ARCELOR SECTIONS COMMERCIAL
Arcelor Group

User Manual

IFBWIN 5.3

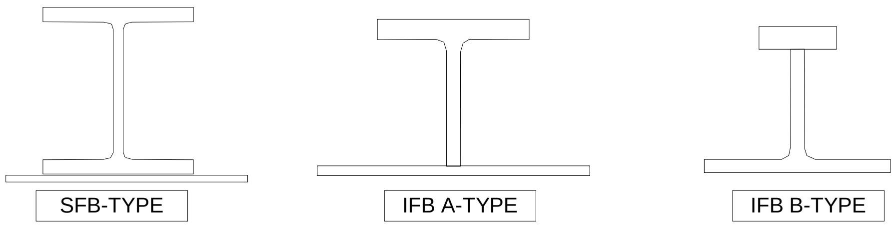
arcelor
Long Carbon Steel
Research Centre

Table of Contents

1 INTRODUCTION

GENERAL REMARKS

The **IFBWIN**-program has been developed for the design of slimfloor slabs based on **Integrated Floor Beam (IFB)** sections, which are composed from a split-up wide-flange section and a plate welded as bottom or top flange. It is only possible to calculate simple beams that are hinged at the two supports. The software may calculate according to DIN 18800 or to EUROCODE 3. It is possible to design also **SFB-sections (SFB = Slim Floor Beam)** which are obtained from a complete wide-flange section welded to a plate as support for the slab elements.



Although the different design steps are not to complex, the unskilled user could encounter problems in understanding the global theory of designing slimfloor beams or in interpreting the obtained results. To avoid these problems, this user manual will tray to give answers to any possible question in order to prevent misunderstandings.

<u>Warning :</u>

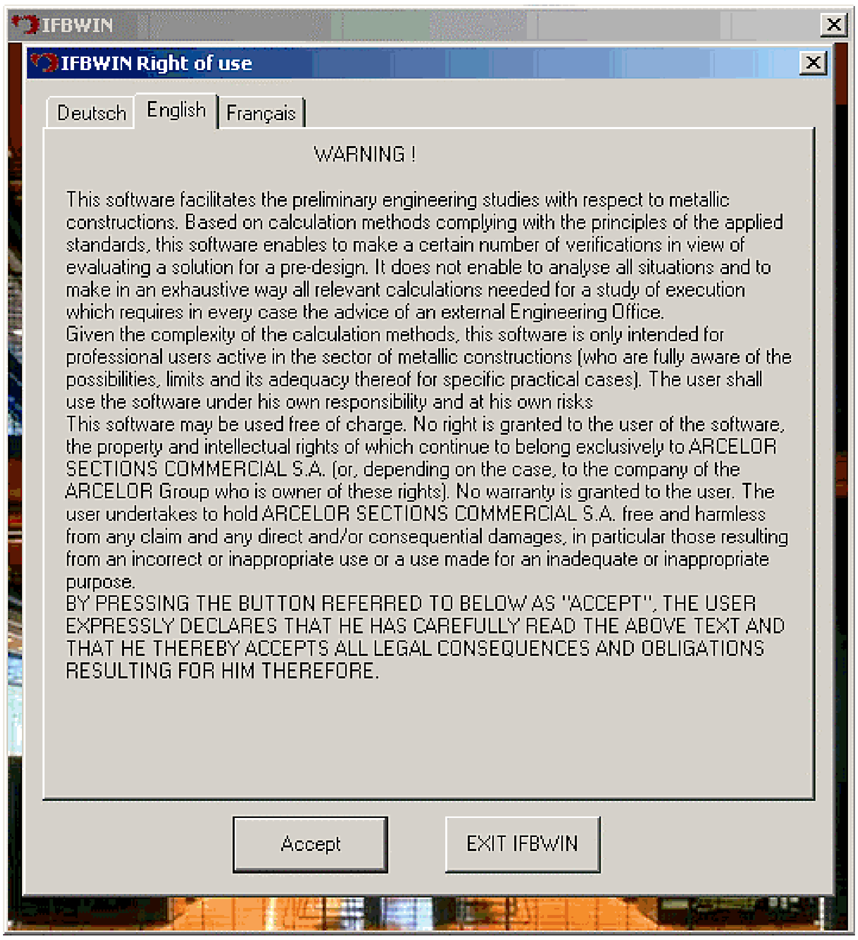
This software facilitates the preliminary engineering studies with respect to metallic constructions. Based on calculation methods complying with the principles of the applied standards, this software enables to make a certain number of verifications in view of evaluating a solution for a pre-design. It does not enable to analyse all situations and to make in an exhaustive way all relevant calculations needed for a study of execution which requires in every case the advice of an external Engineering Office.

Given the complexity of the calculation methods, this software is only intended for professional users active in the sector of metallic constructions (who are fully aware of the possibilities, limits and its adequacy thereof for specific practical cases). The user shall use the software under his own responsibility and at his own risks

This software may be used free of charge. No right is granted to the user of the software, the property and intellectual rights of which continue to belong exclusively to ARCELOR SECTIONS COMMERCIAL S.A. (or, depending on the case, to the company of the ARCELOR Group who is owner of these rights). No warranty is granted to the user. The user undertakes to hold ARCELOR SECTIONS COMMERCIAL S.A. free and harmless from any claim and any direct and/or consequential damages, in particular those resulting from an incorrect or inappropriate use or a use made for an inadequate or inappropriate purpose.

BY PRESSING THE BUTTON REFERRED TO BELOW AS "ACCEPT", THE USER EXPRESSLY DECLARES THAT HE HAS CAREFULLY READ THE ABOVE TEXT AND THAT HE THEREBY ACCEPTS ALL LEGAL CONSEQUENCES AND OBLIGATIONS RESULTING FOR HIM THEREFORE.

START MENU

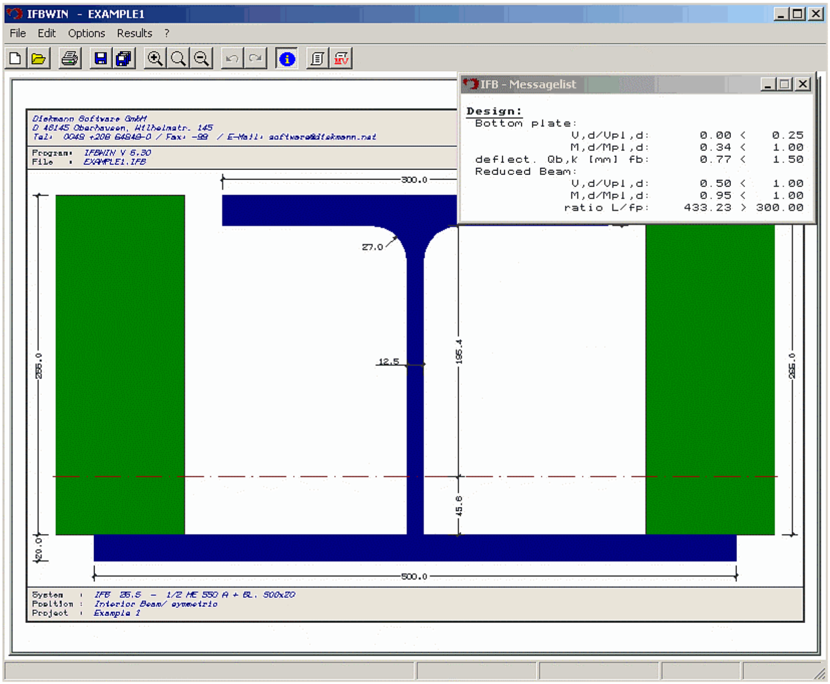


Picture 1.1 Start menu

The program can only be started if the conditions for using are accepted.

2 USER INTERFACE

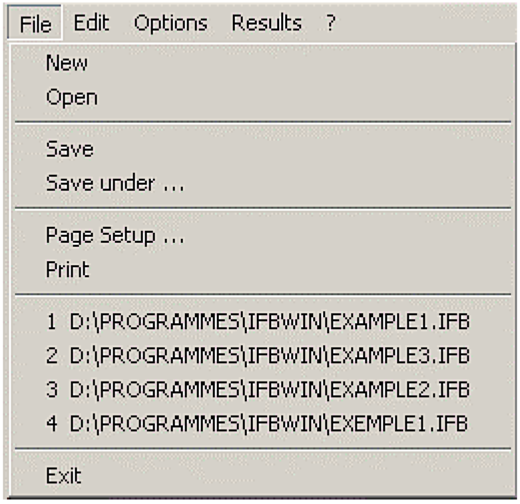
PROGRAM WINDOW



Picture 2.1 Program Window

MENU BAR

FILE



Picture 2.2 Pull-Down-Menu "File"

New

This function opens a new project named: "UNNAMED.IFB".

Open

This function opens IFBWIN-Files by the help of the filebrowser. The files have the extension "IFB“.

Save

This option saveguards the results obtained during the last loop to an output file "name.IFB". The file is created in the actual working-directory without finishing the program. "Name" is the name of the actual project (shown in the head-line of the program window). If an output file of the same name already exists, this one will be overwritten without any warning. It is therefore sometimes very important to pay attention to the names given to your files.

Save under ...

This option saveguards by using the file-browser the results obtained during the last loop to an output file without finishing the program. The actual file name changes to the new name given by the user (see head line of the program window).

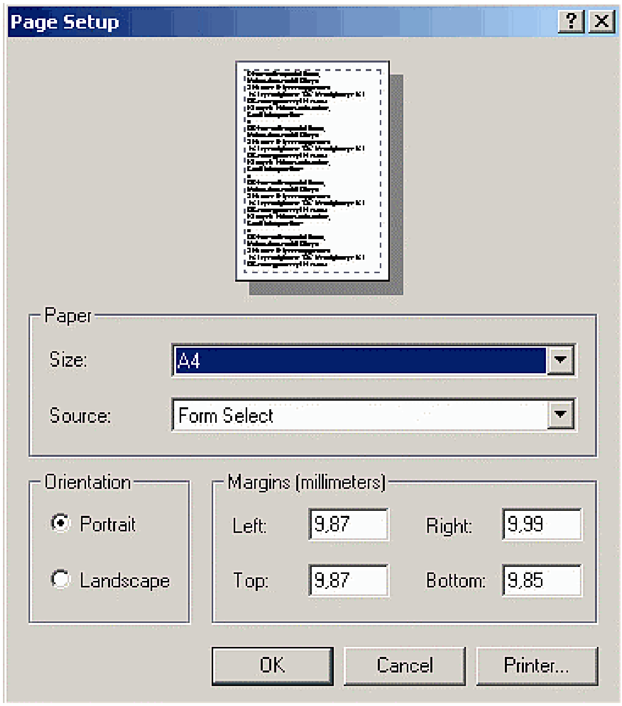
Print

This option sends the actual screen view without printer dialog to the printer.
To select printer and page setup see "Page Setup"

Page setup

With this option you can format page settings for grafic output.

The button ***{ Printer }*** selects a Windows-Printer and configeres him.



Picture 2.3 Page setup

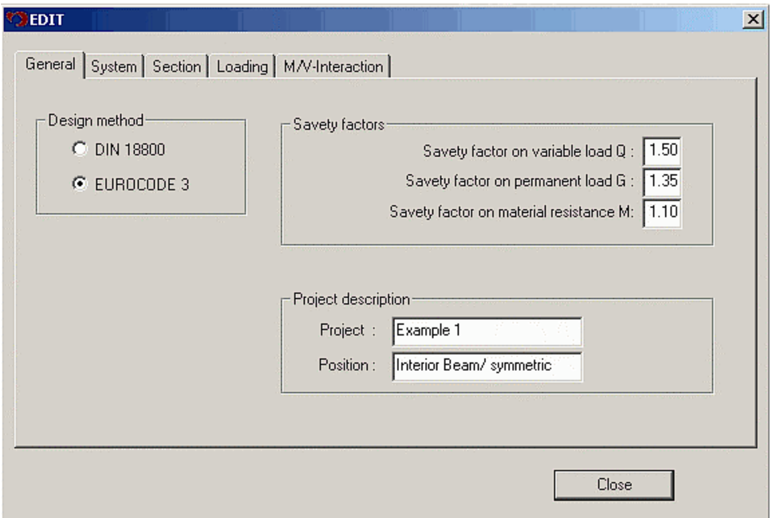
Last edited files

Listing of the last four edited files.

Exit

This option finishes the program. If there have been made any changes, the program will ask you to save the changes.

EDIT



Picture 2.4 Edit / General

General parameters

Design method

Design may be made according

DIN 18800 or

EUROCODE 3

Safety factors

These parameters are corresponding to the partial safety factors for variable loads (sQ), permanent loads (sG) and material resistance (sM) according to DIN or the case being to Eurocode 3. The program suggests to keep the parameters unchanged.

Safety factor on variable load Q ?	*:1.5*
Safety factor on permanent load G ?	*:1.35*
Safety factor on material resistance ?	*: 1.1*

Remark 1

If you are changing a partial safety factor, you have to justify your choice!

Remark 2

You can take into account only one variable load. If several variable loads with different safety factors are acting simultaneously (f.i. live load and snow), the program offers you a calculation possibility throughout the M/V-interaction described later on.

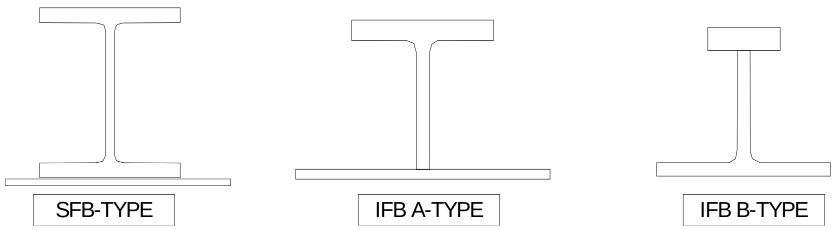
Project description

Here the user can note some specific information of the project as the name of the project and the position. These notes are parts of the result file.

System parameters

Type of section

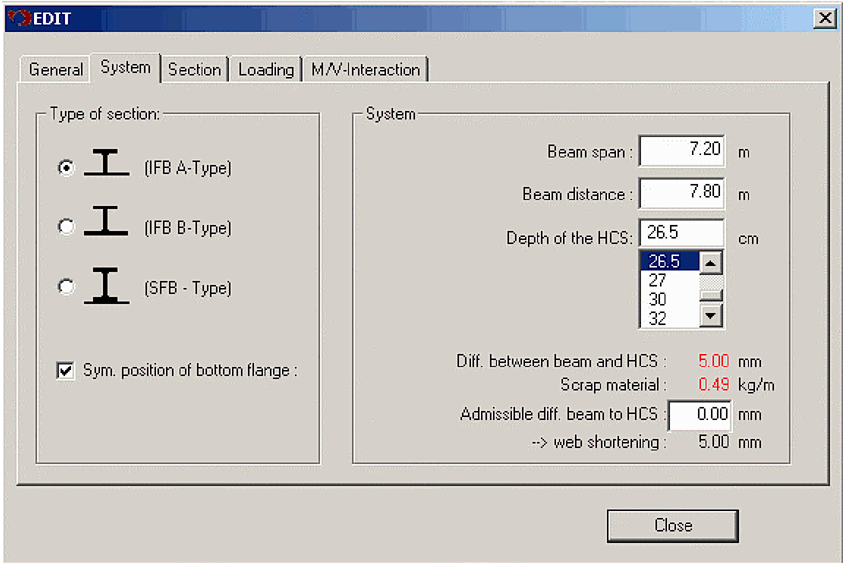
Since release 4.0, it is possible to choose between IFB- or SFB-sections.



IFB-Type A: split-up wide-flange section and a plate welded as bottom flange

IFB-Type B: split-up wide-flange section and a plate welded as top flange

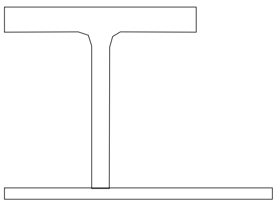
SFB-Type: complete wide-flange section welded to a plate as support for the slab elements



Picture 2.5 Edit / System

Asymmetric position of the bottom flange

An **asymmetric** cross section, that means IFB A-Type with asymmetric position of bottom flange (s. picture 2.6), can be an **edge beam** f.i.. In this case an asymmetric loading is obligatory.



Picture 2.6 IFB A-Type with asymmetric position of the bottom flange

In that case, the left side of the plate is always flush to the left side of the upper flange. The plate width should be chosen to be about 10 cm larger then the upper flange.

Remark

IFB edge beam have always to be anchored to the slab in order to avoid problems with torsion.

Beam span

The span is entered in meters. The program designs only simple beams, which are hinged on their two supports. Normally the distance between axis is specified and not the distance between the column flanges.

When using a rectangular grid, generally the greatest span is covered by concrete elements and the smaller one by the slim floor beams for a higher economy. Most of the time, the beam span is varying from 4 up to 8 m. Spans shorter then 4 m are not economic. On the other hand, for spans over 8.4 m service capacity design becomes decisive and not ultimate bearing capacity design, which may lead to deflection- and vibration problems ruled by the beam inertia. It should be mentioned, that due to the restricted depth of the slab, the moment of inertia of the slimfloor-beam can only be influenced in a limited way, in spite of a considerable increase of steel consumption.

Beam distance

The distance between beams only is important for symmetric loading.

Depth of the HCS

The program indicates the most usual depth available on the market.

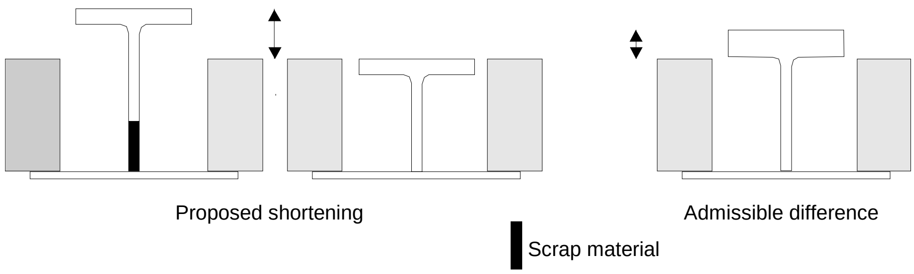
Preferential sizes 15,18,20,25,26,26.5,27,30,32,40 <cm>?

The user is nevertheless free to choose any depth, according to the delivery possibilities of his slab supplier or corresponding for instance to the depth of an in-situ concrete slab. For the preferential depths, the program proposes a dead weight corresponding to a mean value of the main products available.

Admissible difference between beam and HCS

If the depth of the IFB-section is higher then the depth of the hollow core slab so that the upper flange looms into the screed (f.i. a hollow core slab of 27 cm and an IFB-section based on an 1/2 IPE 600 section), the program gives you the depth (red coloured) by which the web has to be shortened in order to obtain the same depths of the beam and of the slab, as well as the corresponding scrap losses due to this shortening.

difference between beam and HCS	<mm>
scrap material	<kg/m>



Picture 2.7 IFB A-Type with symmetric position of bottom flange

At this place an
admissible difference beam to HCS <mm>
can be given. The decision whether the beam may be higher then the slab and about how much, has to be taken by the user. The maximum difference is of course corresponding to no shortening as the beam cannot be stretched. However the admissible difference may become negative. The upper side of the beam is then located deeper then the upper side of the slab.

Remark

A positive difference up to 10 mm is generally acceptable. It should however be paid attention to the facts that the screed thickness is remaining sufficient and that the laying of possible reinforcements and installations is not obstructed.

Section parameters

When using a standard rolled section, **IFB** sections will be spliced centrically and can be assembled in 2 ways:

T-section + plate as bottom flange **(A-Typ)** or

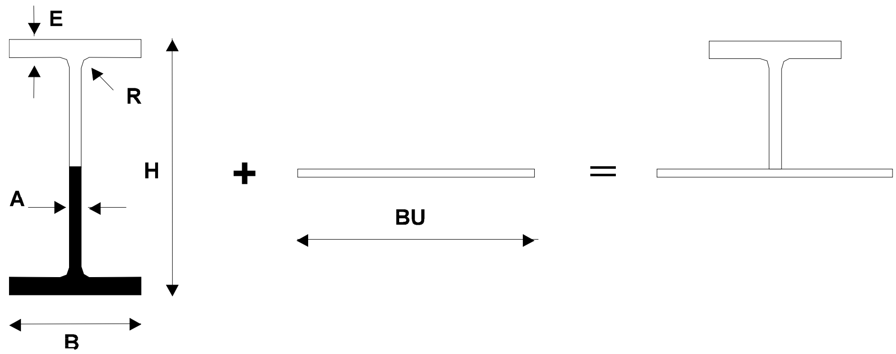
Inverted T-section + plate as top flange **(B-Type).**

For SFB beams the rolled section will not be split up but will be used entirely. The problem of scrap losses is therefore not applicable. The user must take care from the beginning that the beam depth and the slab depth are more or less the same.

Standard wide-flange section

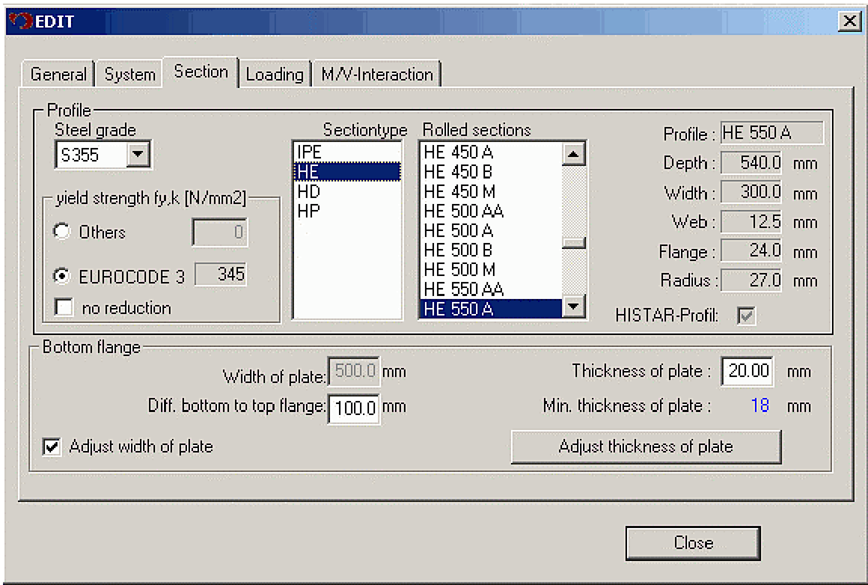
IFBWIN offers the IPE-, HE-, HD- and HP-rolled sections to the user, according to the database of Arcelor Sections Commercial.

The different parameters are visualised in the following drawing



Section depth	*H*	*<mm> ?*
Section width	*B*	*<mm> ?*
Web thickness	*A*	*<mm> ?*
Upper flange thickness	*E*	*<mm> ?*
Radius (rolled section)	*R*	*<mm> ?*
Plate width	*BU*	*<mm> ?*

The switch "HISTAR- Profil" shows if the section is available in HISTAR quality.



Picture 2.8 Edit / Section

Steel grade

Actually steel grade for sections and plates are considered:

S235 (EN 10025)

S275 (EN 10025)

S355 (EN 10025)

S420 (EN 10113)

S460 (EN 10113)

The program automatically reduces the yield strength according to the max. thickness of plate (s. table as EUROCODE).but the user has the opportunity to turn off the reduction of the yield strength by the help of the switch **"*no reduction*"** (f.i. if he uses HISTAR-sections).

He also has the opportunity by using the switch "***User***" to define the yield strength by himself. This option should be used very careful.

Standard	**Steel Grade**	**Yield strength**					
		Max. Thickness					
		≤ 16	> 16	> 40	> 63	> 80	> 100
			≤ 40	≤ 63	≤ 80	≤ 100	≤ 150
EN 10025	S 235	235	225	215	215	215	195
EN 10025	S 275	275	265	255	245	235	225
EN 10025	S 355	355	345	335	325	315	295
EN 10113	S 420	420	400	390			
EN 10113	S 460	460	440	430			

Bottom flange

Width of bottom flange

Generally the bottom flange should be about 200 mm wider then the top flange for interior beams (about 100 mm for edge beams).

If the option **Adjust width of plate** is switched on, the width of the bottom flange automatically becomes 200 mm wider (IFB-A Typ, SFB-Typ) than the top flange or for an IFB-B Typ the top flange will be reduced about 200 mm.

If the option ***Adjust width of plate*** is not switched on, ***width of plate*** must be defined by the user.

Thickness of bottom flange

After having entered all the data, IFBWIN realises a pre-design of the bottom flange or top flange.

For Typ A this pre-design of minimal thickness for the bottom flange bases on an uniaxial elastic stress verification under transversal flexion as well as on a deflection control. While computing, the program is doing a plastic design of the section, where the interaction between longitudinal flexion in the beam and transversal flexion in the bottom flange is considered. This process is an iterative one. If no equilibrium of forces is possible within the section, the bottom flange thickness is automatically increased in steps of 1 mm until reaching the required equilibrium.

For SFB sections, the bottom flange of the rolled section is controlled in addition to the pre-design of the bottom plate. For Type SFB the plastic neutral axis may move to the beam bottom flange, but not into the welded plate.

For the thickness of the top flange of Type B sections, the program proposes a default value which makes that the bottom and the top flange area are more or less equal. When using small top flanges, this may lead to very thick plates The user should therefore try in that case with thinner plates, displacing by the way the neutral axis towards the bottom flange.

If **Thickness of plate** is lower than minimum thickness of plate, the value of minimum thickness of plate is red coloured.

With the button ***Adjust thickness of plate*** thickness of plate (rounded up to half cm) can be adjusted to the minimum thickness of plate.

Load Data

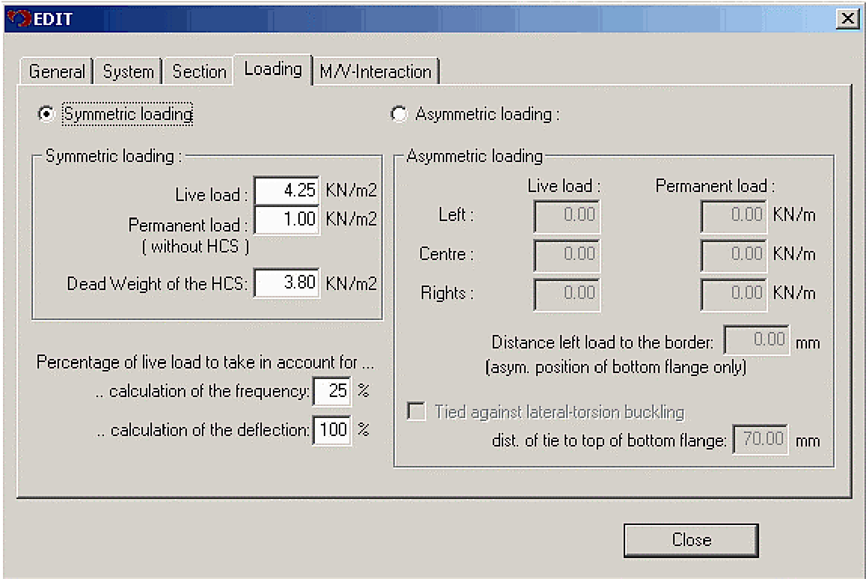
Only uniform line loads over the whole span are taken into account. <u>Triangular, trapezoidal and other distributed loads, as well as concentrated loads are not considered.</u> If the grid is regular and the beam therefore symmetrically loaded, the user can enter his loads as surface loads, which are internally converted by the program into line loads.

Symmetric loading

This is the simplest case. You are asked the beam distance in meters, the live load in kN/m2 and the permanent load (without the dead load of the hollow core slab, but with the eventual dead weight of a structural screed) in kN/m2. These loads are serviceabilities, which are internal multiplied by the program by the safety factors.

Live load <kN/m2>?
Permanent load (without HCS) <kN/m2>?
Dead weight of the HCS <kN/m2>?

For the preferential depths(s. system parameters), the program proposes a dead weight corresponding to a mean value of the main products available. This default value can be modified by the user. If the retained depth is not a preferential one, the default value is zero and you have to enter the real weight.



Picture 2.9 Edit/Loading

Remark 1 The weight of the steel beam as well as the infill concrete between the beam and the slab elements are added automatically by the program.

Remark 2 The depth and the weight of the slab must always be greater then zero, otherwise the program stops

Remark 3 The default values given for dead weight are sufficient for a predesign. For a final design, the real weight according to suppliers information, as far as known, should be used. If this is not the case, use the maximum value from regional suppliers.

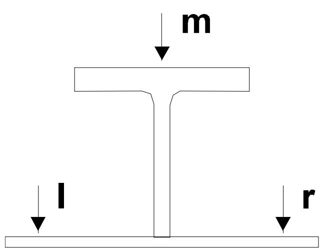
Remark 4 The dead weight of the hollow core slabs includes always the weight of grouting, but never the weight of a possible structural screed..

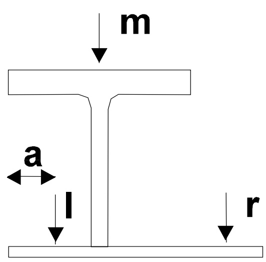
Asymmetric loading

An asymmetric loading is either corresponding to an edge beam or to an interior beam with different distances to the next beams. This kind of load input can also be used to specify a centric line load on the beam, which is not applied via the bottom flange but directly to the beam (partition wall on a beam f.i.), as for the “symmetric loading” option all the loads are supposed to be introduced via the bottom flange.

For designing an edge beams see system parameters (asymmetric position of the bottom flange).

The different loads have to be entered as shown in the following drawing.





symmetric cross section asymmetric cross section

Loading

Left live load Pl *<kN/m> ?*
Centre live load Pc *<kN/m> ?*
Right live load Pr *<kN/m> ?*
Left permanent load Gl (with HCS) *<kN/m> ?*
Centre permanent load Gc (with HCS) *<kN/m> ?*
Right permanent load Gr (with HCS) *<kN/m> ?*

Remark

For an asymmetric loading, the weight of the hollow core slab (HCS) has always to be added to the permanent loads. There is no special input for this.

The safety factors should however not be included

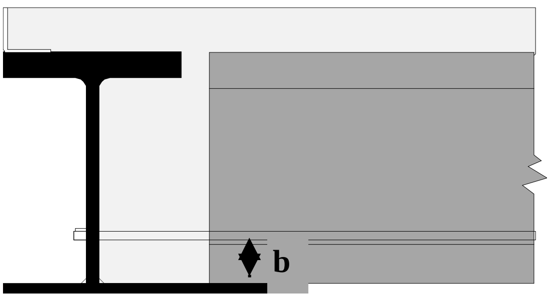
The program adds automatically the beam weight. The weight of infill concrete is to be taken into account by the user. Generally it is sufficient accurate to use the slab weight from beam axis to beam axis and to leave out the infill concrete.

Distance left load to the border

At an asymmetric position of the bottom flange the program will ask for the *distance left load from the border a <mm> ?*.

Tieing the edge beam

Edge beams are in service state loaded asymmetrically and are so solicited by a torsional moment. This kind of solicitation can be calculated in a rather complex way, which is mostly leading to a beam reinforcement especially for IFB sections whose torsional inertia is rather low. Economy is decreased hereby. A simplified solution consists in stopping torsion from the beginning, by creating a collaboration between steel and concrete as shown in the following drawing and which gives good results in practise.



In this model, the upper flange of the beam is pushing continuously against the concrete, leading such only to very small stresses in concrete. The lower part of the beam however will be tied by rebars or threaded bolts every 1.2 or 0.6 meters in the slab elements, depending on the anchor force. The loaded side of the bottom flange has to be propped until the full resistance of concrete is reached. If the design of this tie is asked before, the following answer must be given now

Distance b between the tie and the upper face of bottom flange <mm> ?

for IFB sections or

Distance b between the tie and the upper face of the plate <mm> ?

for SFB sections. The default value is 70 mm.

Percentage of live load

For the verification of serviceability state the program needs the percentage of live load to take into account for the calculation of the deflection and of the natural frequency. The default values are equal to 25% for the frequency and to 100% for the deflection.

Percentage of live load to take into account for

the calculation of the natural frequency <%>?
the calculation of the deflection <%>?

Remark

Today even in standard office buildings, the required live loads become more and more important (500 kg/m2 and more). This is mostly due to the fact that at the planning and even construction stage, the final use of the building is very often not yet known, or that the investor or owner wants to keep a complete flexibility for a later change of use. In reality however the specified loads won't most probably never be reached (except for archives and warehouse surfaces perhaps). It would therefore make no sense to determine the deflection in serviceability state under this high load level, as very often deflection will then rule the complete design, to the disadvantage of rentability. It is herefore recommended to reduce the live load level for the deflection control when this one exceeds 500 kg/m2.

In a similar manner it is very difficult to excite a fully packed structure. Therefore the program allows a reduced live load for the calculation of the natural frequency. The default value is 25%, which seems to be acceptable in most of the cases. For live loads less or equal to 200 kg/m2 this value should be increased to 50%; over 500 kg/m2 it can be reduced to 10%.

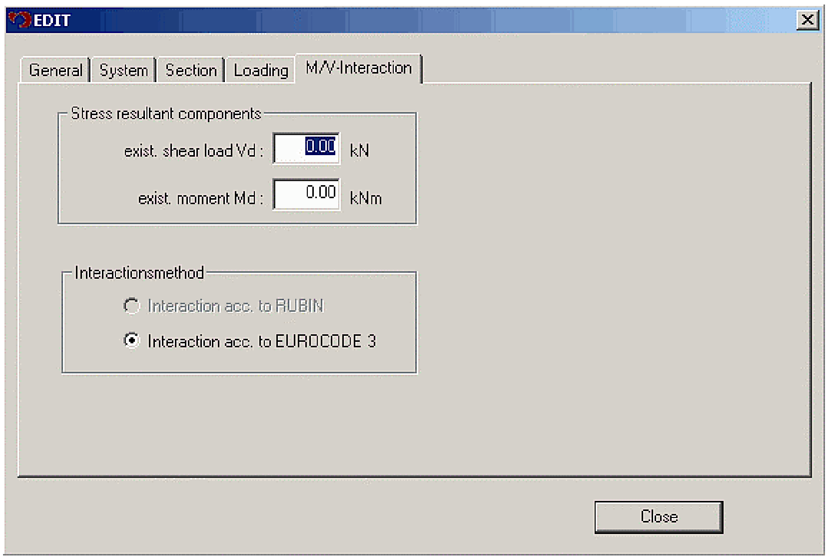
M/V-Interaction

This option gives the ability to take into consideration some single loads, which is not possible in the main program, as it leads to an interaction between a shear force V and a moment M. The user has to calculate the design forces Md and Vd manually or to take them over from a foreign static calculation package. The IFB-Program verifies the interaction between both solicitations.

For a design two interaction models are available:

	RUBIN	when designing according to DIN 18800
or	*EUROCODE 3*	when designing according to EUROCODE 3

The two models are similar. While the model according to RUBIN reserves a certain web area for the shear resistance, in the Eurocode model, the yield strength of the web is reduced. Both procedures lead to a reduced plastic moment which has to be compared to the design value of the moment. The ratio ***Md/Mpl,d,red*** must remain less or equal to 1.0 and the plastic neutral axis cannot be displaced in the top or bottom flange.



Picture 2.10 Edit / M/V-Interaction

OPTIONS

English

This option makes the program to use english language for input and output data.

French

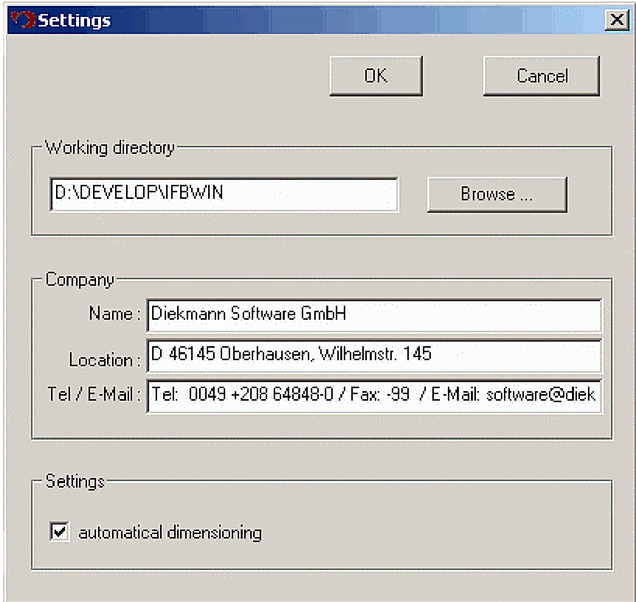
This option makes the program to use french language for input and output data.

German

This option makes the program to use german language for input and output data.

Settings

This function opens the dialog box "Settings", where the input of different options for the specific projects take place.

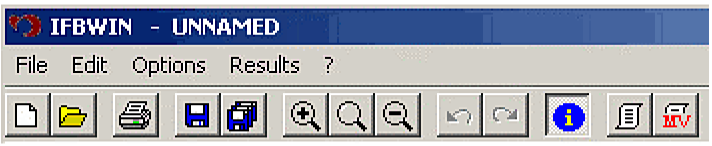


Picture 2.11 Settings

RESULTS

The results of calculations are written into the file ***name*.out** and are to be seen by an editor. Theory and results see Chapter 3.

FUNCTION BAR



Picture 2.12 Function bar

NEW 

This function opens a new project named: "UNNAMED.IFB".

OPEN 

This function opens IFBWIN-Files by the help of the filebrowser. The files have the extension "IFB“.

PRINT 

This option sends the actual screen view without printer dialog to the printer.
To select printer and page setup see "Page Setup"

SAVE

This option saveguards the results obtained during the last loop to an output file "name.IFB". The file is created in the actual working-directory without finishing the program. "Name" is the name of the actual project (shown in the head-line of the program window). If an output file of the same name already exists, this one will be overwritten without any warning. It is therefore sometimes very important to pay attention to the names given to your files.

SAVE AS ...

This option saveguards by using the file-browser the results obtained during the last loop to an output file without finishing the program. The actual file name changes to the new name given by the user (see head line the program window).

ZOOM

With this option vou can enlarge details for 100% by mouse-click, that means the point of mouse-click becomes the center of the new screen the factor of zooming is 2.

ZOOM WINDOW

With this option vou can enlarge details by pulling up a zoom window with the help of your mouse.First click to the top of the left side of your screen, then draw the mouse so far as you want to enlarge your detail to the right bottom. (The edges of your new screen can only being fitted by mouse-click).

If you want to return to your total screen, you make a mouseclick to the ZOOM OUT – button.

ZOOM OUT

Before every enlargement of details takes place the actual screen-shot is saved by the program. With this function you can go back to the latest screen-shot step by step. The program can save max. 10 steps.

UNDO

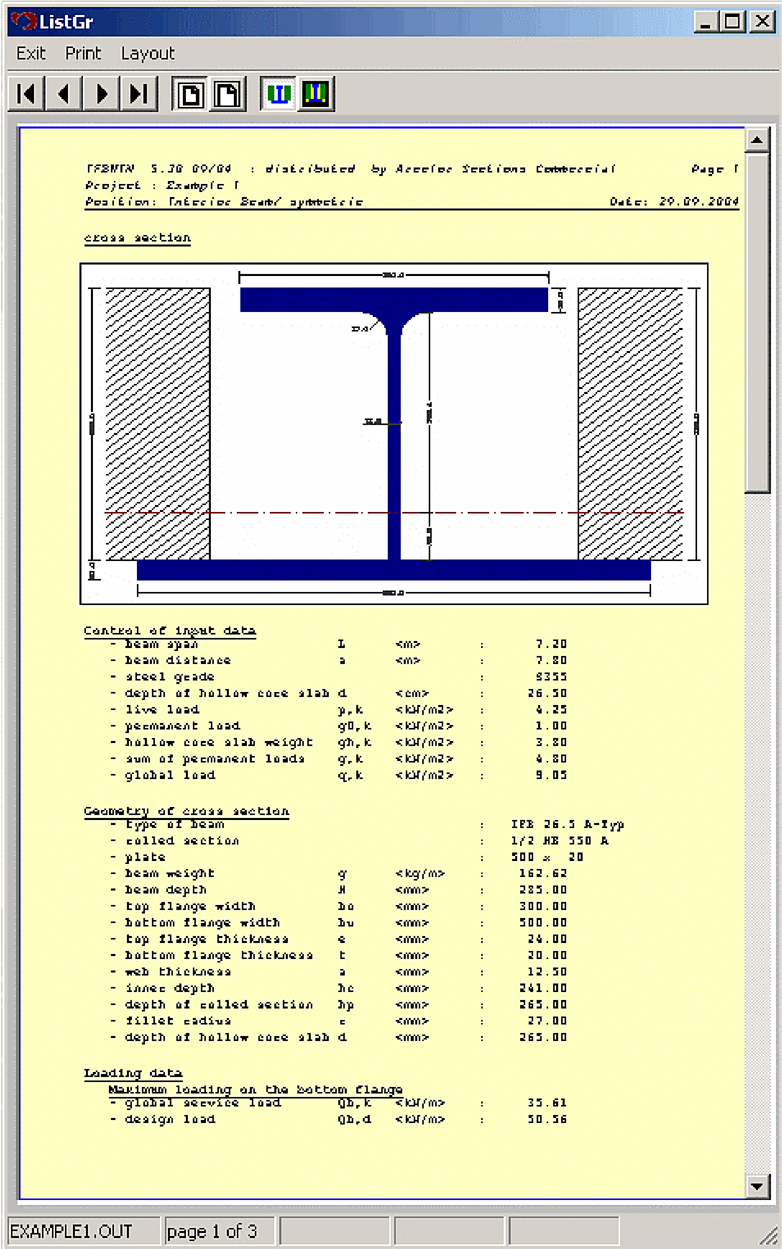
All changes you made since last saving can be taken back step by step.

REDO

All changes you took back by **undo** since loading the actual project or last saving can be recovered by this option.

LISTING

The results of the calculation are written into the file ***name.out*** and displayed ina window. For the theory of the results see chapter 3.

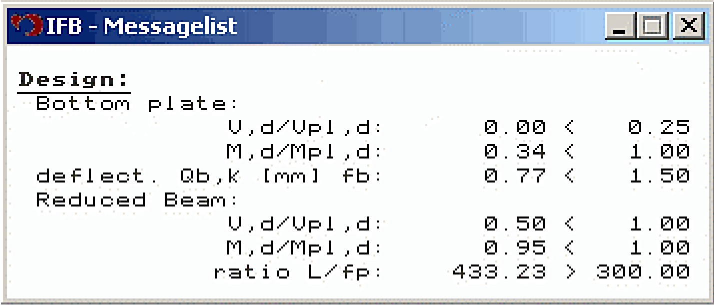


LISTING WITH M/V-INTERACTION

The results of the calculation and the results of the M/V-Interaction are written into the file ***name.out*** and displayed in a window. For the theory of the results see chapter 3.

MESSAGE LIST

This function opens the messagelist and closes it again.



Picture 2.13 Message list

The message list shows the results of design of the actual project. The message list is associative, that means that every user input into the dialog-box "Edit" will be automaticly analysed by the calculating modul and the results are shown in the box.

3 THEORY AND RESULTS

General notes

The output file is structured in an easy-to-understand and logical way. For each beam calculated, the user obtains 3 pages of input data and static output, optionally together with one page of section drawing (by clicking the *print button in the main window)*, several pages of interaction results or a page with results concerning the ties for edge beams. Several typical result files are given in the annex.

The front page of each listing indicates the program name, the release number and the release date. Furthermore the project name, the position designation and the date of computation are given in the header. This three values are repeated over all the pages. The pages are numbered.

Input data

The first blocks contained in the output file are dealing with input data:

- Control of input data
- Geometry of cross section
- Loading data
- Safety factors

Control of input data

This block repeats the most important input data like beam span, distance between beams, steel grade, load definition,.. in the same form as they were entered, to allow a fast control.

Geometry of cross section

First is indicated the beam designation derived from beam type (IFB or SFB) an the depth of the slab.

Subsequently are given the different components of the beam (H- or T-profile and plate dimensions) together with the theoretical weight and a list of all geometrical data of the steel beam.

Remark

The global slim floor beam weight is calculated by using a weight per unit volume of 7850 kg/m3 for the rolled section and one of 8000 kg/m3 for the plates.

Loading data

This block lists the values of the loads used for the calculation and derived from the user input. The values are reproduced separately for the loads acting on the bottom flange and leading to transversal flexion and those leading to longitudinal flexion in the beam.

If the beam is loaded asymmetrically, the greatest flange solicitation is given.

The index k indicates, that the load is a service load, while index d means a design load (including safety factors).

Control of slenderness ratios

The elasto-plastic design method requires that the slimfloor cross sections are at least class 2, in order to support the full plastic moment without moment redistribution. The limits for the slenderness ratios are given in Eurocode 3, table 5.3.1 and in DIN 18800, table 15.

As the beams are not continuous, only the top flange and the web are checked. For IFB sections the program distinguishes between type A (rolled) and type B (welded).

Remark

If the slenderness limits are not respected, the results obtained will be wrong. The user has then to define a less slender section or to make manually an elastic design. The program asks therefore for a new section.

Safety factors

Along with the user-defined partial safety factors, are also indicated the safety factors for welds and bolts which may not be changed by the user.

Ultimate load bearing capacity state

Two verifications are realised, one for the bottom flange under transversal flexion and one for the reduced beam under longitudinal flexion.

Bottom flange

Under transversal flexion, the bottom flange is behaving as a cantilever beam with a rectangular cross section, on which are acting two concentrated loads (dead weight of the concrete slab and live load).

As shear and flexion are at their maximum near the support, normally an M/V interaction would be required. This is not necessary if Vd/Vpl,d is smaller then 0.25, which is true in nearly every case (in 90% of the cases even smaller then 0.03). Md/Mpl,d may then be equal to 1.0.

Reduced beam

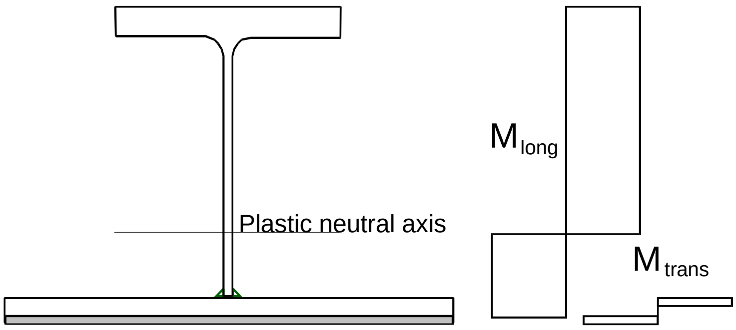
As the bottom flange is under a bi-axial stress, it is necessary to introduce the notion of a comparison stress like *von Mises* for example.

However the static theorem from the theory of plasticity allows to admit any (as simple as possible) stress distribution, which fulfils the following two conditions:

- the stress distribution must be in a perfect equilibrium
- the comparison stress cannot exceed in any point of the section the yield strength

$$\sigma_{vM}^2 = \sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y \leq f_y^2$$

From here you can derive that if σx and σy are of the same sign, they can reach both simultaneously the yield strength without violating the condition above. If σx and σy are of different signs, one of them has to go to zero when the other one goes towards the yield strength. The application of these rules leads to a model where the lower area of the bottom flange is reserved for transversal bending, while for longitudinal bending only a reduced beam section is available.



For SFB section the lower beam flange is reduced as well as the plate. However, only the plate is checked explicitly, while the program controls simply if the beam flange is sufficient, as it makes no sense to increase one flange of a rolled beam only.

The output file indicates both the original thickness(es) and the reduced thickness(es) of the bottom flange(s), followed by the position of the plastic neutral axis. As the beams are only simply supported, no M/V-interaction control is required, as one of the solicitations is zero when the other one is at his maximum.

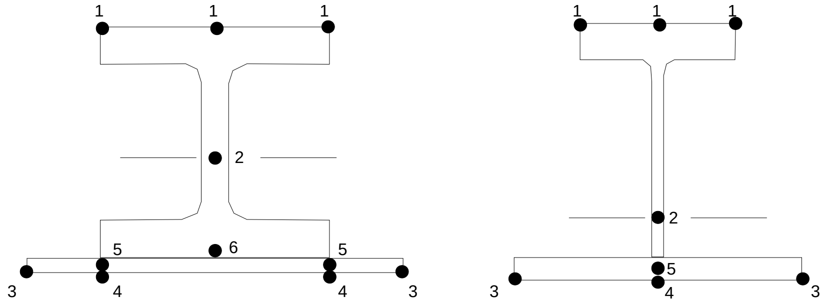
For information, the elastic moment of the beam is also given.

Serviceability state

Basis of calculation

Deflections are determined by assuming that the beam remains in an elastic state under service loads (safety factors equal 1.0). In order to check if the obtained results are liable, the program controls if the foregoing assumption is fulfilled by considering only the bare steel section.

For the above shown points of the section, therefore different stress components are calculated and compared with the corresponding admissible values.



The meaning of stresses is as follows:

Point 1: Compression from longitudinal bending
Point 2: Maximum shear in the web
Point 3: Tension from longitudinal bending
Point 4: Von-Mises-stress from longitudinal –and transversal bending
Point 5: Von-Mises-stress from longitudinal bending and shear
Point 6: Von-Mises-stress from longitudinal- and transversal bending as well as shear (only for SFB sections)

Ensuing deflections resulting from longitudinal- and transversal bending are evaluated.

Deflection of the bottom flange

The listing indicates the moment of inertia of the bottom flange (for a width of 1 meter), the arm of forces and the deflection in the load application point under service loads.

Remark

As the element is a cantilever beam, L is equal two times the arm of forces. In practical life, a limitation to 1.5 mm has been proved successful.

In any case, welding causes a deformation of the plate towards the centre of the beam, acting as a camber for SFB - and IFB type A sections, whose dimension depends on several welding parameters.

Deflection of the beam

Even if concrete bears theoretically no stress, it can be assumed that concrete collaborates to the inertia of the steel beam. The program adds therefore the part of uncracked concrete contained between the flanges to the inertia of steel.

The output file contains the deflections and deflection rates at mid-span under dead load fG, live load fP and user-defined deflection load fQD. See Eurocode 3 for the recommended limits. Generally a ratio of L/250 should not be exceeded . A value for cambering is also proposed..

Remark

Concerning cambering, it should be mentioned that fabrication tolerances are about ± 5 mm. Cambers smaller then 20 mm therefore make no sense

Natural frequency of the beam

To avoid resonance problems, the natural frequency has to be different from possible excitation frequencies. Otherwise structural damages or at least unwellness of people have to be expected.

Floors where people is generally walking on (office buildings, housings,...) the frequency should be at least 3 Hz. Floors used for dancing, jumping or rhythmic movements (fitness centres,...) require at least 5 Hz.

The program calculates the frequency of the steel beam for the user-defined load. Damping due to partition walls are not taken into account, however the moment of inertia is increased the same way as for the deflection evaluation. Nevertheless the global vibration behaviour of the structure, which may differ largely from that of a single element, depending on design, becomes decisive.

Recent measures taken on several reference objects lead to the following preliminary conclusions:

- In service state, a bi-directional vibration behaviour can be assumed, therefore the frequency of the beam f_1 is interfering with that of the slab f_2 The resulting frequency f_3 can be determined as follows:

$$\frac{1}{f_3^2} = \frac{1}{f_1^2} + \frac{1}{f_2^2}$$

- The frequency of the beam is determined on a simple supported beam. In service state, this assumption may be only partly correct, as an additional in-situ concrete or a structural screed are modifying as well the moment of inertia as the conditions at the supports, leading to frequencies up to four times those calculated. When using a thin autolevelling screed or a raised floor, the calculation is correct.

Weld design

The weld between rolled section and plate is always composed by a double fillet weld without weld preparation. The root thickness is determined under consideration of the shear stresses, the suspension of the bottom flange and eventually a bending moment (represented by a couple of forces) caused by an asymmetric loading.

The calculated thickness is compared with the minimum and maximum values foreseen in the different standards and adapted to the connected material thickness.

Beam-to-column design

Beam-to-column joints are generally realised through traditional end plates. The joint is designed for bolt shearing and for basic material yielding. As the connection has only one shear level, bolt shearing is generally decisive. As mostly threaded bolts are used instead of normal bolts, it is assumed for security, that the shear level is always located within the threaded section

As a standard, 4 joint combinations are given, based on the use of 2 bolt grades (10.9 and 8.8) and 2 bolt distributions (2 and 4 bolts). Generally a solution with 4 bolts should be retained.

Remark

If threaded bolts are used, bolt grade should be limited to 8.8.

For these 4 combinations are subsequently given the minimum thickness of the end plate and of the column flange to avoid local material yielding. This thickness is generally less then 10 mm.

The indicated thickness retained by the program corresponds to the next standard available thickness.

The program designs also the weld connecting the end plate to the beam, by determining the required weld surface as well as the length of welds going up from the minimum to the maximum fillet weld allowed.

Remark

The program does not check if the calculated length can be realised

M/V-Interaction

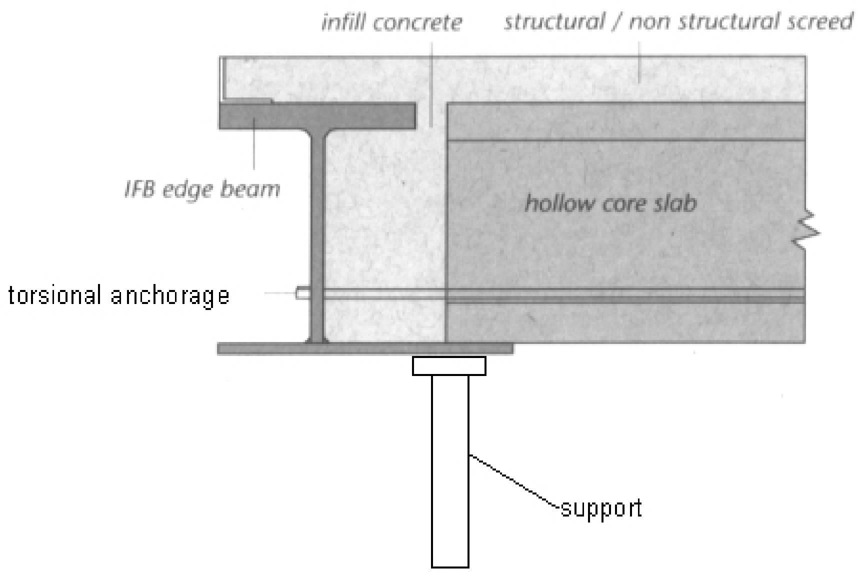
First is checked the shear force and second the bending moment. For a design according to RUBIN, the listing includes also the web thickness and the reduced web thickness.

Tieing of the edge beams against torsion

If the edge beam was required to be tied, the result file indicates also the position of the tie bar, the design quenching compression transmitted to the concrete by the top flange and the design force to be tied per meter of beam length. Furthermore the corresponding rebar diameters are given for different distance between the tie bars.

The design of the torsional anchorage is based on following method :

During construction stage (laying on the concrete hollow slabs, putting in the concrete infill or structural/non-structural screed) the beams are propped in the support area of the hollow core slabs(see figure below).

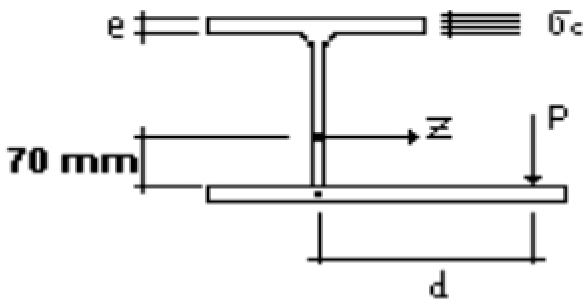


A minimum of two supports per span are required.

Before filling up with concrete, the torsional anchorage is placed either into the system joints of the hollow core slabs, if they are wide enough to guarantee a sufficient concrete cover of the rebars, or into some opened cavities of the slab.

The distance between the rebars is in general 0.60 m or 1.20 m

The calculation of the torsional anchorage is based on an equilibrium calculation between the torsional moment in longitudinal direction (Mt) and a force couple consisting of a lateral compression force (σc*e) at the edge of the upper flange and a tension force (Z) which will be taken up by the torsional anchorage rebars.



Mt= P*d

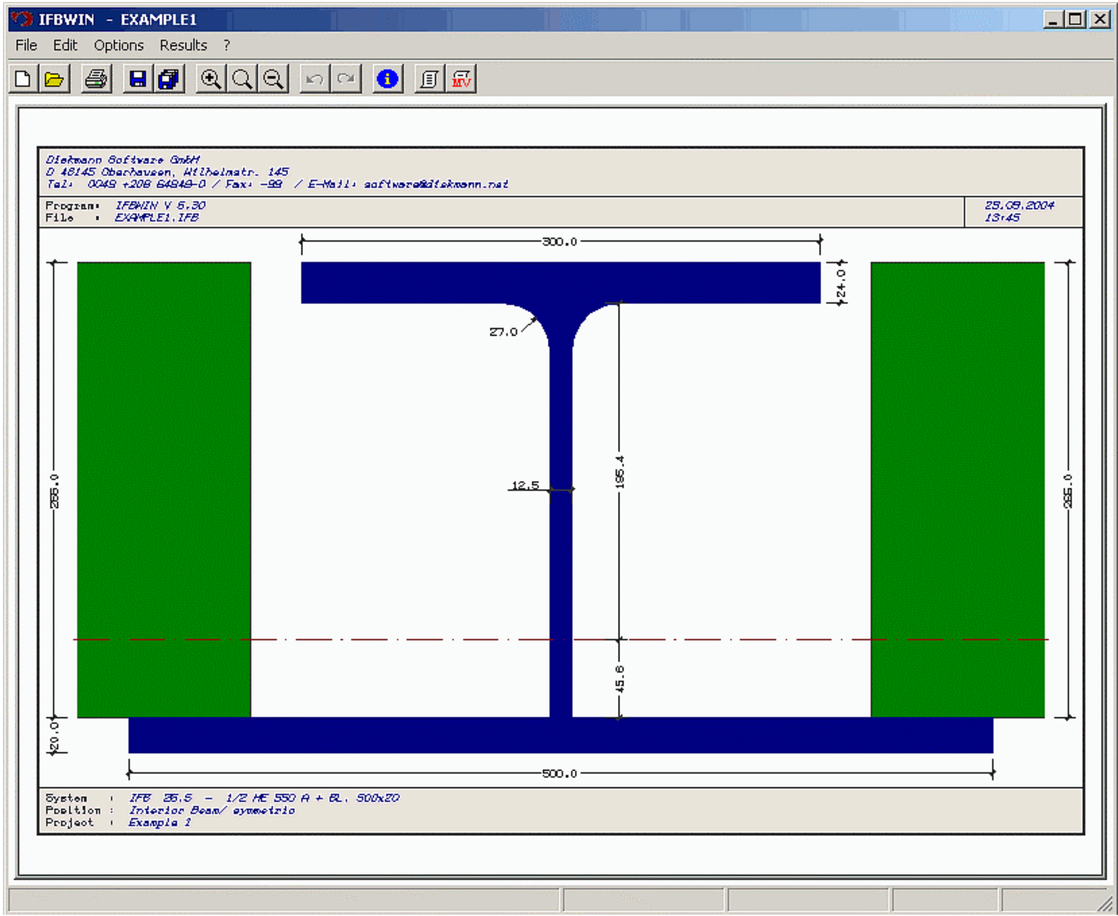
in equilibrium with the force couple (Z,σc *e * a)

a : horizontal distance of the reinforcing bars

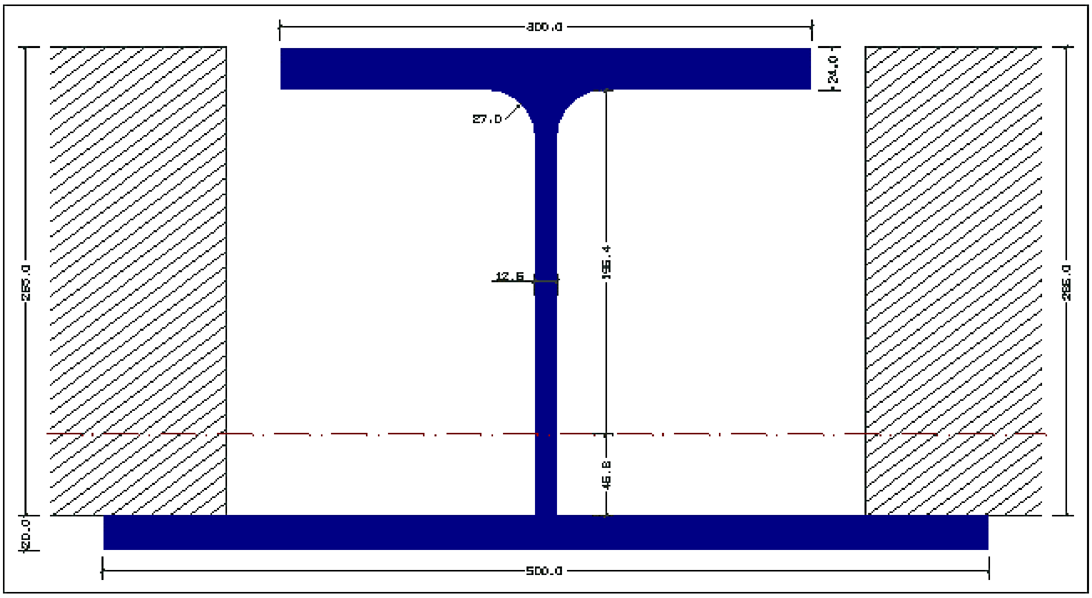
The usual load factors and the partial safety factors for materials are considered in the calculation.

ANNEX : EXAMPLES

EXAMPLE 1: Interior beam / Symmetric Loading IFB A-TYP



cross section



Control of input data

- beam span	L	<m>	:	7.20
- beam distance	a	<m>	:	7.80
- steel grade			:	S355
- depth of hollow core slab	d	<cm>	:	26.50
- live load	p,k	<kN/m2>	:	4.25
- permanent load	g0,k	<kN/m2>	:	1.00
- hollow core slab weight	gh,k	<kN/m2>	:	3.80
- sum of permanent loads	g,k	<kN/m2>	:	4.80
- global load	q,k	<kN/m2>	:	9.05

Geometry of cross section

- type of beam			:	IFB 26.5 A-Typ
- rolled section			:	1/2 HE 550 A
- plate			:	500 x 20
- beam weight	g	<kg/m>	:	162.62
- beam depth	H	<mm>	:	285.00
- top flange width	bo	<mm>	:	300.00
- bottom flange width	bu	<mm>	:	500.00
- top flange thickness	e	<mm>	:	24.00
- bottom flange thickness	t	<mm>	:	20.00
- web thickness	a	<mm>	:	12.50
- inner depth	hc	<mm>	:	241.00
- depth of rolled section	hp	<mm>	:	265.00
- fillet radius	r	<mm>	:	27.00
- depth of hollow core slab	d	<mm>	:	265.00

Loading data

Maximum loading on the bottom flange

- global service load	Qb,k	<kN/m>	:	35.61
- design load	Qb,d	<kN/m>	:	50.56

```
IFBWIN  5.30 09/04  : distributed  by Arcelor Sections Commercial          Page 2
Project : Example 1
Position: Interior Beam/ symmetric                                   Date: 29.09.2004

   Loading of the beam
   - live load                 P,k     <kN/m>     :     33.15
   - sum of permanent loads    G,k     <kN/m>     :     39.70
   - global service load       Q,k     <kN/m>     :     72.85
   - design load               Q,d     <kN/m>     :    103.32
   - Q (frequency)   QF = G + 0.25xP   <kN/m>     :     47.99
   - Q (deflection)  QD = G + 1.00xP   <kN/m>     :     72.85

Control of slenderness ratios b/t according to table 5.3.1
   - web                                          :     17.12 <  40.19
   - flange                                       :      6.25 <   8.95

Safety factors according to EC3, ENV 1993-1-1
   Partial safety factors :
   - live load                 sQ                 :      1.50
   - permanent load            sG                 :      1.35
   - resistance                sM                 :      1.10
   - assemblies                sMb                :      1.25
   - welds                     sMw                :      1.25
   - yield strength            fy,k    <N/mm2>    :    345.00
   - design yield strength     fy,d    <N/mm2>    :    313.64

Elasto-plastic design (EC3, ENV 1993-1-1)
   Bottom flange
   - design shear force        V,d     <kN/m>     :     50.56
   - plastic shear resistance  Vpl,d   <kN/m>     :   3621.56
   - V,d/Vpl,d                                    :      0.01 <  0.25
   - design bending moment     M,d     <kNcm/m>   :   1055.51
   - plastic moment resistance Mpl,d   <kNcm/m>   :   3136.36
   - M,d/Mpl,d                                    :      0.34 <  1.00


   Reduced beam
   - bottom flange thickness   t       <mm>       :     20.00
   - red. flange thickness     tr      <mm>       :     18.15
   - Xpl,top (to bottom of top flange)<mm>        :    195.41
   - Xpl,bottom (to top of bottom flan<mm>        :     45.59
   - design shear force        V,d     <kN>       :    371.96
   - plastic shear resistance  Vpl,d   <kN>       :    746.76
   - V,d/Vpl,d                                    :      0.50 <  1.00
   - design bending moment     M,d     <kNm>      :    669.53
   - plastic moment resistance Mpl,d   <kNm>      :    702.84
   - M,d/Mpl,d                                    :      0.95 <  1.00
   - elastic moment resistance Mel,d   <kNm>      :    610.64

Serviceability state
   Stresses under service loads (cf manual)
   - Y_top elastic                     <cm>       :     15.99
   - Y_bottom elastic                  <cm>       :     12.51
   - Ix steel beam only                <cm4>      :     31124
   - Compression in point 1            <kN/cm2>   :     24.25 max. 34.50
   - Shear in point 2                  <kN/cm2>   :      8.23      19.92
   - Tension in point 3                <kN/cm2>   :     18.98      34.50
   - Von-Mises stress in point 4       <kN/cm2>   :     26.39      34.50
   - Von-Mises stress in point 5       <kN/cm2>   :     17.47      34.50
```

```
Deflection of the bottom flange
- moment of inertia            Ib      <cm4/m>   :    66.67
- arm of forces                zu      <mm>      :   208.75
- deflection under Qb,k        fb      <mm>      :     0.77 <  1.50

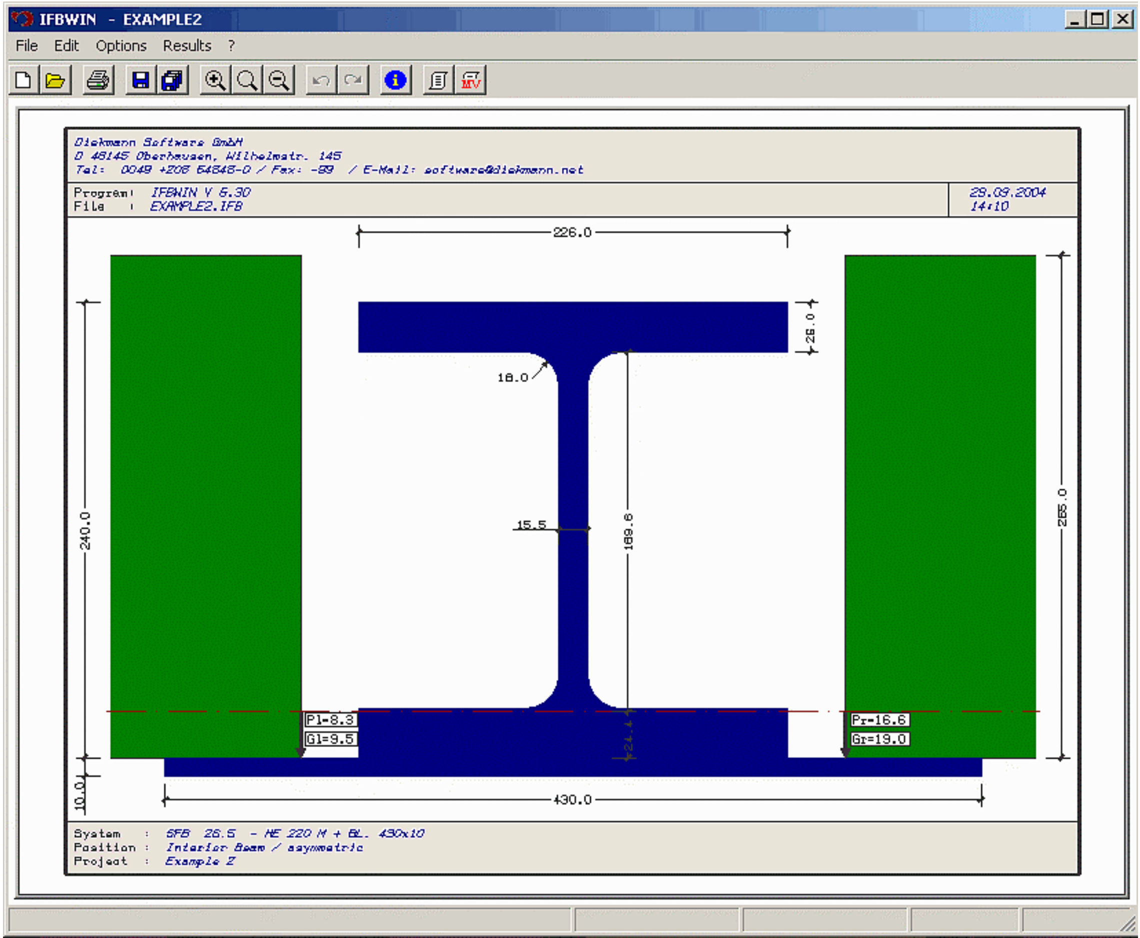
Deflection of the unreduced beam
- composite moment of inertia          <cm4>     :    33237
- deflection under G           fG      <mm>      :    19.90
- ratio                        L/fG              :    361.7
- deflection under P           fP      <mm>      :    16.62
- ratio                        L/fP              :    433.2 >  300
- deflection under QD          fQD     <mm>      :    36.52
- ratio                        L/fQD             :    197.1
- recommended camber           fc      <mm>      :       20

Frequency of the unreduced beam
- composite moment of inertia          <cm4>     :    33237
- frequency under QF                   <Hz>      :      3.6 >  3.0

Weld design (profile - bottom flange)
- fillet weld                  aw      <mm>      :      4.0
- design weld stress           Sw,v    <N/mm2>   :   172.49
- design weld resistance       Sw,d    <N/mm2>   :   261.73
- Sw,v/Sw,d                                      :     0.66 < 1.0

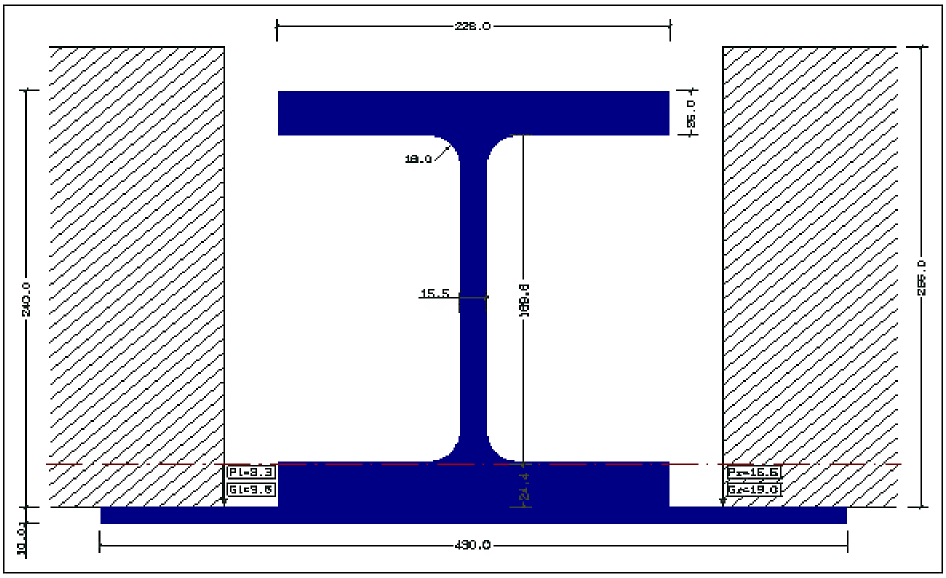
Beam-to-column design EC3, ENV 1993-1-1
 Required thickness of the end plate or of the column flange
 Control of the bearing stress for a shear connection
 (alpha_L: 2.5) when using
 - 2 bolts M30  8.8      min T  <mm>             :      6.08
 - 4 bolts M20  8.8      min T  <mm>             :      4.56
 - 2 bolts M30 10.9      min T  <mm>             :      6.08
 - 4 bolts M20 10.9      min T  <mm>             :      4.56
 Recommended end plate thickness T  <mm>         :      10.0
```

EXAMPLE 2: Interior beam / Asymmetric Loading SFB-TYP



IFBWIN 5.30 09/04 : distributed by Arcelor Sections Commercial *Page 1*
Project : Example 2
Position: Interior Beam / asymmetric *Date: 29.09.2004*

cross section



Control of input data

- beam span	L	<m>	:	7.20
- steel grade			:	S355
- live load :				
left	Pl	<kN/m>	:	8.30
center	Pc	<kN/m>	:	0.00
right	Pr	<kN/m>	:	16.58
- permanent load :				
left	Gl	<kN/m>	:	9.50
center	Gc	<kN/m>	:	0.00
right	Gr	<kN/m>	:	18.96

Geometry of cross section

- type of beam			:	SFB 26.5
- rolled section			:	HE 220 M
- plate			:	430 x 10
- beam weight	g	<kg/m>	:	151.71
- beam depth	H	<mm>	:	250.00
- depth of rolled section	hp	<mm>	:	240.00
- width of rolled section	b	<mm>	:	226.00
- flange thickness	e	<mm>	:	26.00
- web thickness	a	<mm>	:	15.50
- inner depth	hc	<mm>	:	188.00
- fillet radius	r	<mm>	:	18.00
- plate width	bu	<mm>	:	430.00
- plate thickness	t	<mm>	:	10.00
- depth of hollow core slab	d	<mm>	:	265.00

Loading data

Maximum loading on the bottom plate

- global service load	Qb,k	<kN/m>	:	35.54
- design load	Qb,d	<kN/m>	:	50.47

```
   Loading of the beam
   - live load                  P,k     &lt;kN/m&gt;    :     24.88
   - sum of permanent loads     G,k     &lt;kN/m&gt;    :     29.98
   - global service load        Q,k     &lt;kN/m&gt;    :     54.86
   - design load                Q,d     &lt;kN/m&gt;    :     77.79
   - Q (frequency)   QF = G + 0.25xP    &lt;kN/m&gt;    :     36.20
   - Q (deflection)  QD = G + 1.00xP    &lt;kN/m&gt;    :     54.86

Control of slenderness ratios b/t according to table 5.3.1
   - web                                          :      9.81 <  30.92
   - flange                                       :      4.35 <   8.95

Safety factors according to EC3, ENV 1993-1-1
   Partial safety factors :
   - live load                  sQ                :      1.50
   - permanent load             sG                :      1.35
   - resistance                 sM                :      1.10
   - assemblies                 sMb               :      1.25
   - welds                      sMw               :      1.25
   - yield strength             fy,k    &lt;N/mm2&gt;   :    345.00
   - design yield strength      fy,d    &lt;N/mm2&gt;   :    313.64

Elasto-plastic design (EC3, ENV 1993-1-1)
   Bottom plate
   - design shear force         V,d     &lt;kN/m&gt;    :     50.47
   - plastic shear resistance   Vpl,d   &lt;kN/m&gt;    :   1810.78
   - V,d/Vpl,d                                    :      0.03 <  0.25
   - design bending moment      M,d     &lt;kNcm/m&gt;  :    338.12
   - plastic moment resistance  Mpl,d   &lt;kNcm/m&gt;  :    784.09
   - M,d/Mpl,d                                    :      0.43 <  1.00

   Reduced beam
   - bottom plate thickness     t       &lt;mm&gt;      :     10.00
   - red. plate thickness       tr      &lt;mm&gt;      :      8.77
   - profile flange thickness   e       &lt;mm&gt;      :     26.00
   - red. flange thickness      er      &lt;mm&gt;      :     25.33
   - Xpl,top (to bottom of top flange)&lt;mm&gt;      :    189.56
   - Xpl,bottom (to top of plate)       &lt;mm&gt;      :     24.44
   - design shear force         V,d     &lt;kN&gt;      :    280.04
   - plastic shear resistance   Vpl,d   &lt;kN&gt;      :    820.58
   - V,d/Vpl,d                                    :      0.34 <  1.00
   - design bending moment      M,d     &lt;kNm&gt;     :    504.07
   - plastic moment resistance  Mpl,d   &lt;kNm&gt;     :    513.42
   - M,d/Mpl,d                                    :      0.98 <  1.00
   - elastic moment resistance  Mel,d   &lt;kNm&gt;     :    420.34

Serviceability state
   Stresses under service loads (cf manual)
   - Y_top elastic                      &lt;cm&gt;      :     14.79
   - Y_bottom elastic                   &lt;cm&gt;      :     10.21
   - Ix steel beam only                 &lt;cm4&gt;     :     19826
   - Compression in point 1             &lt;kN/cm2&gt;  :     26.52 max. 34.50
   - Shear in point 2                   &lt;kN/cm2&gt;  :      5.89      19.92
   - Tension in point 3                 &lt;kN/cm2&gt;  :     18.30      34.50
   - Von-Mises stress in point 4        &lt;kN/cm2&gt;  :     28.29      34.50
   - Von-Mises stress in point 5        &lt;kN/cm2&gt;  :     17.43      34.50
   - Von-Mises stress in point 6        &lt;kN/cm2&gt;  :     18.55      34.50
```

```
IFBWIN  5.30 09/04  : distributed  by Arcelor Sections Commercial         Page 3
Project : Example 2
Position: Interior Beam / asymmetric                                Date: 29.09.2004

   Deflection of the plate
   - moment of inertia          Ib     <cm4/m>    :     8.33
   - arm of forces              zu     <mm>       :    67.00
   - deflection under Qb,k      fb     <mm>       :     0.21 <  1.50

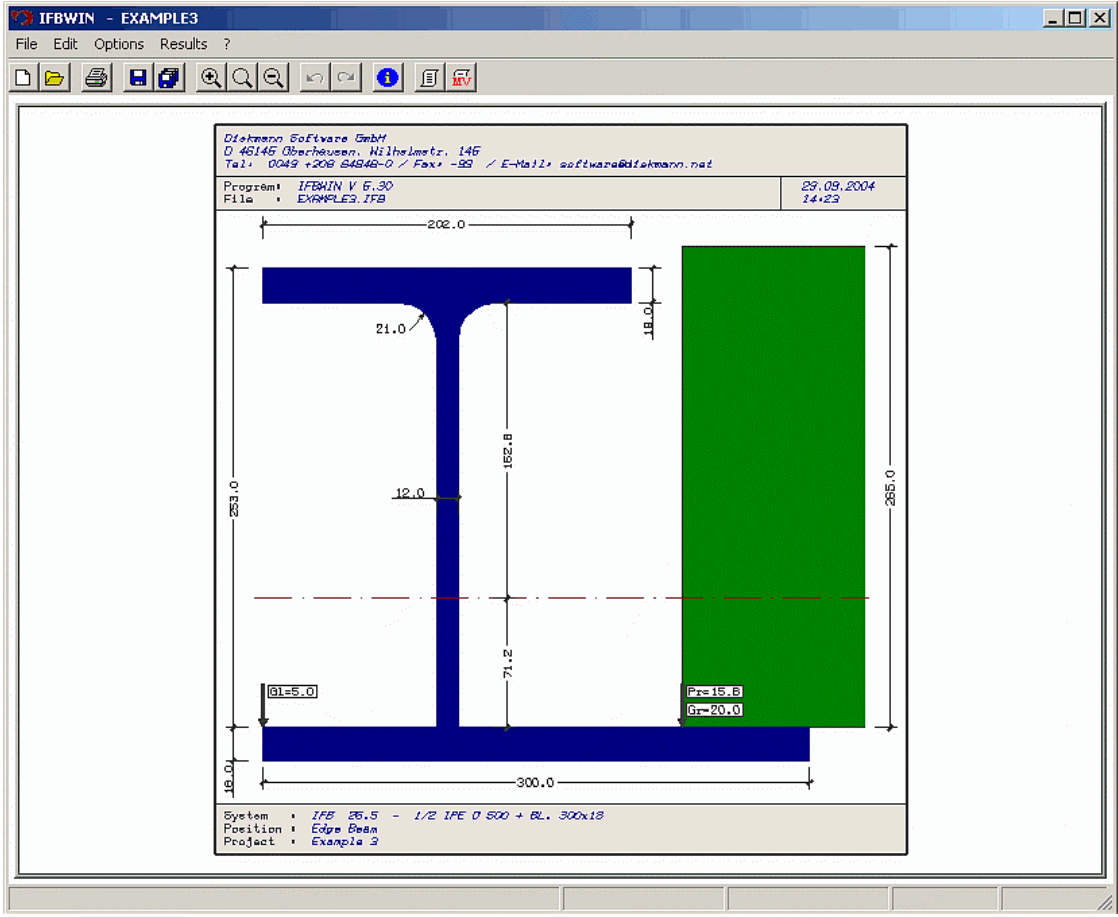
   Deflection of the unreduced beam
   - composite moment of inertia       <cm4>      :    20985
   - deflection under G         fG     <mm>       :    23.80
   - ratio                      L/fG              :    302.5
   - deflection under P         fP     <mm>       :    19.76
   - ratio                      L/fP              :    364.5 >  300
   - deflection under QD        fQD    <mm>       :    43.56
   - ratio                      L/fQD             :    165.3
   - recommended camber         fc     <mm>       :       25

   Frequency of the unreduced beam
   - composite moment of inertia       <cm4>      :    20985
   - frequency under QF                <Hz>       :      3.3 >  3.0

   Weld design (profile - bottom flange)
   - fillet weld                aw     <mm>       :      4.0
   - design weld stress         Sw,v   <N/mm2>    :    74.78
   - design weld resistance     Sw,d   <N/mm2>    :   261.73
   - Sw,v/Sw,d                                    :     0.29 < 1.0

Beam-to-column design EC3, ENV 1993-1-1
   Required thickness of the end plate or of the column flange
   Control of the bearing stress for a shear connection
   (alpha_L: 2.5) when using
   - 2 bolts M27  8.8     min T  <mm>             :     5.08
   - 4 bolts M20  8.8     min T  <mm>             :     3.43
   - 2 bolts M24 10.9     min T  <mm>             :     5.72
   - 4 bolts M20 10.9     min T  <mm>             :     3.43
   Recommended end plate thickness T  <mm>        :     10.0
```

EXAMPLE 3: Edge beam


IFBWIN - EXAMPLE3
File Edit Options Results ?
Diekmann Software GmbH
D 46145 Oberhausen, Wilhelmstr. 146
Tel: 0049 +208 64848-0 / Fax: -99 / E-Mail: software@diekmann.net
Program: IFBWIN V 6.30
File : EXAMPLE3.IFB
29.09.2004
14:23
202.0
21.0
18.0
12.0
162.8
253.0
71.2
265.0
G1=5.0
Pr=15.8
Gr=20.0
18.0
300.0
System : IFB 26.5 - 1/2 IPE O 500 + BL. 300x18
Position : Edge Beam
Project : Example 3

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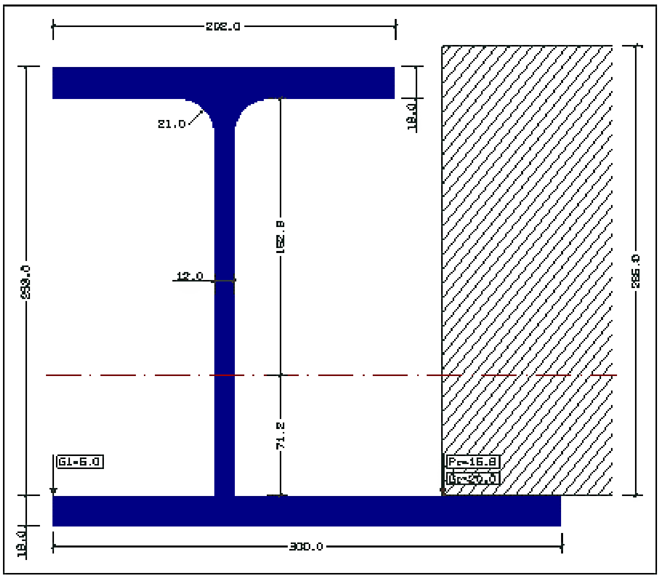
Project : Example 3
Position: Edge Beam *Date: 29.09.2004*

cross section



Control of input data

- beam span	L	<m>	:	7.20
- steel grade			:	S355
- live load :				
left	Pl	<kN/m>	:	0.00
center	Pc	<kN/m>	:	0.00
right	Pr	<kN/m>	:	15.58
- permanent load :				
left	Gl	<kN/m>	:	5.00
center	Gc	<kN/m>	:	0.00
right	Gr	<kN/m>	:	19.96

Geometry of cross section

- type of beam			:	IFB 26.5 A-Typ
- rolled section			:	1/2 IPE O 500
- plate			:	300 x 18
- beam weight	g	<kg/m>	:	96.86
- beam depth	H	<mm>	:	271.00
- top flange width	bo	<mm>	:	202.00
- bottom flange width	bu	<mm>	:	300.00
- top flange thickness	e	<mm>	:	19.00
- bottom flange thickness	t	<mm>	:	18.00
- web thickness	a	<mm>	:	12.00
- inner depth	hc	<mm>	:	234.00
- depth of rolled section	hp	<mm>	:	253.00
- fillet radius	r	<mm>	:	21.00
- depth of hollow core slab	d	<mm>	:	265.00

Loading data

Maximum loading on the bottom flange

- global service load	Qb,k	<kN/m>	:	35.54
- design load	Qb,d	<kN/m>	:	50.32

```
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Project : Example 3
Position: Edge Beam                                                Date: 29.09.2004

   Loading of the beam
   - live load                  P,k     <kN/m>     :     15.58
   - sum of permanent loads     G,k     <kN/m>     :     25.93
   - global service load        Q,k     <kN/m>     :     41.51
   - design load                Q,d     <kN/m>     :     58.37
   - Q (frequency)   QF = G + 0.25xP    <kN/m>     :     29.82
   - Q (deflection)  QD = G + 1.00xP    <kN/m>     :     41.51

Control of slenderness ratios b/t according to table 5.3.1
   - web                                           :     17.75 <  48.46
   - flange                                        :      5.32 <   8.95

Safety factors according to EC3, ENV 1993-1-1
   Partial safety factors :
   - live load                  sQ                 :      1.50
   - permanent load             sG                 :      1.35
   - resistance                 sM                 :      1.10
   - assemblies                 sMb                :      1.25
   - welds                      sMw                :      1.25
   - yield strength             fy,k    <N/mm2>    :    345.00
   - design yield strength      fy,d    <N/mm2>    :    313.64

Elasto-plastic design (EC3, ENV 1993-1-1)
   Bottom flange
   - design shear force         V,d     <kN/m>     :     50.32
   - plastic shear resistance   Vpl,d   <kN/m>     :   3259.40
   - V,d/Vpl,d                                     :      0.02 <  0.25
   - design bending moment      M,d     <kNcm/m>   :    794.99
   - plastic moment resistance  Mpl,d   <kNcm/m>   :   2540.45
   - M,d/Mpl,d                                     :      0.31 <  1.00

   Reduced beam
   - bottom flange thickness    t       <mm>       :     18.00
   - red. flange thickness      tr      <mm>       :     16.46
   - Xpl,top (to bottom of top flange)<mm>         :    162.83
   - Xpl,bottom (to top of bottom flan<mm>         :     71.17
   - design shear force         V,d     <kN>       :    210.14
   - plastic shear resistance   Vpl,d   <kN>       :    635.70
   - V,d/Vpl,d                                     :      0.33 <  1.00
   - design bending moment      M,d     <kNm>      :    378.26
   - plastic moment resistance  Mpl,d   <kNm>      :    389.84
   - M,d/Mpl,d                                     :      0.97 <  1.00
   - elastic moment resistance  Mel,d   <kNm>      :    334.43

Serviceability state
   Stresses under service loads (cf manual)
   - Y_top elastic                      <cm>       :     15.02
   - Y_bottom elastic                   <cm>       :     12.08
   - Ix steel beam only                 <cm4>      :     16015
   - Compression in point 1             <kN/cm2>   :     25.23 max. 34.50
   - Shear in point 2                   <kN/cm2>   :      5.19      19.92
   - Tension in point 3                 <kN/cm2>   :     20.29      34.50
   - Von-Mises stress in point 4        <kN/cm2>   :     27.03      34.50
   - Von-Mises stress in point 5        <kN/cm2>   :     18.79      34.50
```

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Project : Example 3
Position: Edge Beam                                               Date: 29.09.2004

   Deflection of the bottom flange
   - moment of inertia          Ib      <cm4/m>    :     48.60
   - arm of forces              zu      <mm>       :    158.00
   - deflection under Qb,k      fb      <mm>       :      0.46 <   1.50

   Deflection of the unreduced beam
   - composite moment of inertia        <cm4>      :     16680
   - deflection under G         fG      <mm>       :     25.90
   - ratio                      L/fG               :     278.0
   - deflection under P         fP      <mm>       :     15.56
   - ratio                      L/fP               :     462.6 >   300
   - deflection under QD        fQD     <mm>       :     41.47
   - ratio                      L/fQD              :     173.6
   - recommended camber         fc      <mm>       :        30

   Frequency of the unreduced beam
   - composite moment of inertia        <cm4>      :     16680
   - frequency under QF                 <Hz>       :       3.3 >   3.0

   Weld design (profile - bottom flange)
   - fillet weld                aw      <mm>       :       4.0
   - design weld stress         Sw,v    <N/mm2>    :    192.69
   - design weld resistance     Sw,d    <N/mm2>    :    261.73
   - Sw,v/Sw,d                                     :      0.74 < 1.0

Beam-to-column design EC3, ENV 1993-1-1
   Required thickness of the end plate or of the column flange
   Control of the bearing stress for a shear connection
   (alpha_L: 2.5) when using
   - 2 bolts M22  8.8     min T  <mm>              :      4.68
   - 4 bolts M16  8.8     min T  <mm>              :      3.22
   - 2 bolts M22 10.9     min T  <mm>              :      4.68
   - 4 bolts M16 10.9     min T  <mm>              :      3.22
   Recommended end plate thickness T  <mm>         :      10.0

   Weld design (fillet weld):
   - req. weld area  Aw                <cm**2>     :       8.0
   - req. length for a =  min = 3.0 <mm>           :     135.0
   - req. length for a =        4.0 <mm>           :     105.0
   - req. length for a =        5.0 <mm>           :      85.0
   - req. length for a =        6.0 <mm>           :      70.0
   - req. length for a =  max = 7.0 <mm>           :      60.0
```