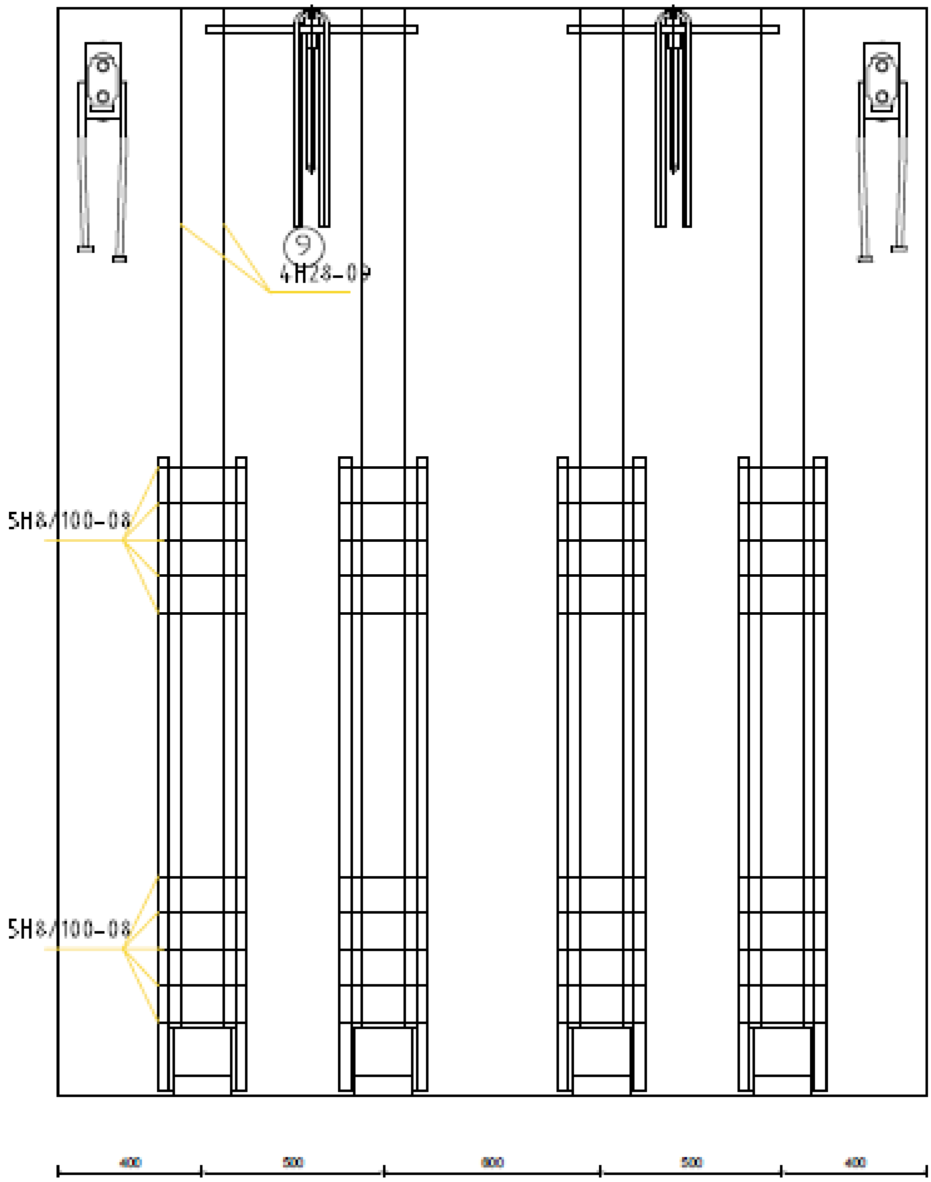


Figure 8 Wall additional reinforcement for wall foundation connection devices

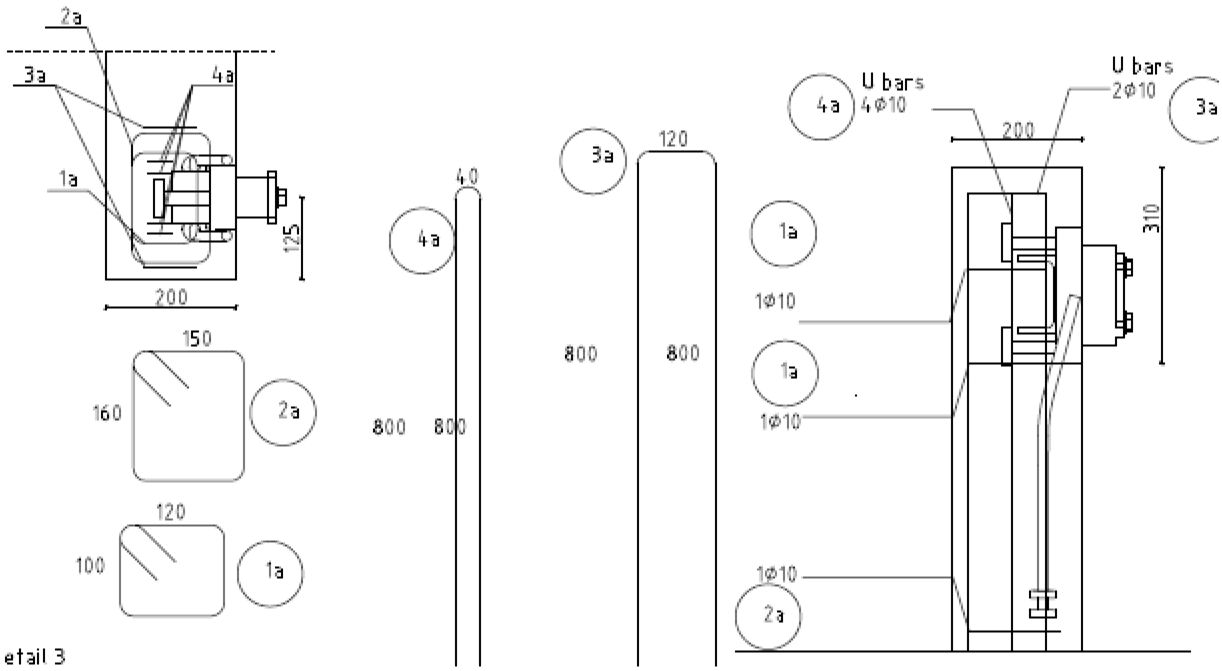


Figure 9 Wall-to-beam connection

Columns drawings

In the following structural drawings for the columns are reported. They show the main longitudinal and transversal reinforcement following structural calculations, additional devices and reinforcement for lifting and for columns to beams connections and foundation devices. The columns to beams connections and foundation devices have been designed in order to absorb the design seismic loads. Supplementary reinforcement is also considered according to the manufacturer technical manual.

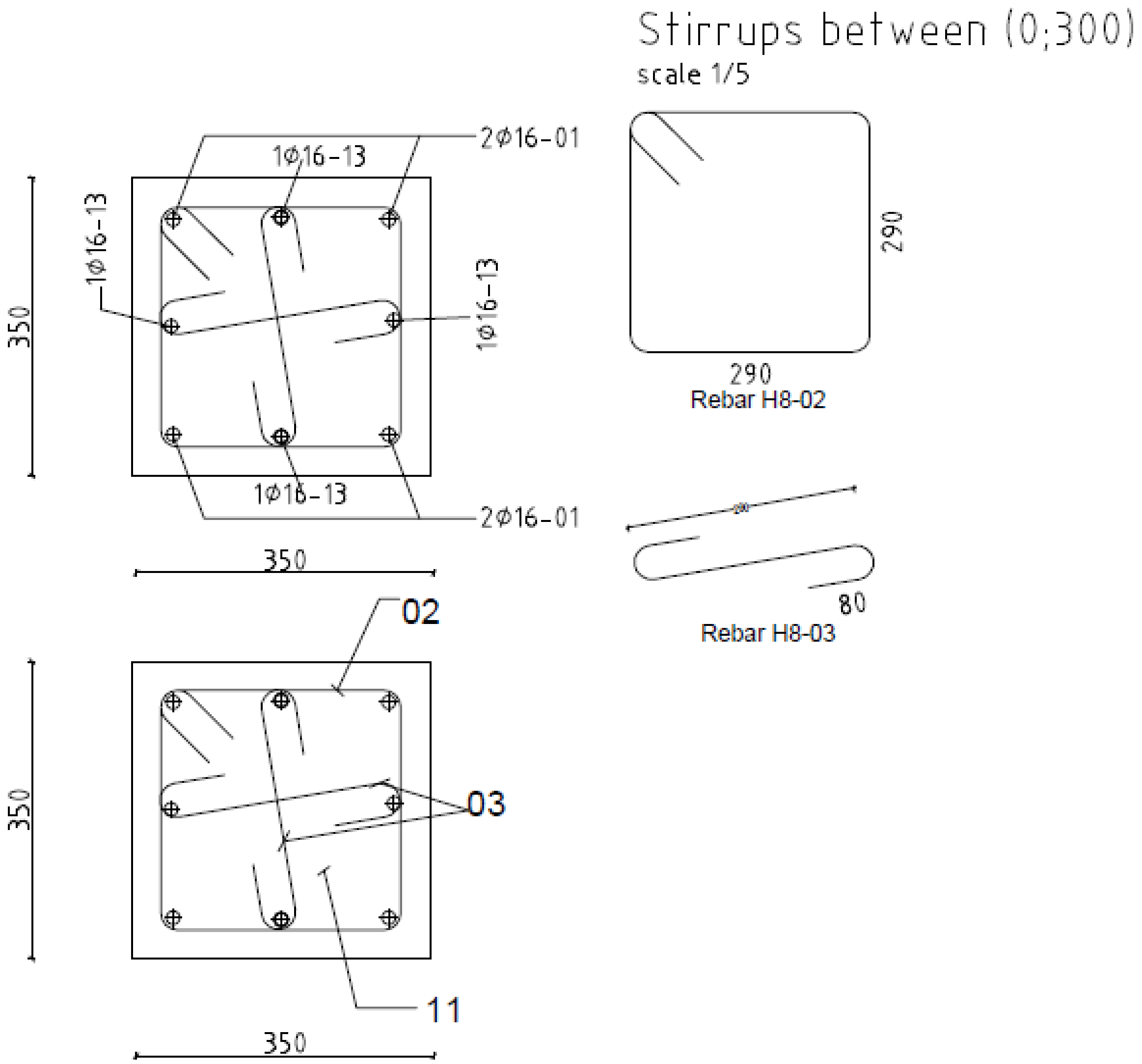


Figure 10 Column primary reinforcement

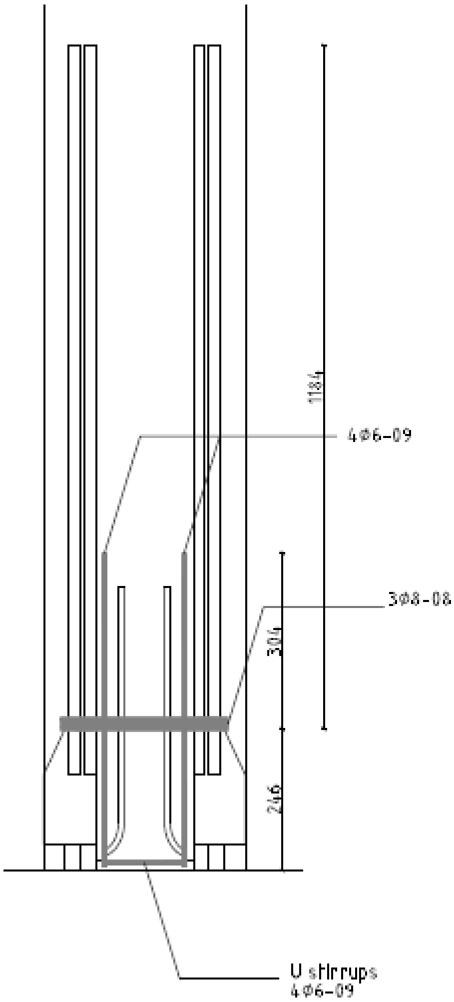


Figure 11 Column additional reinforcement at the column foundation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

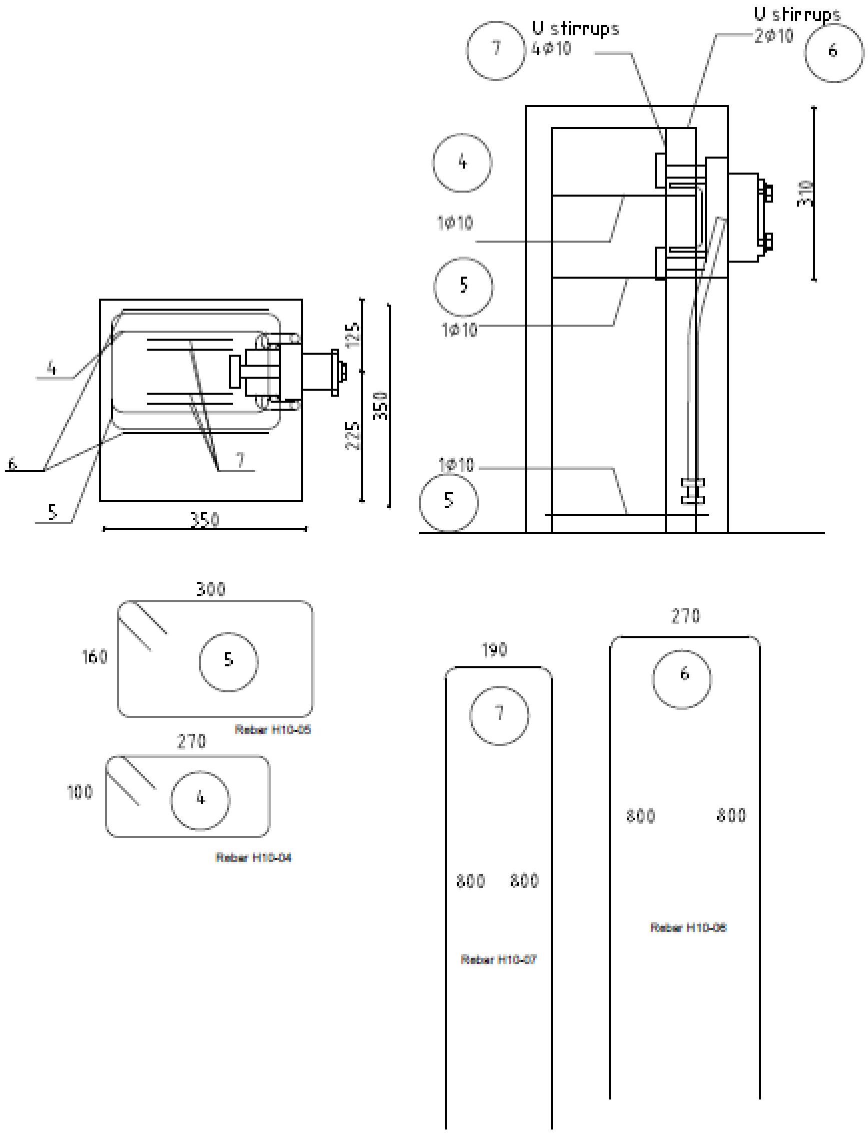


Figure 12 Column-to-beam connection

Beams drawings

In the following structural drawings for the beams are reported. They show the main longitudinal and transversal reinforcement following structural calculations, additional devices and reinforcement for lifting and for columns to beams connections. The connections to columns devices have been designed in order to absorb the design seismic loads. Supplementary reinforcement is also considered according to the manufacturer technical manual.

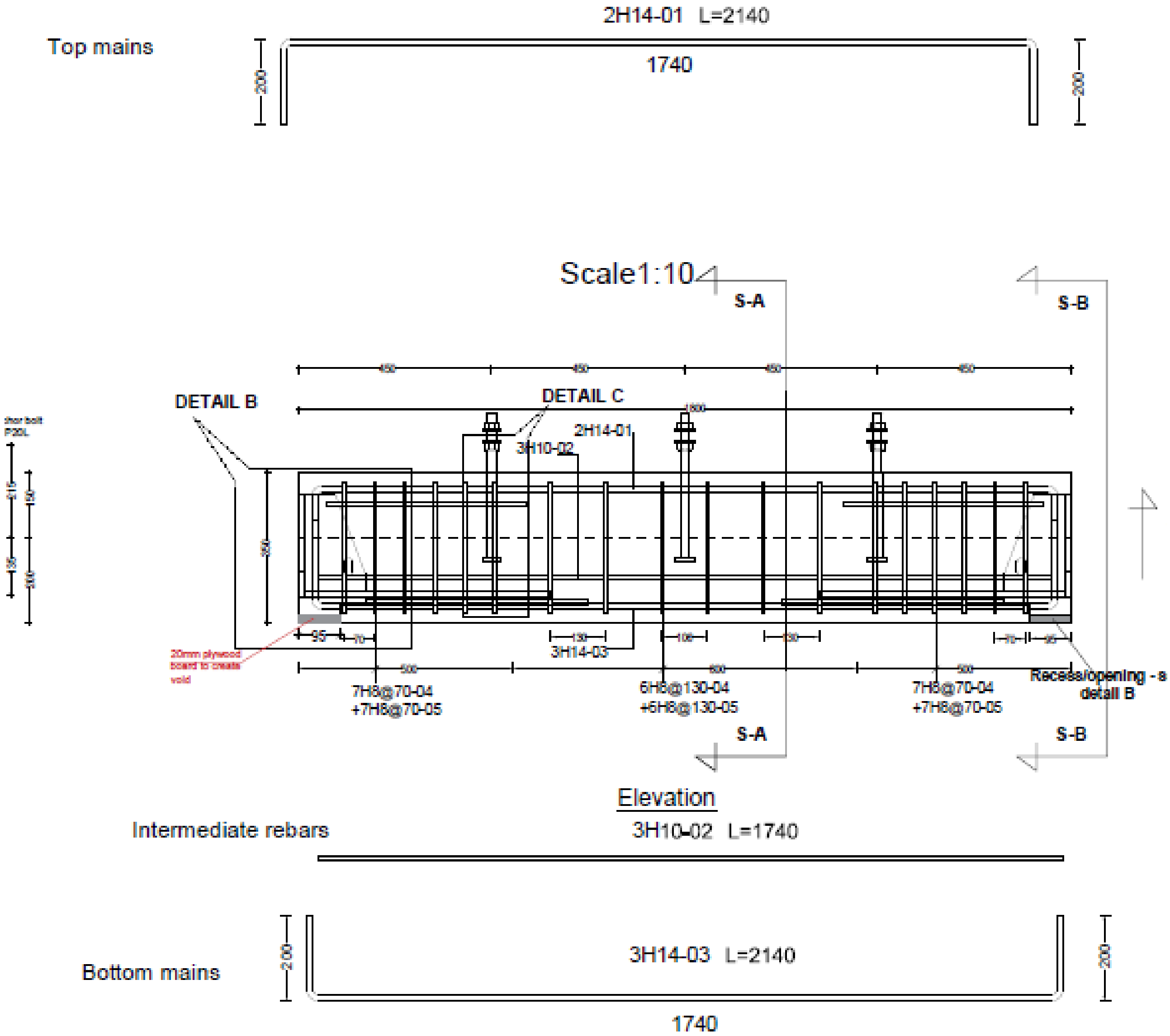


Figure 13 Beams main reinforcement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

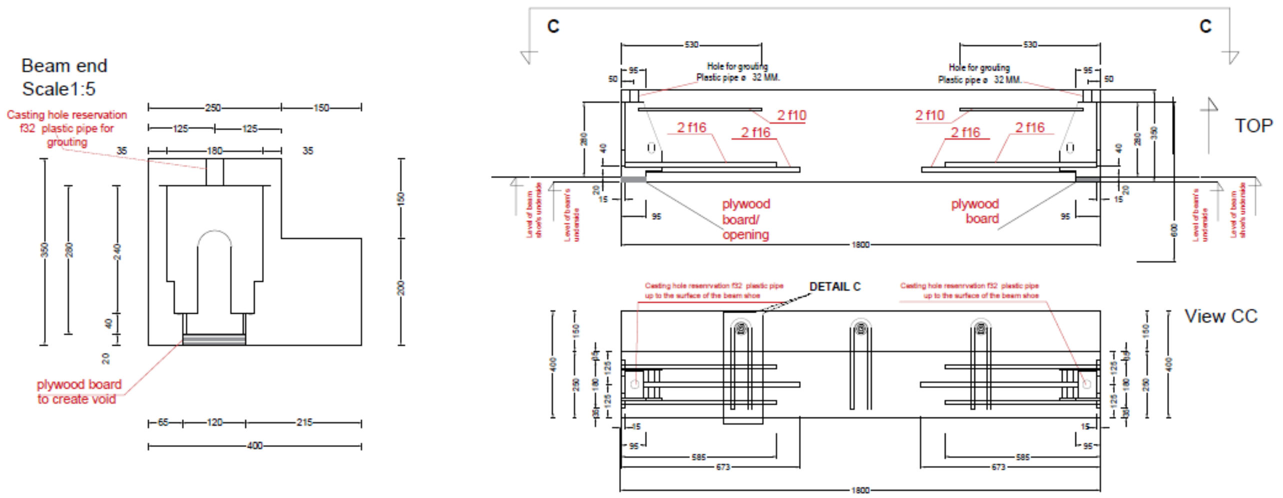


Figure 14 Beam-to-elements connection

3.3 Comments on the results

According to the modelling assumptions and the adopted design procedure, the precast concrete elements achieve the code requirements for seismic performance of buildings in medium ductility class for medium-high seismic loads. Reinforcement details fulfil the stricter ones between the minimum requirements of seismic requirements of Eurocodes and Italian building code, achieving high safety factors value, according to the results of the structural verifications. The mutual connections have been designed considering the worst conditions in terms of design forces and they have been verified for possible different conditions up to the lower level of possible design forces coming from the adjacent concrete elements.

4. CONCLUSION AND RECOMMENDATIONS

The main goals achieved in the present deliverable are:

– Description of the design procedures and assumptions for the selected prefabricated elements
– Description of the resulting characteristics in terms of geometry and reinforcement of the selected RE^4 elements for seismic test
– investigation of the expected seismic performance (safety factors) of the selected RE^4 elements with respect to European code requirements

The designed elements will be assembled in the seismic mock-up for shaking table test to be performed within WP6-T6.2 at the ITC-CNR facilities in Naples (Italy).

5. REFERENCES

CEN (2001) Eurocode 1: Actions on structures - Part 1-1 - EN 1991-1-1. Brussels, Belgium

CEN (2004) Eurocode 2 - Design of concrete structures - EN 1992 Brussels, Belgium

CEN (2005) Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings. Brussels, Belgium,

Circolare 02/02/2009 n. 617 (2009) Istruzioni per l'applicazione delle "Nuove norme tecniche per le costruzioni" di cui al D.M. 14 gennaio 2008. Gazzetta Ufficiale n. 47 del 26 febbraio 2009

D. M. 14/01/2008 (2008) Norme Tecniche per le Costruzioni. G.U. n. 29 4 febbraio 2008 (in Italian),

DISCLAIMER