PRECAST, PRESTRESSED GRANDSTAND OF PFRC IN STADIUM, HUNGARY

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SUMMARY

A stadium with 20.020 people capacity will be built in Debrecen, Hungary. The slab part of the precast, multi-stairs grandstand is only 12 cm thin and prestressed; PFRC is used instead of mild stirrups. Six types of polymer fibres were tested and compared according to RILEM regulations with the same dosage. Two selected types were tested with different amount of fibres between 0 and 10 kg/m^3. The effect of increasing the amount of fibres was determined. 6 pieces of real size grandstand elements were made, 4 with selected fibres and 2 with stirrups calculated according to EC2. Bending and shear tests were made under laboratory conditions. A FEM model was built up, which corresponds to the real size tests. The minimum dosage of fibres was determined with the FEM model.

Keywords: *polymer, fibre reinforced concrete, prestress, grandstand, stadium, FEM, Rilem*

1. INTRODUCTION

A stadium with 20.020 capacity and with 28.700 m^2 built-up area will be built in Debrecen, Hungary in 2013-2014. The structure is divided up into four separate units: the lower part of the building has two floors, the higher has five floors, and the intermediate curved sections represent a transition between them. Steel roofing covers the building.

To prove short installation time the load-bearing structure of the stadium consists of precast pinned frames with 7.5 m long tribune and ribbed floor (with cast-in-situ topping) elements. The grandstand consists of more than 400 different types of tribune elements with total of 11.000 m^2 surface. Most of the elements are straight, but there are many curved in the intermediate zone.

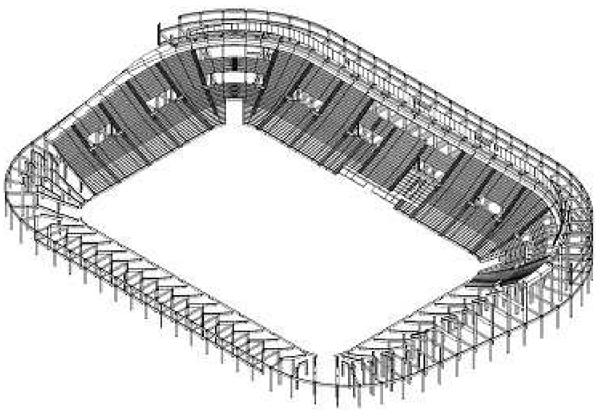

Fig. 1 *General view of the structure (partly covered by the grandstand elements)*

2. GRANDSTAND ELEMENTS

Common tribune elements are “L”-shaped, single stairs with terraced lower surface and sometimes with so-called raker-beam as support, but in this project - because of architectural reasons - the lower side of the elements is plain, and only on the upper side of the elements are “multiple-stairs” as can be seen in ***Fig. 2***.

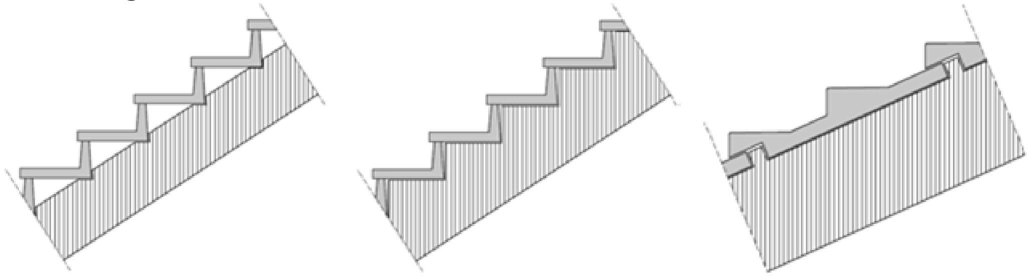

Fig. 2 a. *L-shaped stairs* ***b.*** *L-shaped stairs with raker beam* ***c.*** *multiple-stairs*

In the tender documentation grandstands were designed with mild reinforcement and with a 22 cm thick slab under the stairs. In our solution (see ***Fig.2.***) pre-stressing strands were used to make the slab thinner (12 cm) and to reduce the self weight. Pre-stressing also increases the shear resistance, this has enabled us to use fibre reinforced concrete instead of traditional stirrups in the zone, where $V_{Ed} < V_{Rd,c}$ which cause reduced manual labour during casting [1]. For reasons of high aesthetic demand polymer fibres are used instead of corrosion prone steel fibres, although in the very exposed parts of the stadium welded meshes were used to avoid protruding fibres.

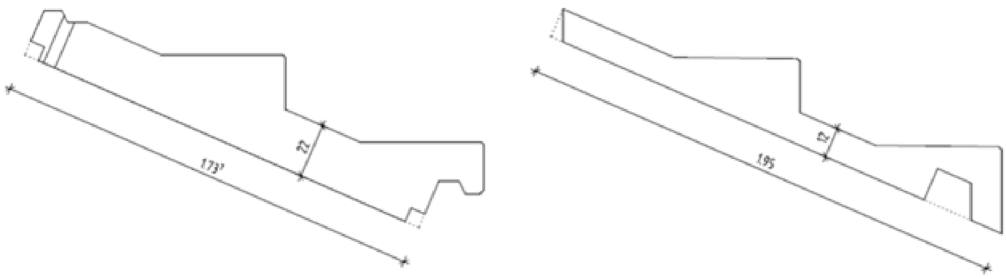

Fig. 3 a. *Tender and* ***b.*** *designed cross-section*

3. CHOOSING THE SYNTHETIC POLYMER FIBER

3.1 The effect of different types of fibres

We investigated in the Budapest University of Technology, Hungary, in the research project called *"The Big Crack 2012"* different synthetic fibre types distributed in Hungary [3]. We researched 6 types of macro synthetic, 3 types of micro and 2 types of steel fibre. We made the test according to the RILEM TC 162-TDF [4], with 3 point beam bending test (***Fig. 4.***), measured the load-deflection and load-CMOD results. Taking into account these results we were able to calculate the R_{e3} number according to the JSCE SF-4 Japanese standard [5], which is also called the measure number of ductility. The minimum dosage of the fibre according to the British TR34 guideline [6] of industrial floors is the dosage where the results reach the R_{e3} of 30%. All the macro fibres were dosed at 5 kg/m^3, so as to make the results of each fibre comparable.

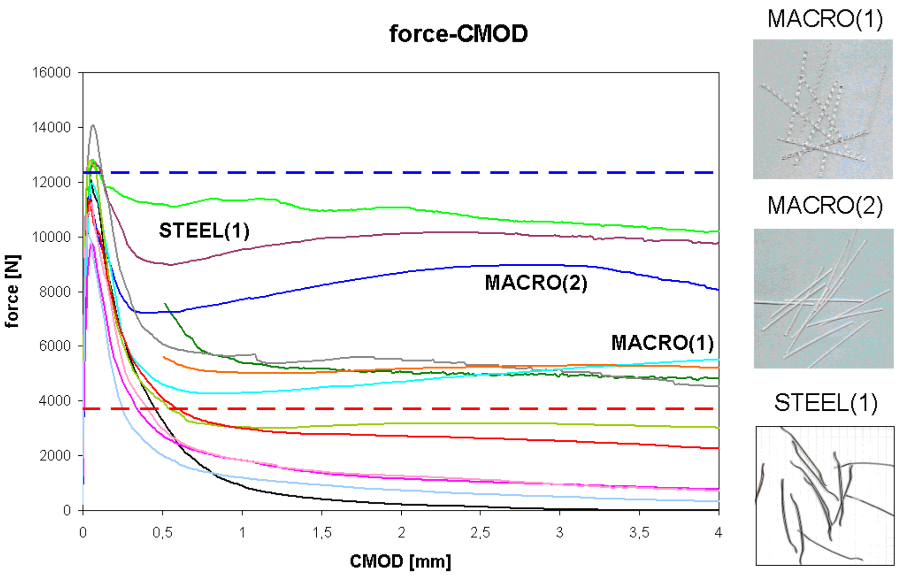

Fig. 3 *Results of the Big Crack 2012*

After the final results we continued the research with 2 types of fibres: MACRO(1) waved and MACRO(2) embossed macro synthetic fibre. We had experience with the fibre MACRO(1) and we knew its mixing properties. The fibre MACRO(2) was a new product in Hungary and has the best results along from the testing with a performance level of approximately twice that of the fibre MACRO(1). There are lots of factors modifying the behaviour of synthetic fibres, so we only could measure its properties and material parameters from the laboratory test. We tried to compare on the basis of the test series what are the values that make one fibre greater and other fibre smaller R_{e3} value. The basis of comparison of the fibres is the weight of the mixed fibre in one cubic meter of concrete. Hence, the number of the mixed individual fibres and the total length of the whole amount of fibre could vary significantly. The fibre MACRO(2) total length was more than twice that of the fibre MACRO(1) at the same kg/m^3 dosage. However, we didn't see any mixing problem with it.

With the micro fibres we researched two kinds of fibrillated and one kind of mono fibre, and the results showed correspondence with the results in the literature: the micro fibres marginally increased the ductility of the FRC. The fibrillated and the mono fibres helps only to control the early age plastic cracking, yet at the same time in each test it was shown that there was a decrease of the flexural strength of micro fibre reinforced concrete compared to plain concrete.

3.2 The effect of increasing dosage in the selected types of fibres

Tests continued with the selected two polymer fibres according to RILEM TC 162-TDF regulations. 6 pieces of 150 x 150 x 700 mm prism-shaped and standard cylinder samples were made for each dosage of fibres: 0; 2,5; 5; 7,5 and 10 kg/m^3. The post-critical behaviour was determined by force-displacement and force-CMOD diagrams.

The results can be seen in ***Fig. 5.***, it shows the higher the fibre content is, the higher the post-critical zone. In the case of MACRO(1) there is not a significant difference between 5 and 7,5 kg/m^3 dosage. Half the dosage of MACRO(2) fibres have roughly the same effect as MACRO(1) fibres. MACRO(2) has a hardening phase after cracking.

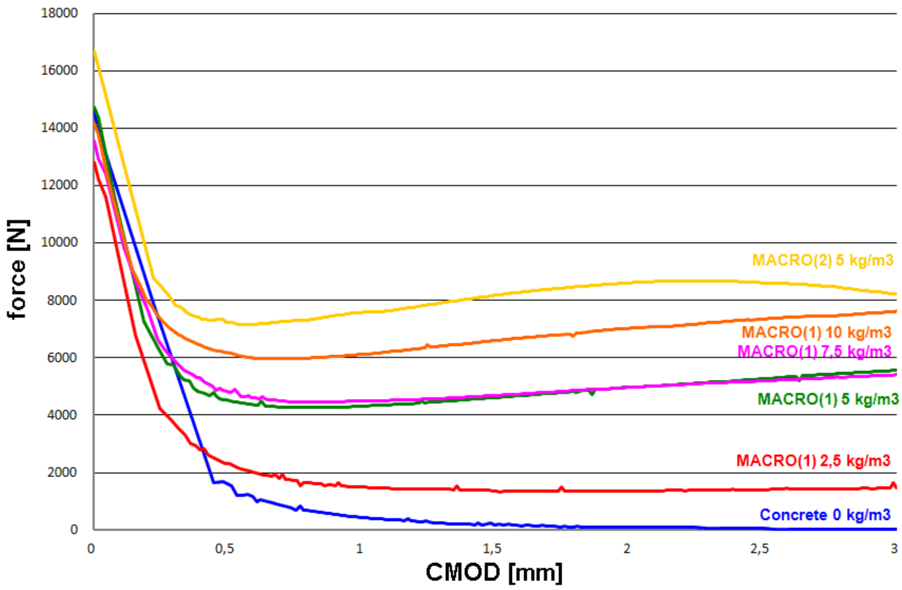

Fig 5. *Post-critical behaviour with different amount of fibres between 0 kg/m^3 and 10 kg/m^3*

4. LABORATORY TEST ON REAL SIZE ELEMENTS

6 pieces of real size grandstand elements were made, all of them were prestressed. 4 pieces were made of MACRO(1) PFRC with 5 kg/m^3 dosage and without stirrups in the zone where $V_{Rd,c} > V_{Ed}$; 2 pieces were made of concrete without fibres, but with stirrups according to regulations of EC2.

Bending and shear tests were made under laboratory condition. Elements were loaded on both stairs continuously, loads, deflection (vertical displacement: in front of and in the back of the element in the middle and in both ends; horizontal displacement: only in the middle of the grandstand) and crack patterns were recorded.

Results show all of the elements met the requirements and carried the load in the same way. The effect of stirrups can be proved by fibres in the concrete. There were more cracks on PFRC elements but with smaller widths. In the ultimate limit state the compressed zone was crushed and shear cracks from the support appeared at the same time, see Fig.5. In SLS the deflection was under 1,0 cm, it is not suspected to have significant displacement differences between a crowded and an empty element.

Fig.5. a. *Laboratory tests* ***b.*** *Compressed zone* ***c.*** *Shear*

5. FEA

We optimized the final dosage of fibre with Finite Element Analysis (**Fig. 6.**). The material model of the FRC was generated by inverse analysis: we modelled the laboratory beam test with *Atena* and compared its load-deflection with the real laboratory results (**Fig.7.**). After we found the suitable material model we used it for modelling the whole structure and also compared their load-deflection diagrams. Their diagrams fit, so we started to calculate with different fibre dosages. We chose the optimum from them, which was 3 kg/m^3 from MACRO(2). Different load combinations were calculated with this accepted dosage and material model, e.g. asymmetric load, local force.

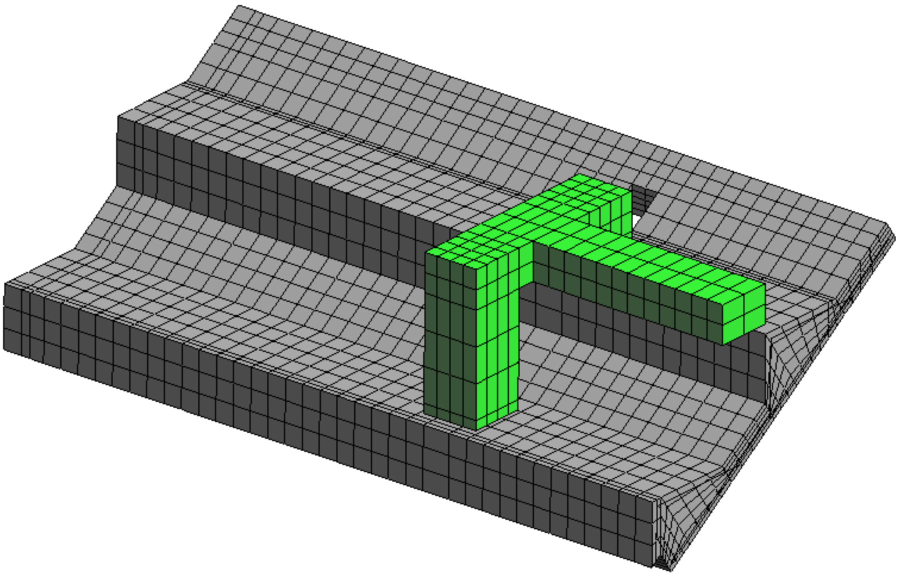

Fig 6. *FEA model*

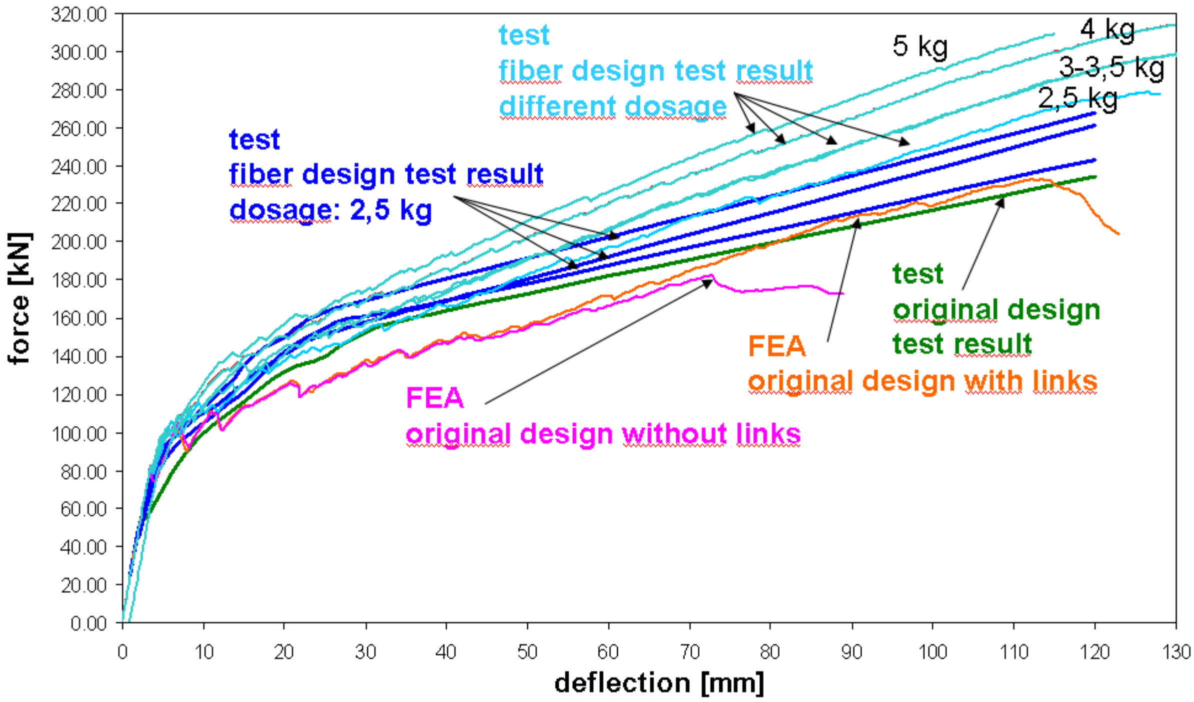

Fig 7. *comparing test and Atena FEA results*

6. CONCLUSION

Micro fibres control only the early age plastic cracking, but with a decrease in the flexural strength. The total length of MACRO (2) was more than twice of the MACRO(1) at the same kg/m^3 dosage, which caused twice as much amount of MACRO (1) had the same post-critical behaviour than MARCO (2). Real size tests showed the effect of stirrups can be proved by fibres. The FEA with *Atena* program showed an adequate fit with the real behaviour of the structure and was able for fibre amount optimisation.

7. REFERENCES

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