PRECAST FIBRE REINFORCED CONCRETE ELEMENT OF RETAINING WALL

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Abstract

Fibre reinforced concrete (FRC) is a material whose utilization has been rapidly increasing in the concrete industry recently. The paper is focused on the study of FRC use for precast elements of retaining wall which is going to be built in the second half of this year. The aim of the study is to verify the feasibility of the precast element made of a concrete composite with addition of polypropylene fibres and minimum amount of conventional reinforcement. The article describes the whole procedure of the design and manufacture of the precast polypropylene fibre reinforced concrete (PFRC) element. The design and manufacturing technology of the material as well as the numerical simulation of the precast element on a finite element model are demonstrated. Three various stages of production (load cases) - demoulding, transportation and intended use were analyzed. Besides, the informative tests were conducted in order to acquire the properties of concrete at 28 days that was used for the manufacture. The static loading test of the PFRC element has not been performed yet as the applied research is in the phase of cost-effective pilot study which has to only verify the feasibility of the precast element.

Keywords: Fibre reinforced concrete, precast element, pilot study, numerical simulation

1. Introduction

Recently fibre reinforced concrete (FRC) is a material whose utilization has been rapidly increasing in the concrete industry. This development is caused by its physical and mechanical properties which contribute to traditional concrete elements and structures various economical benefits such as structure subtlety, part or full elimination of conventional reinforcement, resistance to mechanical load and surrounding environment. Therefore, it is necessary to search for appropriate structures where the benefits of FRC could be used.

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A structural application which at first glance seems to be ideal for the FRC use is the precast element of retaining wall (Fig.1). The wall is made up of several rows of elements

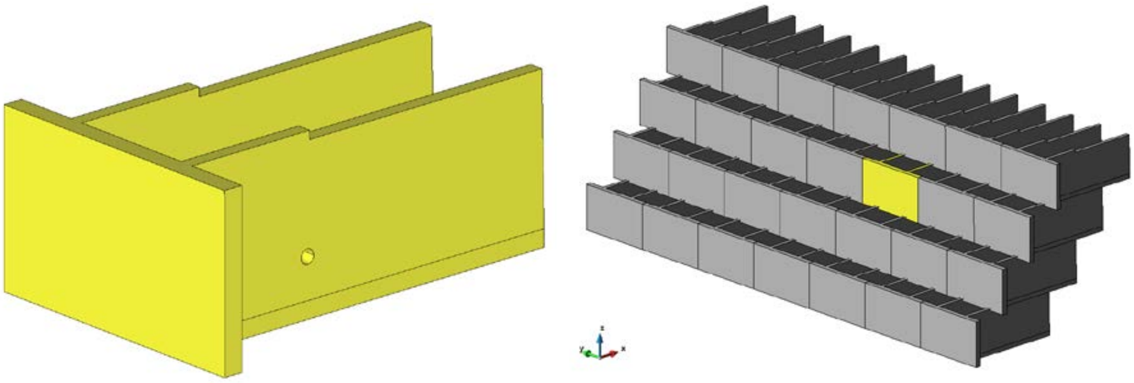

Fig. 1: Precast PFRC element (left) of retaining wall (right)

which together with infill soil constitutes the wall retaining backfill and undisturbed soil behind it. The precast element itself consists of a front wall (with stone facing), internal walls and bottom plate. All parts are made of polypropylene fibre reinforced concrete (PFRC) with minimum conventional reinforcement used for bonding separately manufactured parts. In this case the idea of the substitution PFRC for reinforced concrete clearly leads to many economical benefits, mainly the reinforcement installation is reduced at a minimum and thereby the manufacture process is more simple and faster.

This paper presents the whole procedure for the design and manufacture of the structural precast PFRC element of retaining wall. Within the scope of work, the design and manufacturing technology of PFRC is demonstrated, as well as the numerical analysis of the precast element on a three dimensional nonlinear model. Besides, the informative tests were conducted in order to acquire the properties of concrete at 28 days that was used for the manufacture. The tests were performed in accordance with conventional experimental methods. However, the amount of test specimens was limited as the tests were only informative. Also the experimental static loading test of the precast PFRC element has not been undertaken yet because currently the pilot study is only aimed at verifying the feasibility of the member.

Generally, considering the certain applications, the procedure when reinforced concrete is substituted by FRC with either minimum or no conventional reinforcement is adequate and thereby it offers the high possibility of practical utilization of FRC. Obviously, in case of the successful pilot tests it is necessary to apply to an experimental institute for the certified static loading test of the precast element before the member is approved for its practical utilization.

2. Structure of retaining wall

2.1 Precast element

The precast element is 600 mm high and consists of four basic parts - front wall (with stone facing), two internal walls and bottom plate (Fig.2) all made of PFRC. The thickness of each part is in the range from 50 mm to 70 mm. Due to the complex shape of the element the front wall is manufactured separately. The segment is concreted lying down in two steps. First, stone facing 30 mm thick as well as a double folded reinforcement mesh are placed into a mould (Fig.3). Then the segment is cast. The rest parts of the element are concreted at one go. The finished front wall is coupled with the rest parts of the precast element by the reinforcement mesh which is anchored to the internal walls and bottom plate while they are being concreted. Despite the robustness of the precast element it weighs only 450 kg.

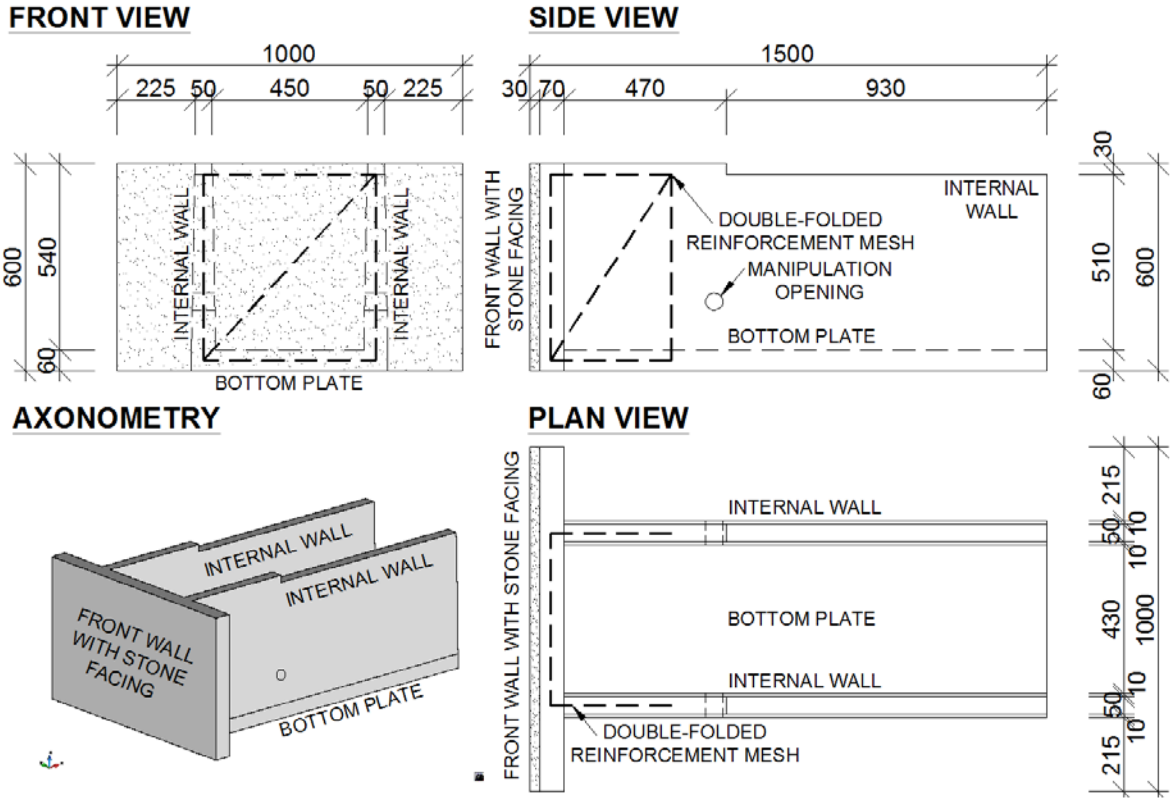

Fig. 2: Dimensions of the precast element

2.2 Construction process of retaining wall

The retaining wall consists of a number of precast elements which are gradually placed next to each other. First of all, the bottom row is installed directly on ground with sufficient bearing capacity. Then each element is filled up to its top surface with infill soil which is carefully compacted gradually along both sides of the internal walls in order to avoid excessive one side loading. In case of the void behind the row of elements backfill is

Fig. 3: Stone facing placed into mould (left) and front wall after concreting (right)

also used and compacted. Afterwards the second row of elements is positioned on the bottom one and filled up with infill soil which is compacted again. This whole procedure is repeated until the intended height of the retaining wall is reached.

3. Analysis of precast element

3.1 Demoulding

The analysis of the PFRC folded plate exposed to load induced by the manipulation with the element during its demoulding was performed especially in accordance with CSN EN 199-1-6 Eurocode 1: Actions on structures - part 1-6: General actions - actions during execution [1] and CSN EN 1991-3 Eurocode 1: Actions on structures - part 3: Actions induced by cranes and machinery [2]. Timber moulds standing upside down are used for casting the elements. This position during concreting requires two manipulation openings in the internal walls for a lifting steel rod. The elements are stored in a factory two days after casting. So in the phase of the manipulation right after demoulding it is necessary to take into account mechanical properties of concrete C30/37 XF4 at 2 days (Tab.1) which were determined by using a coefficient depending on the age of the concrete (1) in accordance with CSN EN 1992-1-1 Eurocode 2: Design of concrete structures - part 1-1:

$$\beta_{cc}(t) = exp\{s.[1 - (28 / t)^{1/2}]\} \tag{1}$$

General rules and rules for buildings [3], then concrete adhesion, inertial and dynamic effects induced by vertical acceleration. The value of coefficient of concrete adhesion was determined with respect to a type of used formwork which was smooth and oiled before concreting. The value of dynamic load factor was considered for common craves with manipulation speed no bigger than 1 m/s.

The numerical simulation on a three dimensional nonlinear model showed that the precast PFRC element is deemed to satisfy ultimate limit state criteria. That is confirmed by the stress distribution on the plate under the maximum considered load (Fig. 4). Tensile stress is distributed at the top of the element when the peak values about 0,5 MPa are situated in the area above the manipulation openings. On the other hand the area of compressive stress is only at the bottom of the segment, especially underneath the openings. Considering the stress distribution and vertical deformation, the position of the manipulation openings also looks optimal as the segment does not tend to overbalance.

Tab.1: Mechanical properties of concrete C30/37 XF4

Age of concrete	Type of value	f_{cm} [MPa]	f_{ck} [MPa]	f_{ctm} [MPa]	$f_{ctk,0,05}$ [MPa]	E_{cm} [GPa]
28 days	Characteristic	38,00	30,00	3,20	2,20	32,00
	Design	25,30	20,00	2,10	1,50	32,00
2 days	Characteristic	22,00	14,00	1,80	1,30	28,00
	Design	14,60	9,30	1,20	0,90	28,00

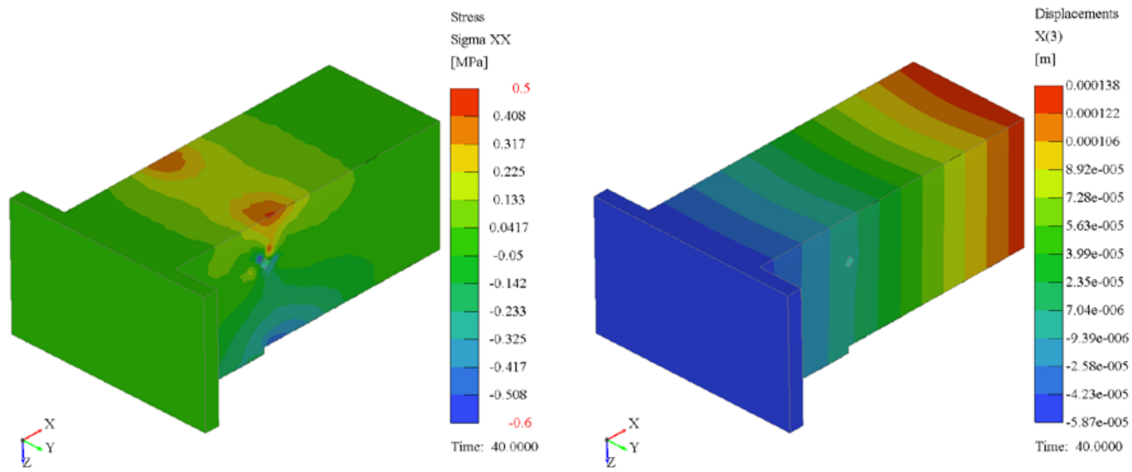

Fig. 4: Stress distribution (left) and vertical displacement (right)

3.2 Transportation

The precast PFRC elements are transported to the building site no early than at 28 days concrete age. Two manipulation openings in the internal walls are used for the manipulation. Inertial and dynamic effects caused by vertical acceleration were taken into account during the numerical simulation on a three dimensional nonlinear model. The value of dynamic load factor was considered for common craves with manipulation speed no bigger than 1 m/s. Considering both the dynamic factor and safety factor for live load the design value of the element weight equals 822 kg (8,22 kN).

Based on the stress distribution (Fig.5) it is evident that the precast PFRC element is deemed to satisfy ultimate limit state criteria under consideration. Despite the element subtlety and use of only two manipulation openings, the peak tensile stress is below the tensile strength of concrete composite which means that the state when the first crack occurs is not reached. The vertical displacement is neglected. Considering the stress distribution and vertical deformation, the way of lifting seems to be adequate as the element does not tend to overbalance during the manipulation.

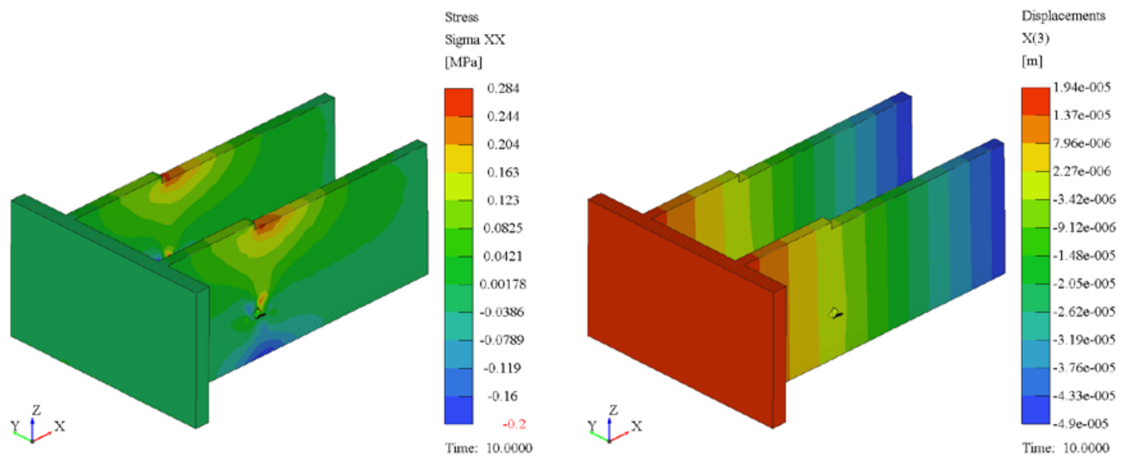

Fig. 5: Stress distribution (left) and vertical displacement (right)

3.3 Intended use

The last stage of production (load case) represents the element in its final position exposed to lateral soil pressure and load caused by compacting infill soil. During the construction of retaining wall infill soil is supposed to be placed and compacted gradually along the both sides of the internal walls in order to avoid excessive one side loading. However within the analysis the worst scenario is considered when infill soil is put and compacted only between the internal walls. The mechanical properties of common silty gravel as well as a characteristic value $2kN/m^2$ of load from compacting are considered for the analysis. Hydrostatic pressure is not taken into account as it is assumed that a drainage system is provided so that the hydrostatic pressure is eliminated.

The stress distribution and horizontal deformation (Fig.6) on the element look adequate for the considered load. The peak tensile stress occurs at the bottom of the walls on their internal sides. The maximum value is about 0,5 MPa which is far below the tensile strength of concrete composite. Conversely compressive stress can be seen on the external sides of the walls. Considering the peak values of both tensile and compressive stress the PFRC element is deemed to satisfy ultimate limit state criteria under consideration. The horizontal deformation at the top of internal walls is also neglected and does not play an important role.

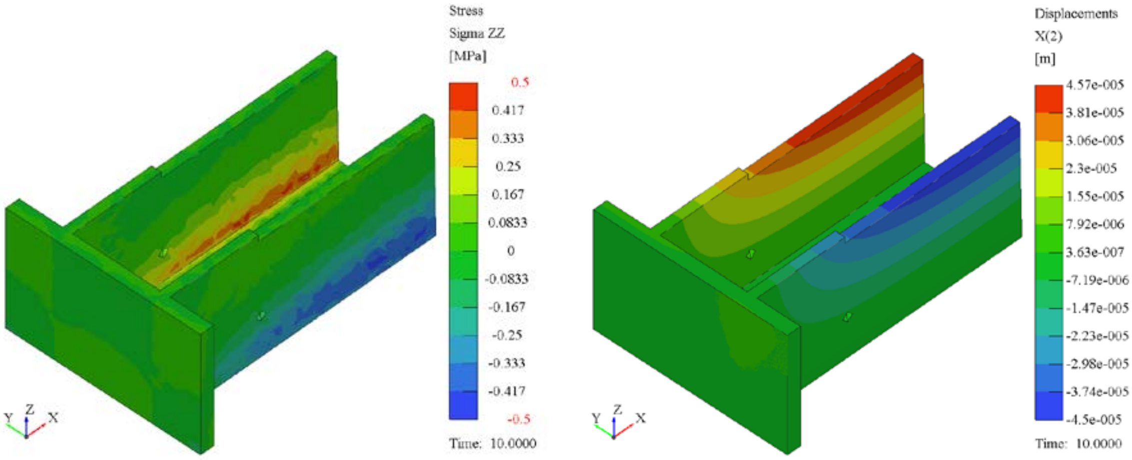

Fig. 6: Stress distribution (left) and horizontal displacement (right)

4. Manufacturing technology

4.1 Concrete composition

During designing the composition of concrete with addition of polypropylene fibres, it was necessary to reach the concrete strength class C30/37 XF4 which was required by a client. This strength class is widely used for concrete elements and structures in the prefabricated construction. The PFRC mixture is designed of available components used by the factory where the precast elements are produced. The PFRC composition had to be verified and optimized before the production of the elements started. The main issue was to ensure the workability of fresh concrete mass as well as its low viscosity. All the adjustments done during the optimization process were based on the extensive knowledge of qualified academic researches specialized in manufacturing technology of concrete.

4.2 Pilot production

The pilot production of the PFRC element of retaining wall was carried out in a standard factory of precast concrete elements in May 2015. Mixing concrete components and placing fresh concrete mass were conducted in a common way. The concrete mixture was transported 50 m from a mixture device to the prepared timber moulds. The procedure of concreting such subtle elements in their vertical position brought high requirements for PFRC itself. However, after demoulding the precast elements did not exhibit any significant defects on their surface caused by inappropriate casting (Fig. 7).

Fig. 7: The PFRC element

At the same time, the specimens for the informative tests were manufactured. The tests were conducted with the aim to verify the mechanical properties of the used concrete composite. The compression and split tension tests were performed on cubes 150 x 150 x 150 mm in accordance with CSN EN 12390-3: Testing hardened concrete - part 3: Compressive strength of test specimens [4] and CSN EN 12390-6: Testing hardened concrete - part 6: Tensile splitting strength of test specimens [5], respectively. The four point bending test was conducted on prisms 100 x 100 x 400 mm in accordance with CSN

Tab.2: Mechanical properties of PFRC

Mechanical properties	Test specimen	Strength [MPa]
Compression strength	1	49,5
	2	43,9
	3	48,6
Tensile splitting strength	1	3,2
	2	3,0
	3	3,1
Flexural strength	1	6,2
	2	5,1
	3	4,8

EN 12390-5: Testing hardened concrete - part 5: Flexural strength of test specimens [6]. According to the test results (Tab.2) it is evident that the strength class of PFRC used for the manufacture of the precast elements is at least C30/37 XF4.

5. Conclusion

In case of the considered precast element of retaining wall, the idea of utilization of concrete composite with addition of polypropylene fibres instead of conventional reinforced concrete brings many benefits. The manufacturing technology is more simple and faster as well as fixing reinforcement is eliminated and thus the production costs are reduced at a minimum. Besides, the elements exhibit better resistance to dynamic impact load, shrinkage and freeze thaw cycles. Thereby their durability increases. According to the numerical simulation, the precast PFRC elements satisfy the ultimate limit state criteria in all production phases when the total load is usually significantly below the ultimate bearing capacity. All the elements manufactured until the end of June also have not exhibited visible cracks or any other defects caused by the innovative manufacturing technology.

Acknowledgements

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant number SGS15/136/OHK1/2T/11.

References

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