EXPERT SYSTEM FOR DIMENSIONING OF FAÇADE CLADDING

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Abstract
A web-based expert system for the dimensioning of natural stone claddings is presented. The dimensioning principles are based on the Eurocodes and the partial coefficient concept for invoking safety factors to cladding failures. The material properties needed for the dimensioning are determined through experiments defined by various EN-standards designated to natural stones.

Keywords: Façade cladding, natural stone, dimensioning, material testing, expert system.

1. Introduction

The use of thin natural stone claddings on facades is a relatively recent invention in building construction. The development of efficient production methods for cutting thin stone panels leading to competitive products has opened up a widespread use of thin stone claddings. However, the lack of common design principles of this relatively new type of product with accompanying anchoring systems has unfortunately resulted in façade installations that have been inappropriately executed. This results in subsequent problems leading to excessive maintenance and repair expenses. In more severe cases, panels have even fallen down from the buildings at a high risk for properties and people. For example, Winter (2002) raised severe criticism to the industry connected with façade panels.

The Standing Committee on Structural Safety, SCOSS (2000), which earlier concluded that problems with claddings are persistent, despite constant repetitions and warnings of difficulties and recurrent new failures. SCOSS also points out problems of attitudes towards design and the manufacture as new materials are more widely used, compliancy or cost-cutting by clients, reluctance to use professional engineers and the sheer difficulty of inspecting such elements and cladding fixings. Some problems stem from liability issues and unclear written agreements where, in the event of problems, the building owner will be the one that finally pays the bill for others mistakes.

Building stone products can't fulfill the safety requirements of the European construction products directive (CPD) by testing in accordance with the European standards for Natural stone alone since they do not give guidance about requirements concerning strength versus durability of the final construction.

One part of the EC-funded FP6 project I-STONE (NMP2-CT-2005-515762) focused on safety and quality aspects on the use of natural stone products. The strategic aim of the described project was e.g. to define solutions and strategies, to be adopted by the standardization committee CEN TC 246, to guarantee the ongoing development of a comprehensive and efficient use of natural stones. One aim was also to provide designers with an expert system fulfilling the requirements of Eurocodes, cf. EN 1990.

In general, the selection of design parameters in stone building can be controlled by conditions concerning mechanical functionality such as keeping their structural integrity during the service life within a predefined safety margin and/or fulfilling mandatory requirements controlled by regulations. There can also be economical conditions such as production, installation, service and maintenance costs. Other conditions concern esthetical aspects, policy or environmental values. However, only mechanical safety considerations have been included in the first version of the here presented expert system.

The first step towards this goal was to develop a new dimensioning and design basis for natural stones cladding panels mainly used in exterior construction applications. Through this also to secure improvements of existing technical

descriptions and to develop new recommendations where needed. The jointly developed new web-based software for dimensioning of façade cladding according to Eurocodes considers loads from gravity and wind along with strength properties of the material which together are used in the strength analysis. The program presently includes two types of anchoring systems: traditional dowels (most common system in Europe) and Fischerwerke's undercut anchors. The software is still a development version and free for anyone to use. It can be found on http://expertsystem.sp.se/. The use of this tool will ensure a transparent calculation and dimensioning procedure free of subjective influence.

2. Anchor systems for façade claddings

Two common anchor system types, dowel anchors and undercut anchors, have been chosen as implementation cases for the expert system. Pins (dowels) inserted in drilled holes at the side of the panels fixate the panels in the dowel anchor system which are attached to a frame or similar on the building. The other system is undercut anchors (Fisher FZP) which are pins that expand into specially shaped drilled holes on the back side of the panels which locks the pins in the holes. This system provides a concealed anchor system. The location of the anchoring points is shown in Figure 1.

3. Dimensioning of thin veneer façade claddings of natural stone

3.1 General

The partial safety factor concept is established within the building industry through the Eurocodes and has the advantage of being easy to standardize. Namely, when all sources of uncertainty have been identified it is possible to agree on the establishment of one safety factor representation for each uncertainty source and use it consistently. The first problem is to agree about all these uncertainty representations. This has not previously been done for stone cladding. The second problem with the method is that it has a tendency to be too conservative, since all safety factors are applied simultaneously. However, the probability that the unfavourable deviations for all sources appear at the same time is negligible. The Eurocodes have therefore introduced correction factors for this effect in some cases. However, such a procedure may become quite complex and needs a lot of time and experience to be properly calibrated.

There is a large problem of determining the correct partial coefficients for certain rock types which have a large natural scatter of strength properties, e.g. due to inhomogeneities. It is a prerequisite that the test specimens are representative for the actual claddings that are mounted on the buildings. Sadly, this is not always the case. In addition, the material can deteriorate due to a number of factors such as temperature and moisture variations, cyclic mechanical loading, chemical and bacteriological processes. The means of quantifying and handling these facts are active research areas and are beyond the current scope. The materials considered in this work are given in Table 1 and are exactly in accordance with EOTA (2006).

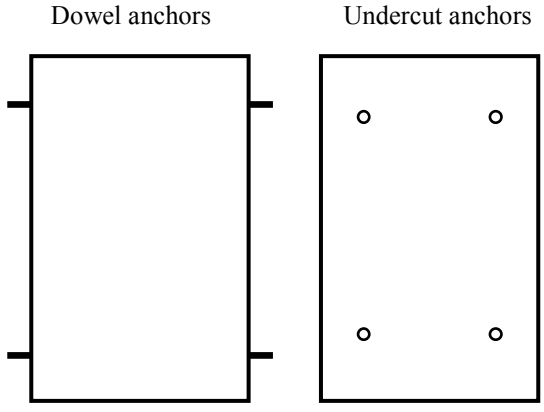

Figure 1: Principal picture showing the location of the anchoring points for the two anchor systems.

Table 1: Stone types for which the dimensioning procedures herein are valid.

Group of stone	Rock types
High quality magmatic plutonic rocks (plutonites)	granite, granitite, syenite, tonalite, diorite, monzonite, gabbro, other magmatic plutonic rocks
Metamorphic rocks with "hard stone character"	quartzite, granulite, gneiss, migmatite

3.2 Undercut anchors (Fischer FZP)

The partial factor safety approach was used by Fisherwerke in their proposed dimensioning procedure for Fischer FZP given in the ETA for the system, cf. EOTA (2006), see also Unterweger and Lehmann (2004). The partial coefficients were set by using data from a thorough experimental test program on natural stone specimens. Moreover, detailed installation

instructions were given. The considered loads acting on the panels are wind load, gravity and possible constraint loads from mismatching during mounting. Effects from other phenomena, such as temperature changes are not explicitly considered and are invoked in the general safety factors. The dimensioning was based on the anticipated failure modes in the stone panels due to plate bending and stone rupture due to tensile or compressive forces in the pins. Moreover, the strength of the steel pins was checked.

3.3 Dowel anchors

A dimensioning procedure was developed for the dowel anchor system based on a partial safety factor approach. The idea was to use the same dimensioning approach that was used for the Fischer FZP as far as possible for the dowel anchors as it is an approved procedure. The loads and partial coefficients were assumed to be the same. The failure modes in the stone panel in this case are also due to bending and rupture in the stone at the anchor points. When the external wind load, the cladding geometry and stone density are set, the maximum forces at the anchor points and maximum bending moments can be computed. The resulting forces at the anchor points can be computed. An assumption that only two bolts are taking the load was assumed, each with 50 % of the total load. This load is then checked against the allowed design value for stone rupture at the anchor point. A series of FE-computations were carried out for different cladding geometries and anchor positions. The results were summarized in diagrams where various geometry factors could be obtained in the same manner as in EOTA (2006) for the undercut anchors. The maximum bending stress based on a linear elastic analysis was then checked against the allowed design value of the bending stress.

4. Expert system

A web-based solution of the implementation of the expert system has been chosen over alternative implementations such as text based (handbook style) or computer based via distributed computer programs. There are a number of advantages with a web-based solution. The most important advantage concerns the quality assurance; the latest version of the expert system will always be available for the users. The free use of the software is a great advantage for an extensive implementation around Europe. The idea is that common underlying knowledge can be gathered at the same site as the dimensioning tool is used. At this point the expert system contains only the dimensioning tool for the two types of anchoring systems.

The design tool contains a user input section and a summary section, see Figure 2. The input section contains the following parts:

Dimensions: In the dimension module the user shall specify the stone panel dimensions, length, height, thickness and thickness tolerance.

Anchoring system: The user can select from the different implemented anchoring systems and pertinent anchor specifications, e g positions of the anchor points.

Material: A number of material parameters are entered on this page. The density of the material determined according to EN 1936 taking into account the water absorption under atmospheric pressure according to EN 13755 is used according to EN 1991-1-1. The characteristic values for the failure loads for the normal and shear forces, respectively, determined according to EN 1469. The characteristic failure bending strength with the outward panel side in tension is determined according to EN 13161 with specimen dimensions specified in EOTA (2006). The characteristic values are the 5% fractile values determined at a confidence level of 75%.

Load: The data to compute wind pressures according to EN 1991-1-4 are given. This comprises the building dimensions, the region on the wall where the panels are placed, the terrain category and wind parameters. The actual wind speed to use in a specific area is normally given in national documents.

Perform analysis: Additional data on the anchor bearing conditions are given. The computation can be executed resulting in a systematic list for

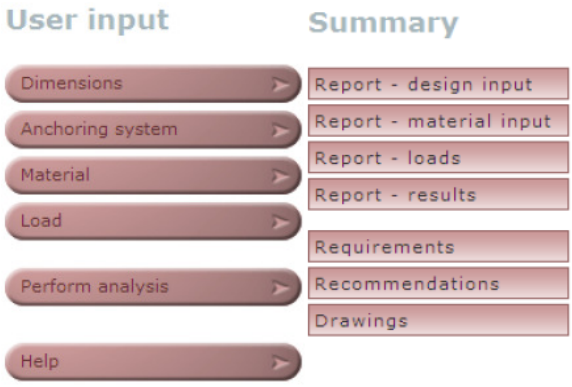

Figure 2: Pictures of the User input and Summary sections.

the control of computed results against all given design parameter requirements.
The summary section contains:
Report – design input: Contains a table with all entered input values for the panel geometries and anchoring system.
Report – material input: Contains a table with all material values and partial coefficients used in the subsequent computation.
Report – loads: Contains a table with all entered values for the building geometry, terrain category, wind parameters and calculated wind parameters according to EN 1991-1-4.
Report – results: Contains a table with all computed design parameters and pertinent allowed limits according to ETA and a check whether the design values are within allowed bounds.
The fields *Requirements*, *Recommendations* and *Drawings* are not used and defined at the moment.
It is possible to jump between the different sections to change parameters and rerunning the analysis. For pictures of the pages which are successively entered during the input stages and summaries we direct the readers to the website of the expert system due to limited space.

5. Conclusion

The persistent problem with inappropriately executed façade installations which has economical and safety implications justifies the necessity of an increased knowledge of the dimensioning of façade claddings. The developed web-based expert system is intended to yield a free access to common and controlled knowledge of the dimensioning of façade claddings of natural stone. The dimensioning procedures for different anchoring systems, dowel anchors and undercut anchors respectively, were implemented. Other anchoring systems and applications may be added. The system can be used today. Underlying material is planned to be added to the website in the near future.

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