DESIGN OF INTEGRAL CONCRETE FACADE ASSISTED BY NUMERICAL SIMULATION

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SUMMARY

Design of façade of the school building in Laimburg, Bozen in northern Italy was based on an integral concept without expansion joints. Outer layer made of architectural reinforced concrete was verified for limitation of crack widths due to shrinkage and temperature. The analysis model was based on the finite element method and fracture mechanics. The method allowed optimization of façade reinforcement and its fastening to the base bearing substructure.

Keywords: *Facade, crack width, fracture mechanics, temperature, shrinkage*

1. INTRODUCTION

Design of building facades are often based on sandwich systems, where each layer is determined for a specific function. The inner reinforced concrete layer serves to bearing capacity, the intermediate layer provides a thermal insulation and the outer layer serves to an architectural design. An obvious major function of the outer layer is its architectural role. In addition it represents a shield of the building, which must resist to environmental actions of sun radiation, atmospheric conditions, wind, rain, etc. Due to the high intensity of these actions the surface layer is often composed of panels separated by expansion joints allowing movements imposed by the environment. However, the architectural design may require a continuous construction of the outer layer. Such a solution, which is referred here as "integral façade", eliminates the problems related to expansion joints (leakage, stress-induced dalamination of layers near joints, etc.). It requires adequate design verification based on the state-of-the-art design tools for actions due to volume changes of materials and more sophisticated resistance model based on advanced numerical methods.

Fig. 1 *Visual design of the building.*

The authors were involved in design of a new building for German and Italian trade school for fruit, gape and gardens in Laimburg, near Bozen in Trentino province of northern Italy as shown in design visualization in Fig.1. The facade of the building is made of architectural reinforced concrete with exposed aggregate, a typical local stone, red Bozen quarz porfyr. This aggregate is gained from a quarry on the building site and would be normally wasted. Due to a remarkable red color and texture of the stone, it provides an impressive architectural design reflecting local natural materials, see Fig.7.

The extremely large size of the façade the temperature changes presented a challenge for design of crack width limitation. Due to the high altitude mountain location of the building the severe weather actions on the façade should be respected. The design performed by a numerical simulation based on the finite element analysis included a crack verification and assessment of fastening performance. The application of the advanced numerical simulation made possible a safe verification of the large façade, see Fig.2, with consideration of complex boundary conditions and extreme actions of temperature and volume changes.

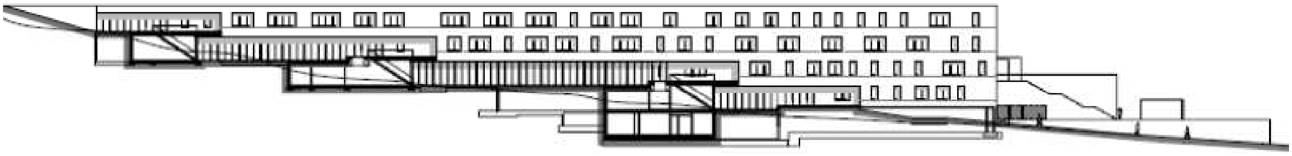


Fig. 2 *View of the façade.*

Authors are involved in a research of model uncertainties related to safe application of numerical simulations. This project provided an opportunity to investigate aspects of design based on numerical simulations. In this paper we shall not treat the theoretical background of the analysis and instead we put emphasis on the practical application. More detail description of the constitutive theory is available in [1].

2. NUMERICAL MODEL

Design was supported by numerical analysis with the commercial software ATENA. The crack propagation is based on a smeared crack approach combined with fracture mechanics. A crack band is used to control the strain localization and makes possible an assessment of crack width. Further, in case of reinforcement an interaction of concrete and reinforcement is possible. In this case two types of reinforcement bars were applied: smeared reinforcement and discrete bars. A bond slip of reinforcement should be also considered because it has a significant effect on the cracks width. The constitutive model is based on a principle of strain decomposition, where for each effect, fracture, plasticity, creep, etc. is assigned a special strain component. This allows a convenient consideration of various constitutive laws and their interaction.

Actions of temperature and shrinkage can be imposed by means of initial strains. In this project the effects such actions were considered by maximal values uniformly distributed over the facade. Alternatively, a development of temperature, shrinkage and creep can be analyzed in time and a detail history of damage can be traced, see [2].

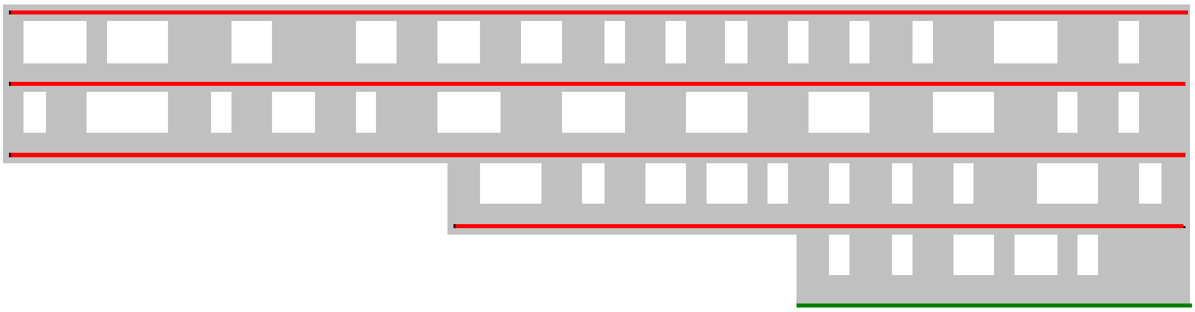


Fig. 3 *Geometry and supports of the façade model.*

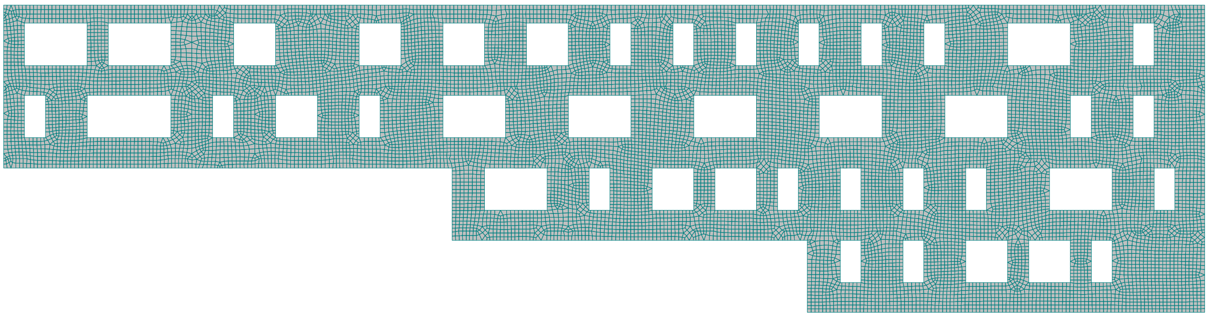


Fig. 4 *Finite element mesh.*

The facade was represented by a geometrical model shown in Fig.3. Reinforced concrete wall with openings for windows but without joints is 64 m long, 16 m high and 200 mm thick. The basic reinforcement was by ø12 at 100 mm but several other reinforcing alternatives were considered. Normal weight concrete C30 was considered.

The sandwich facade structure included: outer reinforced concrete layer 200 mm, insulation by polystyrene foam, and bearing reinforced concrete wall 250 mm. The layer, which is the subject of design, is fixed to the bearing reinforced concrete wall by steel fastenings. In a case study three types of anchors were considered: steel profiles, bolts Ø12 and bolts Ø20. Fastenings are shown in Fig.3 by red marks (showing one of several models considered).

Analysis was performed in a 2D plane stress state. Isoparametric quadrilateral elements of size 200 mm were used for the finite element model shown in Fig.4. Two layers of smeared reinforcement, each with the reinforcing ratio of 1.13%, were assumed in concrete elements. The fastenings are represented by elastic springs, and serve as supports to the 2D model. A second model in 3D was considered in order to investigate detail crack development near corners.

Loading was assumed by two load cases: Shrinkage at -0.00015 and Temperature change at -30 deg. These loads were applied subsequently each at 10 increments.

3. RESULTS

Numerical analysis provided detail information about deformations stresses and damage of the facade. In this project the main objective is a verification of cracks. An example of a crack pattern obtained by analysis is shown in Fig.5.

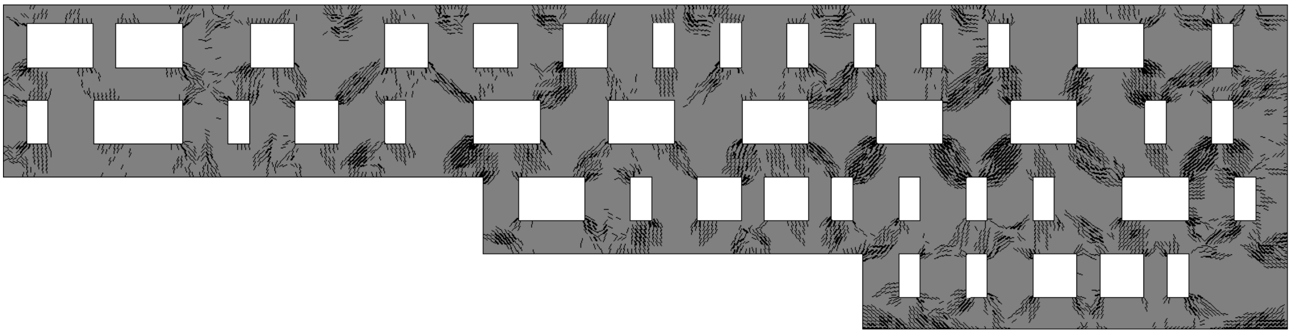


Fig. 5 *Crack pattern. Cracks >0.2mm shown.*

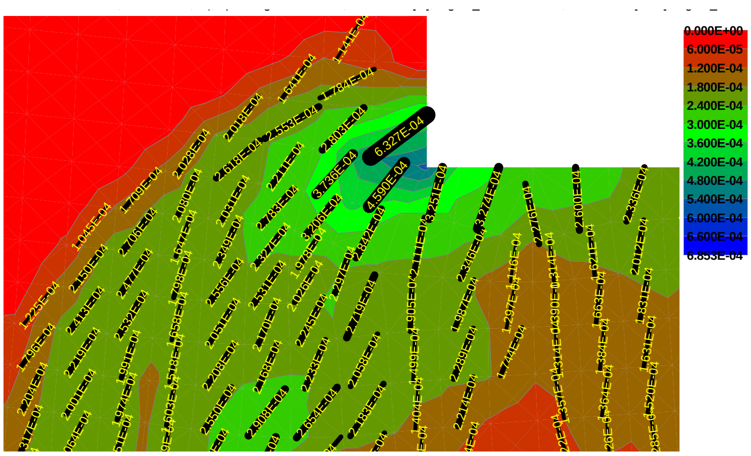
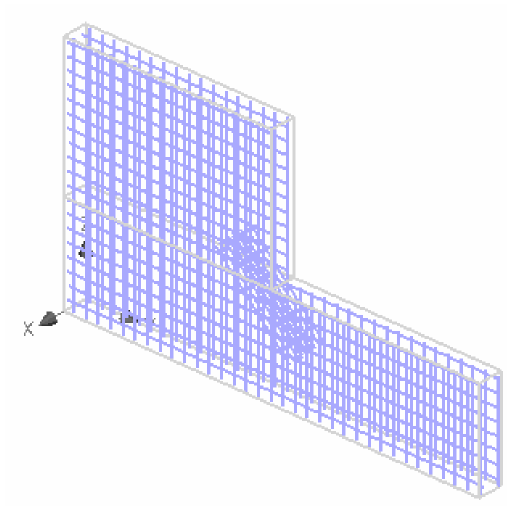


Fig. 6 *Detail of cracks near corner with display of crack widths.*

Fig.7 *Façade surface texture.*

It can be observed that larger cracks appear near the window corners and continue to a next corner. Therefore, additional reinforcement inclined by 45 deg. was considered near corned. This investigation was performed using a 3D model of a small section of wall near window corner, see Fig.8 and 9. Of course, boundary conditions applied to outer edges of this model are very important. Therefore, displacements of boundary surfaces were considered, which reflected expected movements found in 2D model of the entire wall.



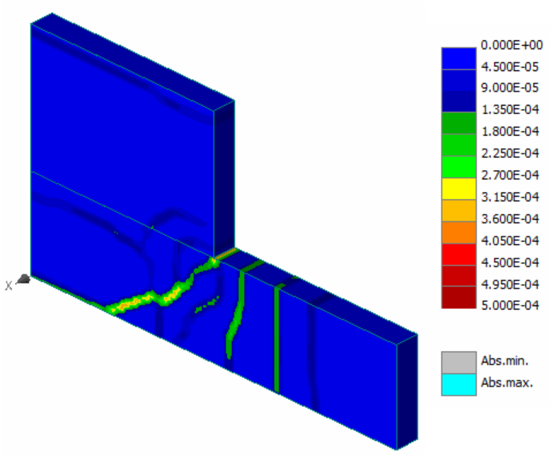


Fig. 8 3D *model of corner, reinforcement.* ***Fig.9*** *Crack widths pattern.*

The 3D model with reinforcement by discrete bars is shown in Fig.8. The crack widths shown in Fig.9 gave more detail data and helped to optimize the reinforcement and fastening of the façade.

Table 1 *Maximal cracks widths in 2D model.*

fastenings	***Crack width mm***		***Max. displacement mm***	
	Corner	***Wall***	***horizontal***	***vertical***
steel plate	**0.63**	**0.30**	**1.5**	**6.9**
bolts ø20	**0.60**	**0.27**	**3.7**	**4.3**
bolts ø12	**0.45**	**0.25**	**10.0**	**6.9**

There are significant differences between 2D and 3D models. The main difference is in fact that the 3D model cannot capture the effect of fastenings and instead the stiffness of fastening is modeled by assumed movements of the boundaries. Thus the model have similar conditions only in case of weak fastenings of 2D model and free boundary movements in 3D model. However such conditions do not correspond to a real conditions. However, the 3D model worked with more refined mesh and could confirm results obtained by the 2D overall model, especially the function of additional inclined reinforcement near the corner.

4. CONCLUSIONS

Design of the façade for the building in Laimburg was supported by a numerical analysis based on finite element method and fracture mechanics. It was confirmed that in locations of singular points in corners of widow openings, which are typical features of facades, the cracks are unavoidable but can be controlled. Considering the special surface texture shown in Fig.9 the crack width limits of 0.4 mm in corners and 0.2 mm in wall were accepted, since they represent mainly an aesthetic condition.

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5. REFERENCES

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