AUTODESK UNIVERSITY 2013

Generation of Rebar Objects Using Results from Analysis and Design

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SE1669

This class demonstrates automatic generation of reinforcement elements using results from analysis and design in Autodesk® Revit® Structure 2014 software. Design requirements from building codes and company standards can be controlled by user-defined rules similar to the approach used in expert systems. Various aspects of this expert system are discussed. Visualization of existing and needed reinforcement further support users to ensure their quality of work.

Learning Objectives

At the end of this class, you will be able to:

- Detail reinforcement faster than before
- Standardize reinforcement design in your organization
- Understand how expert systems work
- Make better selections of Revit add-ins

About the Speaker

After receiving his diploma in structural engineering at Technical University in Munich, Thomas has worked in structural engineering and software development for over 30 years. He is the co-founder and CEO of SOFiSTiK AG, a leading German supplier of software for analysis, design, and detailing of structures. He was on the board of the German section of buildingSMART® for more than 10 years, and chaired the working group “Innovations” of the Bavarian chamber of building engineers. Whenever time allows, he loves to fly balloons and to sail.

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Introduction

From the early days of computers, software vendors tried to support the complete workflow of analysis, design and construction. These software handled single parts of buildings separately and did not become a real standard in the past. The reason for that was their limitation to standard problems, lack of standard modelling tools as well as missing flexibility.

The biggest problem however was that most analysis software handled analytical models only, which in general differ from architectural models. This has been one of the ideas behind Autodesk® Revit® Structure, which supports all engineering disciplines of a building in one data model.

The design of reinforcement differs between different countries due to different design codes. In addition, there are different practices how to reinforce concrete structures and very different opinions about a perfect design of it. This sometimes differs between different engineers in the same office!

This presentation will report about a new general approach to semi automatically generate rebar objects using design results. In a first step focus is on regular areas of buildings containing beams, columns, slabs and walls only.

Workflow

In general the workflow of structural engineers consists of several tasks. Not all of these tasks will be performed in each single step of a planning process. One task is modelling the load carrying parts of the structure. Next is the definition of loads and boundary conditions and performing structural analysis. Using the results various design tasks have to be performed to ultimately determine the required reinforcement in concrete structures.

In a separate step a 3-dimensional reinforcement model has to be designed and finally 2-D-drawings with a symbolic representation of the bars have to be derived from the model.

This presentation will cover the last two steps only.

Generation of Reinforcement

Input Data

Essentially, we require the architectural model (i.e. the concrete layout) and the analytical model based on the architectural model for analysis and design. It is essential, that analysis and design has been started from an integrated model in Revit. Design results (e.g. required reinforcement), calculated by the SOFiSTiK design modules, can be stored in the Revit model as Result Sets in a first step. Similarly, it would also be possible to use results calculated by Autodesk Robot which have been stored in the Result Sets.

As the amount of data which can be stored within Result Sets is somehow limited and does not completely map to the amount of data generated by SOFiSTiK, we also provide the possibility to retrieve the reinforcement results directly from SOFiSTiK's native database.

Rules

The generation of the reinforcement bars is based on the calculated required reinforcement stored for the various structural members. The generation process is controlled by specific rules which are provided in a separate configuration file and which can be modified by the user. The rules are used to control design code requirements as well as user specific settings.

The procedure thereby follows generally the approach of rule-based 'Expert Systems' in which the knowledge of an expert required to accomplish some task is separated from the general program logic and encoded in a specific rule base.

As an example, the definition of the anchorage length in Eurocode EN 1992-1-1:2004 reads:

(2) The design value of the ultimate bond stress, f_{bd}, for ribbed bars may be taken as:

$$f_{bd} = 2{,}25\ \eta_1\ \eta_2\ f_{ctd} \qquad (8.2)$$

where:

f_{ctd} is the design value of concrete tensile strength according to 3.1.6 (2)P. Due to the increasing brittleness of higher strength concrete, $f_{ctk,0,05}$ should be limited here to the value for C60/75, unless it can be verified that the average bond strength increases above this limit

η_1 is a coefficient related to the quality of the bond condition and the position of the bar during concreting (see Figure 8.2):
η_1 = 1,0 when 'good' conditions are obtained and

η_1 = 0,7 for all other cases and for bars in structural elements built with slip-forms, unless it can be shown that 'good' bond conditions exist

η_2 is related to the bar diameter:
$\eta_2 = 1{,}0$ for $\phi \leq 32$ mm
$\eta_2 = (132 - \phi)/100$ for $\phi > 32$ mm

(2) The basic required anchorage length, $l_{b,rqd}$, for anchoring the force $A_s \sigma_{sd}$ in a straight bar assuming constant bond stress equal to f_{bd} follows from:

$$l_{b,rqd} = (\phi / 4)\ (\sigma_{sd} / f_{bd}) \qquad (8.3)$$

Where σ_{sd} is the design stress of the bar at the position from where the anchorage is measured from.

Values for f_{bd} are given in 8.4.2.

These requirements may be defined in the SOFiSTiK rule base as (the '$' precede comment lines):

$ 8.4.2 Ultimate bond stress
*f_bd = 2.25*eta_1*eta_2*f_ctd*

```
$ 8.4.2. Bond conditions
eta_1 = 0.7 ; isBondGood : eta_1 = 1.0
eta_2 = 1.0 ; d_asl > 0.032 : eta_2 = (0.132-d_asl)*10

$ 8.4.3 Basic anchorage length (based on total yield strength)
lb_rqd = (d_asl/4) * (f_yd/f_bd)
```

Each of the rules in the configuration file consists of an IF ... THEN ... type expression which consists of a condition and an assignment which expresses the value of a variable as a function of other variables. A variable consists of its value and a valid domain (min/max), which can also be modified using arithmetic expressions. Most of the variables will be provided and set by the system during runtime, like for example the concrete tensile strength f_ctd, which will be set within Revit from the material definitions, but it would also be possible to define new variables.

The rules can be entered in any order. The program sorts the rules internally depending on their mutual dependencies and evaluates them accordingly, provided that no circular dependencies are given. This 'declarative style' of programming allows to encode the logic in a more readable way, for example it allows to list rules in the same order they are given in the design code. This in turn makes it easier for users with no specific programming background – which is usually the case with the design engineer - to control and modify the settings.

User Preferences

Many engineers (and experienced draftsmen) follow rules of thumb like "main reinforcement in beams with height > 0.4m is at least of diameter 16mm" or "in case main reinforcement in beams is a certain diameter (i.e. 16mm), supplementary bars should not differ more than two values from main reinforcement (i.e. 12mm, 14mm, 16mm, 20mm or 25mm only). Such kind of settings could also be defined in the rule base, for example:

```
d_asl = [0.010, 0.012, 0.014, 0.016, 0.020, 0.024, 0.028, 0.032]

Is_Beam {
  d_asl <= 0.028
  Section_Height >= 0.40 : d_asl >= 0.016
  Section_Height <= 0.60 : d_asl >= 0.020
}
```

After defining the allowed values for the diameter of the longitudinal bars 'd_asl' the range of diameters is restricted according to the section dimensions. The Variables 'Is_Beam' and 'Section_Height' are set during runtime by Revit.

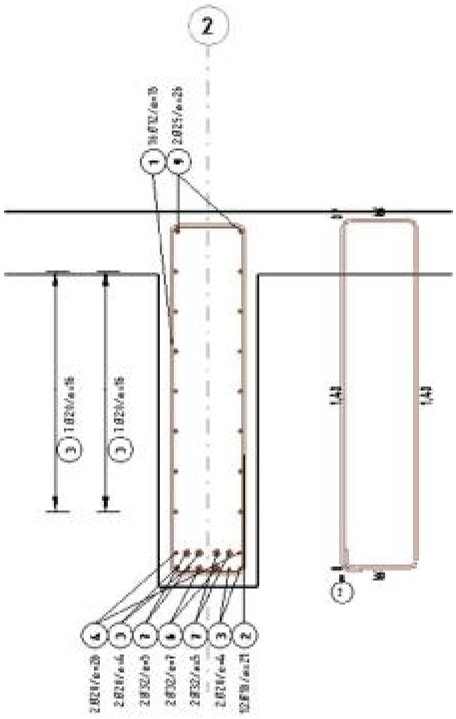
Optimization

Good reinforcement design is always a compromise between several goals. For example, we want to have as little reinforcement mass as possible, but we also want to limit the variation of bars. These kinds of requirements can be controlled by weighting factors, which may be used to influence the outcome.

These factors can also be set within the rule-base. Currently are supported:

- F1: *try to use as less bars as possible (increase rather diameter than number)*
- F2: *try to reduce difference between inserted and required reinforcement*
- F3: *try to avoid using multiple layers of reinforcement (bending beams only)*

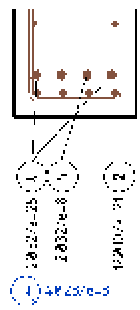
The following sample will demonstrate how different settings lead to different results:



We have a heavy two-span T-beam supporting columns from three storeys above. Its section is 150cm * 40cm and the required maximum bottom reinforcement is 54,7cm² in the middle of the span. Over the support in the middle, 77,2cm² top reinforcement is required according to design.

With standard settings the result is as left, the program generates 6 bars with diameter d=20mm and 6 bars with d=32mm, resulting in 67,1cm². Over the column we get 2 bars d=25mm and 11 bars d=28mm, resulting in 77,6cm², which is almost theoretic optimum. So further optimization for this point in the building is not necessary.

In a second attempt we try to increase the weighting factor F2 from 1 to 5. As expected the generated reinforcement in the field is reduced to 58,1cm² using 8 bars d=25mm and 6 bars d=20mm. The number of the bars has been increased by one.

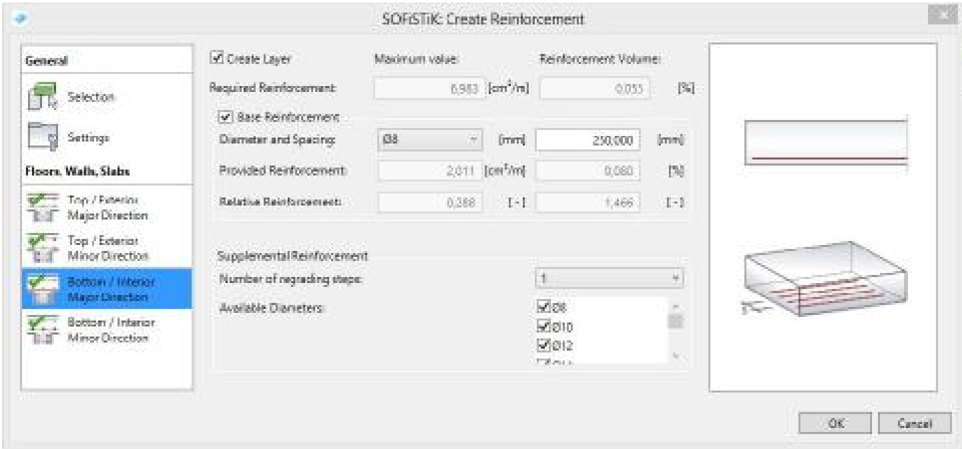


A third attempt is to help the software by choosing 2 bars d=28mm as basic reinforcement. This results in 4 bars d=28mm and 4 bars d=32mm with an area of reinforcement of 56,8cm² (picture on the right).

At present the development process is not finalized. Further optimization of rules and weighting might be achievable through additional investigation.

Basic Reinforcement

During the development of the software it became obvious that in many cases users want to have a direct influence, in particular, on the choice of the basic reinforcement. Therefore a set of dialogs has been created, in which users can see the basic reinforcement proposed by the software and in which it can be modified. All reinforcement except this basic reinforcement will be created automatically.

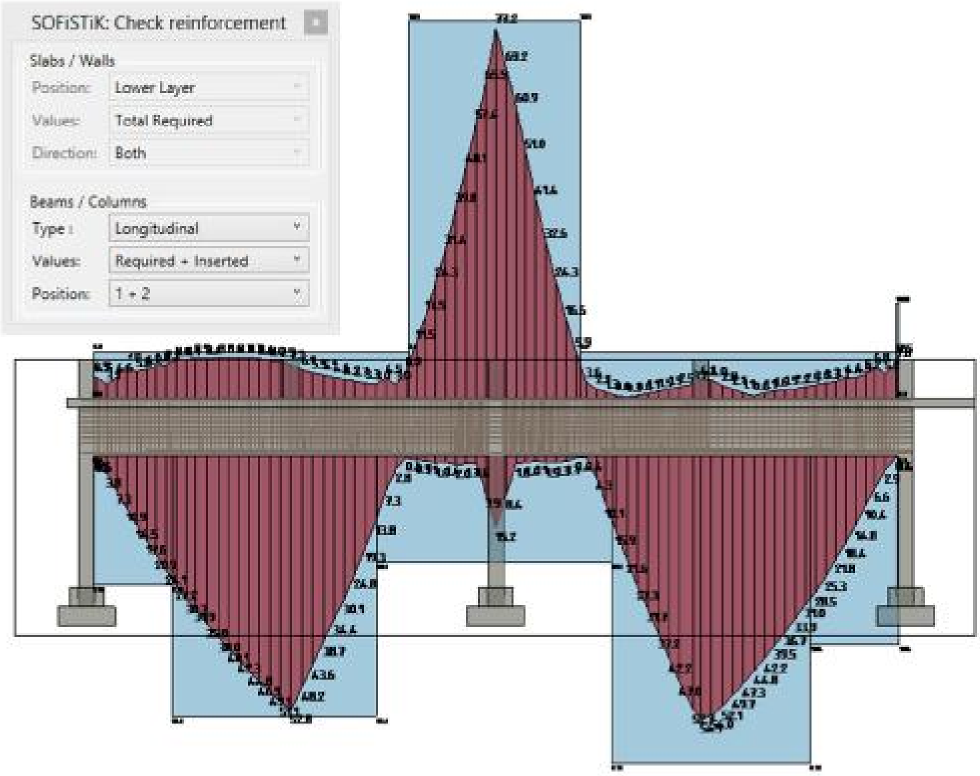


Checking the results

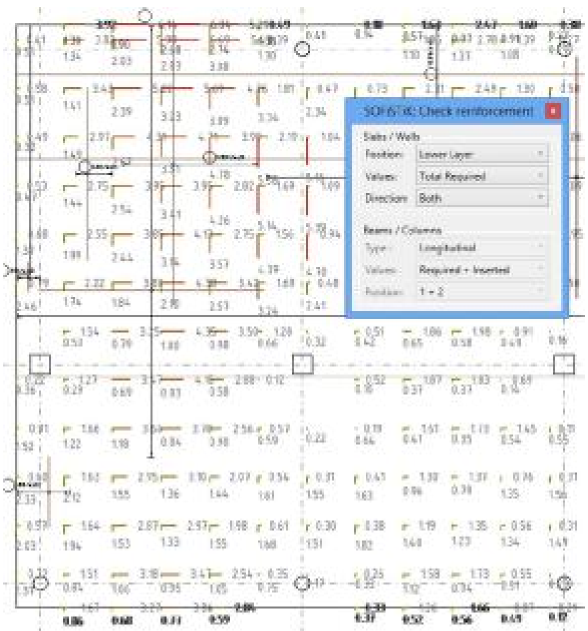
Reinforcement values

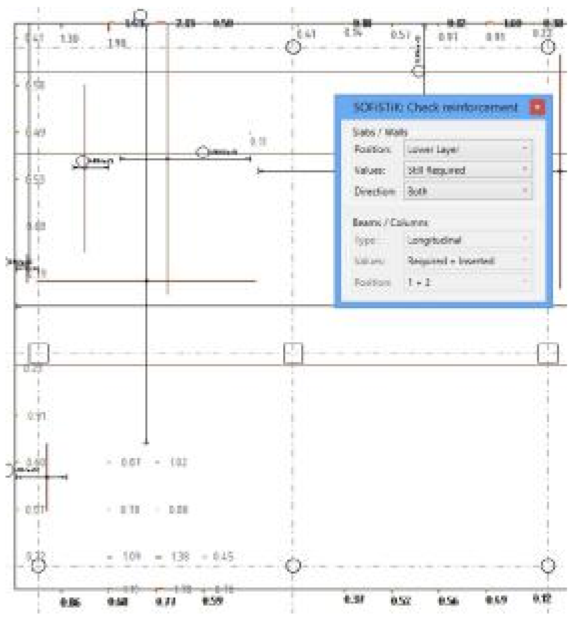
Obviously the resulting reinforcement layout has to be checked properly. Users may want to see

- Reinforcement required, i.e. design results
- Reinforcement distributed in area or area by length, i.e. proposed reinforcement
- Difference between the values above.



For beams and slabs a presentation as areas is common and well arranged. For slabs a presentation as scaled crosses has the advantage, that values of two directions and the angle of the reinforcement can be displayed in a single view.

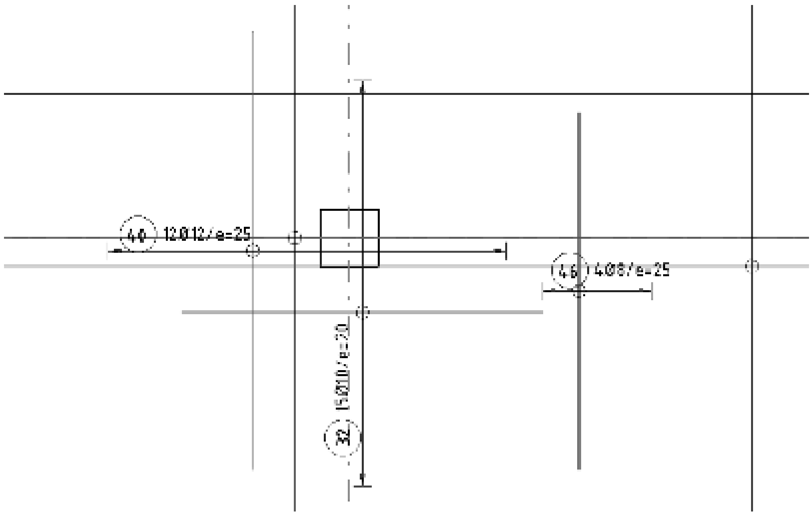




2-D Reinforcement drawings

In almost all cases, 2-D drawing sheets have to be produced out of a three-dimensional reinforcement model. These drawings with annotated symbolic presentation of the reinforcement are not only necessary for building work on site, they also help experienced engineers to judge the quality of the reinforcement.

SOFiSTiK published “SOFiSTiK Reinforcement Detailing 2014” which significantly accelerates the creation of 2D reinforcement sheets out of 3D models in Revit. The product consists of software and a set of families, which can easily be modified to meet local or company standards. Creation of bar lists, bending schedules and cut lists for wire meshes is included as well. This software can be downloaded from Autodesk Exchange Apps.



Conclusion

BIM Methods and Autodesk® Revit® Structure can help to significantly improve the time consuming process of reinforcement design. Specialized applications from independent software vendors are necessary for productive work.

SOFiSTiK tried a new approach to generate a reinforcement layout. Rules in external files help to accommodate the software to various codes and user preferences. We strive to improve our software. Your feedback is a very valuable resource for us. We are looking forward to receiving input from engineers all over the world.