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Design of Pre and Post Tensioned Concrete Structures

Scia Engineer

Eurocodes Solutions

Concrete as a construction material has become the most widely used construction material in the world. It is popular mainly because of its adaptability to architectonic requirements, variability of possible shapes, availability of material and relatively low technological complexity, which leads to extensive savings.

Modern concrete structures can achieve considerable economies by using precast prestressed units or a combination of hybrid systems of precast and cast in place concrete. The economy and speed of the construction are also increased by the application of suitable construction methods. The main load bearing elements are very often fabricated in advance and are used as a supporting system for other structural members in order to reduce overall construction time and costs. The design of structures, in which both technologies of precast and cast-in-place concrete are combined, provides an economy in the construction as well as high standards of quality while minimizing the time needed to complete the construction.

Scia Engineer represents a complex tool for the designing and checking of prestressed structures, enabling the calculation and checking of prestressed and non-prestressed concrete beams, columns, and concrete slabs, even hollow core ones.

Pre-tensioned concrete structures

The module is an effective tool for the design and calculation of pre tensioned concrete beams. The input of individual tendons is made in the form of insertion of prestressing tendons /cables/ wires into holes in boreholes of end sections of a symmetrical concrete beam. The user always works with a group of tendons. That group creates a single entity (beam strand pattern).

The prerequisites for input are.

- Borehole pattern.
- Sectional strand pattern.
- Definition of a stressing bed.
- Beam strand pattern.

Product range

The basic idea for the implementation of a product range library is allowing the user to define their own catalogue of members that are often fabricated and used. The members in the catalogue are "tailor-made", but can be very effectively and quickly used similarly as for example predefined database cross-sections. This can be achieved through a parametric definition of a cross-section and option to filter and sort items in the catalogue using several criteria. More complicated shapes of cross sections can be imported from CAD applications by means of DWG and DXF formats.

This approach seems profitable especially for manufacturers of precast structures.

Borehole patterns

The borehole pattern is based on the shape of the cross-section of a corresponding element. A user-friendly editor can be used to insert individual holes or groups of holes on this pattern. The holes define possible positions of the tendon in the end-sections of the member. This prepared pattern is stored in the borehole pattern library and through a standard library manager it is available for further use or data exchange between different projects/users. The boreholes can be also easily imported from DXF/DWG format.

Sectional strand patterns

The sectional strand pattern (i.e. the reinforcement of end sections of the member by pre tensioned steel) is based on the borehole pattern in which some holes are filled with a prestressing tendon (cable or wire). This pattern is also available through a standard library manager for multiple use in members of the same cross-section.

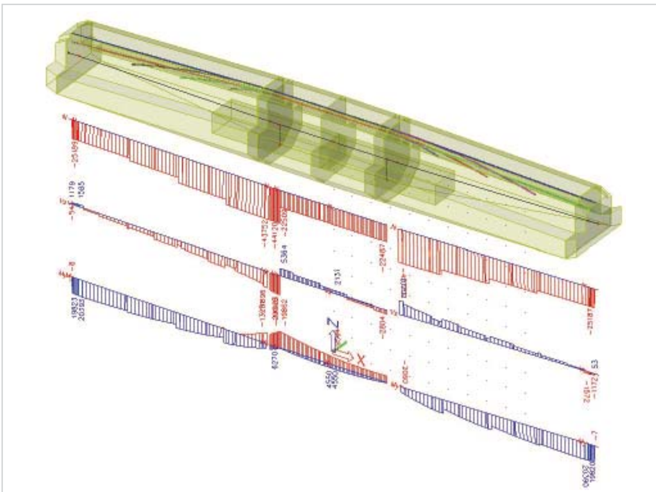
Beam strand patterns

The beam strand patterns are based on the borehole pattern or a sectional strand pattern, and they also contain data on the position of particular tendons/strands along the length of a member. It is possible to delete them as a group or copy them as a group to other members of the same cross-section.

Using a suitable selection of the cross-section reference point they can be copied also on beams of a different cross-section.

Tendons are data related to the particular beam and after any modification of the beam they are automatically edited accordingly (curvature, shortening/elongation).

Insertion of individual tendons into holes of a borehole pattern is done in a graphical dialogue. A clear dialogue offers all important properties and settings for individual tendons, geometry and sectional characteristics of the tendon in the cross-section.



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Types and properties of tendons:

- Draped, fixed (fixed position in cross-section) and debonded (without cohesion with concrete).
- Type of stressing and initial stress,.
- Transfer of prestressing through cutting/ release of strands.
- Anchorage lengths.
- Possible parameterisation.

Stressing beds

Library of stressing beds enables the user to define, among others, heat curing of concrete. From the user defined heat curing, the concrete age is recalculated (acceleration of its maturity).

An equivalent time is added to the time after tensioning to take into account the effects of heat curing on the prestress loss due to relaxation of prestressing steel according to EN1992-1-1.

Transmission lengths and openings

Transmission length, over which the prestressing force is fully transmitted to the concrete, is defined in the sectional strand pattern by the user or is determined by an automatic calculation according to EN1992 1 1.

Creating of openings in precast elements due to various fittings is nowadays an inevitable fact. Pre tensioned strands are automatically edited according to post created holes. The program identifies strands interrupted by inputted openings, breaks the strands, completes the transmission lengths and considers the breaking in the calculation of stress losses. After deleting of an opening from a beam, the reintegration of the interrupted strands is done automatically.

Hollow core slabs in Scia Engineer

A hollow core slab is a special type of precast element which is frequently used as a floor system in buildings. It is characteristic by its high bearing capacity and low weight. Hollow core slabs are also checked for mechanical resistance according to EN1168.

Template for the analysis of hollow core slabs

Hollow core slabs are often used as precast prestressed and non prestressed floor panels in building construction. In Scia Engineer a template is available that can be run easily by an operator or an estimator (without specialized education). The template adopts several simplifications, which result in the reduction of the calculation time without compromising the high quality of the analysis and performed concrete checks. From this template, which is prepared for a simple beam, many variations (precast beams monolithically composed at a support; changes of the static system during construction, etc.) can be easily created.

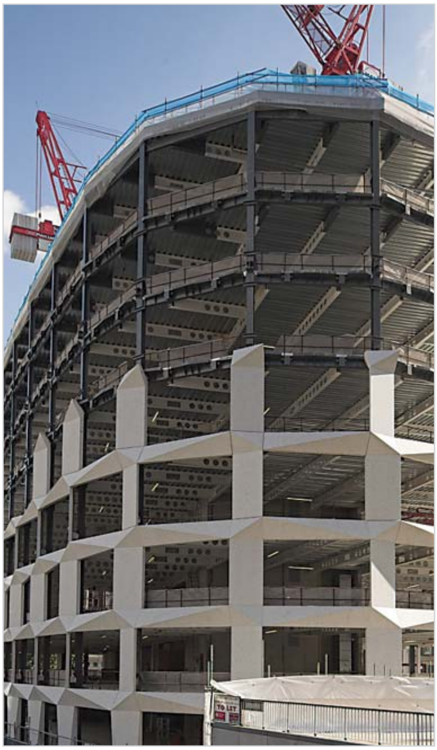
Check of mechanical resistance of hollow core slabs EN1168+A1

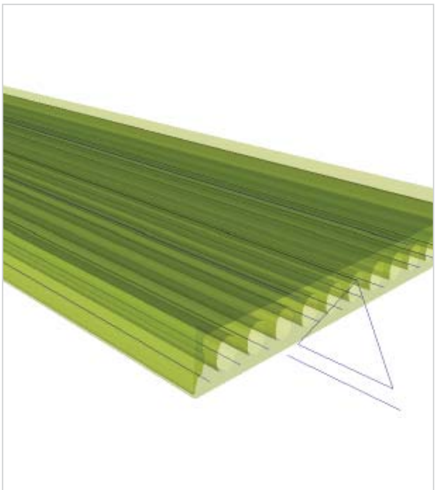
Scia Engineer performs checks of mechanical resistance of hollow core slabs according to EN1168 including the amendment A1. The implemented checks include:

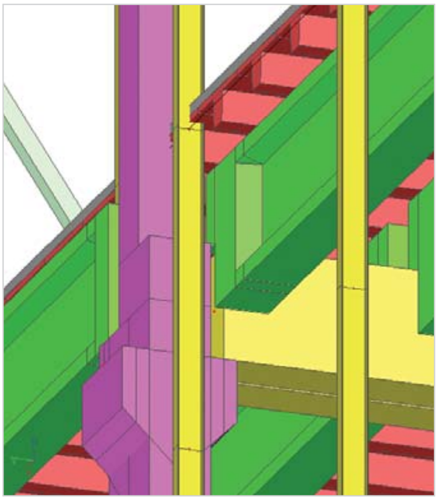
- Check of splitting of panel face.
- Check of shear according to simplified and general method.
- Check of shear and torsion interaction.
- Check of the longitudinal joint between panels.
- Check of punching shear.
- Check of a panel supported on three sides.

Tables of bearing resistance (Load span tables)

Tables, showing dependence of the maximum possible imposed load on the length of a span, are one of the basic outputs of a manufacturer of precast floor units. Tables can be obtained for a specified cross-section, a defined range of load, spans and a number of selected strand patterns. Tables are created using the program for general optimisation, which is a part of Scia Engineer. The batch processing provides results for combinations of lengths, loads and strand patterns. The results are then evaluated according to the defined criteria and the tables are completed after export to the table editor.







Post tensioned concrete structures

Modules for post tensioned concrete structures have been developed for input and calculation of post tensioned concrete beams, slabs and even shells. This module can be used to model mono or multi strand tendons with the bond established by the grouting of tendon ducts.

External tendons
External tendons are defined in Scia Engineer on the assumption of a constant initial stress and without an option of automatic calculation of relaxation.

Input and calculation of effects of thermal loads on a free external tendon

The input of thermal loads was extended by an option of loading a free external tendon with a temperature which is constant along the length of the free tendon. Effects of the load can be shown in standard result services and considered in checks.

Losses in prestressing force

The program allows the calculation and display of losses both in a numerical and graphical form.

Short-term losses:
- Loss due to anchorage slip.
- Loss due to relaxation of prestressing steel.
- Loss due to friction (post tensioned concrete).
- Loss due to sequential prestressing (post tensioned concrete).
- Loss due to deformation of stressing bed (pre tensioned concrete).
- Loss of prestress caused by the temperature difference between prestressing steel and stressing bed (pre tensioned concrete).

Long-term losses - if a TDA solver is used:
- Loss of prestress due to relaxation of pre-stressing steel.
- Loss due to shrinkage of concrete.
- Loss due to creep of concrete.
- Loss due to elastic deformation of concrete caused by load applied after transfer of prestressing.

Calculation

Tendons after the transfer of the prestressing force become an integral part of the prestressed beam. The stiffness of the inserted tendons is then added to the stiffness matrix of the whole structure. The loads imposed after the transfer cause deformation of the structure including the tendon and the resulting change of stress in the tendon is calculated automatically depending on this deformation.

The display of primary and secondary effects of the prestressing load gives the user more information about the model and in case of a deformation load it allows for the decomposition of the calculation steps and a better supervision of the program. The primary effects are displayed as standard results.

Construction and operation stages + TDA

The module Construction and operation stages in combination with the standard solver or TDA solver represents an efficient tool for performing calculations of prestressed and non prestressed structures. Static models are generated automatically considering successive assembling or casting of a structural member and cross-section, the change of boundary conditions and rheological effects of concrete.

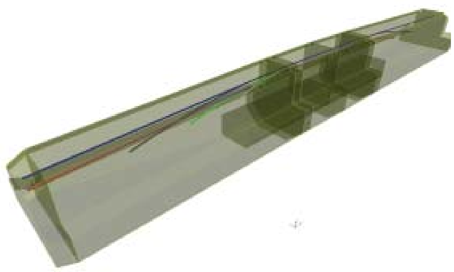
The modules enable gradual application of load and prestressing and removing of temporary structural members. It is possible to model the complete history of fabrication of a precast element (prestressing, casting, storage, final supports, assembling supports) and also the successive construction of multi-storey frames.

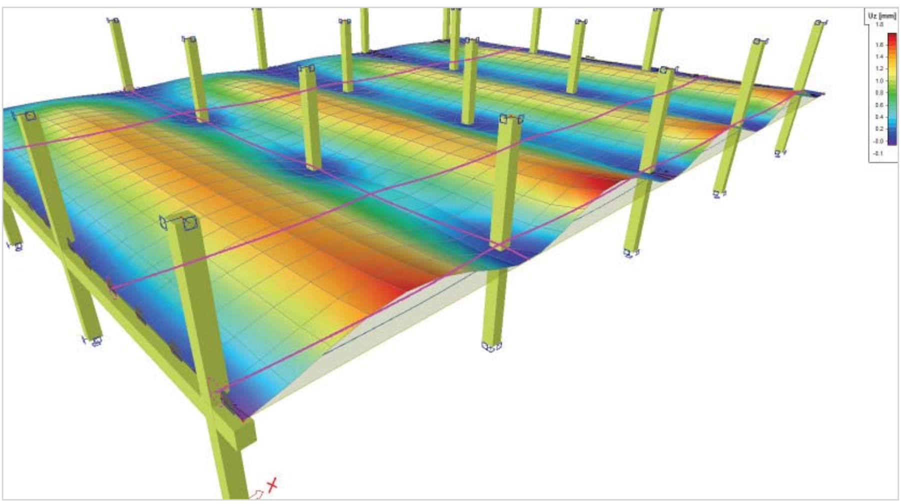
Materials

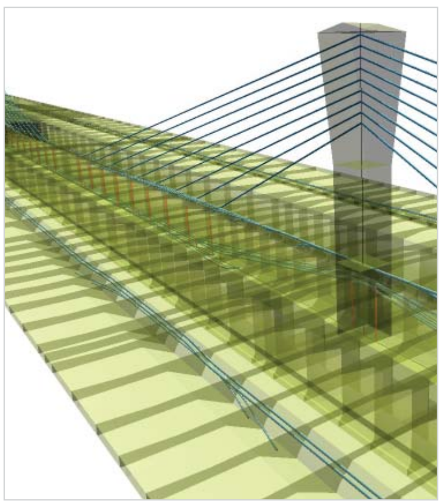
The module for construction and operation stages enables the user to use an extension of the standard material databases with information considering ageing of concrete according to related standards. For the purposes of the time dependent analysis (module TDA), the characteristics are extended by data relating to the concrete composition affecting the speed and rate of the shrinkage and creep of concrete. For EC and CSN (Czech) standards it is possible to input the age of concrete and corresponding experimentally given or required values of compressive strength of concrete. From this the development of the concrete modulus of elasticity over time is determined.

Cross-sections

The database of available profiles is coupled with cross-sections that consist of more parts – composite cross-sections. Each part can be made of different material.







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The module General cross-section allows the user to define any shape of cross-section. Up to 10 possible phases can be defined for one cross-section. During the calculation, each cross-section phase is in longitudinal direction modelled by means of a separate finite element with an eccentricity. Therefore, stress redistribution between two different cross-section phases occurs in the TDA analysis.

Definition of stages

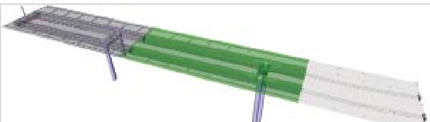
The definition of stages is done through a clear table of properties in the menu ”Construction and operation stages”. The user selects the type of solver. The standard solver provides analysis of general 3D structures, but without automatic considering of effects of creep and shrinkage of concrete. The TDA solver can be used for a general time analysis of a 2D frame. The definition is then extended by the input of load factors for load cases created for the effects of creep and shrinkage and by the setting of the local time axis.

Installation and removal of entities in construction stages

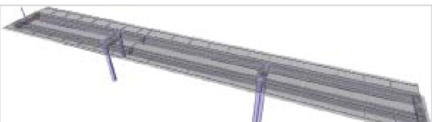
The installation and removal of entities in construction stages can be done from the service “Construction and operation stages” or directly in the Property window of individual entities. In the service “Construction and operation stages”, the installed and removed entities are shown in a different colour. In case of time depending analysis, to each element a “local beam history” can be assigned, containing e.g. the time of casting, time of removal of formwork, end of concrete curing, etc. The inputted data are related to the local time axis of the element, whose origin (zero) corresponds to the time of the element installation into the structure. This time does not need to be identical with the time of the element casting.

The origin of the local time axis is then located to the global time axis of the construction of the whole structure.


Construction Stage 1


Construction Stage 2


Construction Stage 3


Construction Stage 4

Multiple supports in one point or node

Scia Engineer makes it possible to take into account changes in support properties over time e.g. the change of stiffness in spring supports over time. It is possible to input several supports in one point of a beam or in one node including their installation or removal to/from the construction stages. Multiple supports can only be used in the construction stages analysis (i.e. not in a simple analysis). Similarly, resultant reactions can be shown for individual supports depending on the construction stages.

Manager of Construction and operation stages

Input, changes and management of construction stages can be done in a standard library manager, where information related to the individual construction and operation stages of the structure are clearly shown. It concerns e.g. the assigned load cases, descriptions and in case of the TDA module also the time of stage origin.

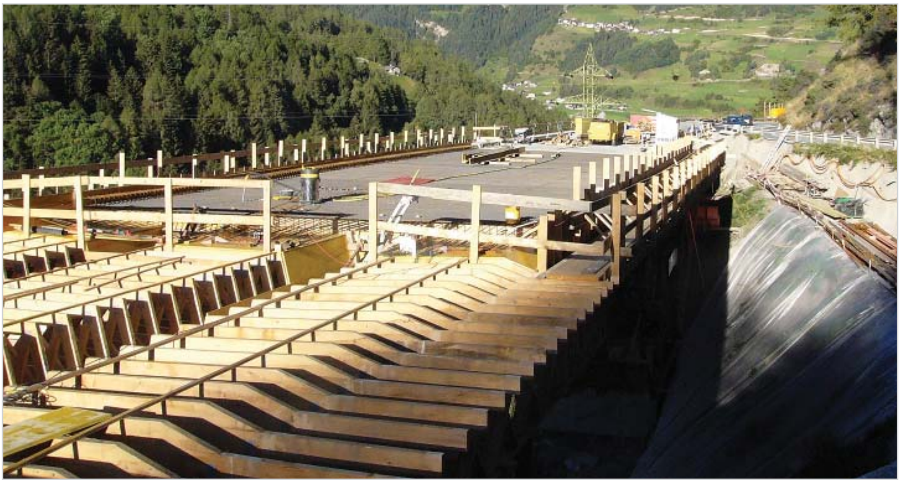
The intermediate time nodes for the TDA solver are then generated automatically by the insertion of local time axes of all elements and by the definition of the detailed time nodes defined by the number of required subintervals in the individual time interval. Detailed time nodes are required for the improved accuracy of the creep calculation.

Calculation of stages by standard solver

Each construction and operation stage has one load case assigned (this load case is reserved for the given stage), in which increments of load effects and construction changes (e.g. removal of supports) in given construction or operation stage are stored.
During the calculation of construction stages the program automatically creates combinations and result classes. For each stage, two classes of results (ULS - consideration of load factors, SLS – load factors = 1) are generated. The results in each class are obtained as a combination of load cases, where the total effects of loads and construction changes from all previous and the given stage are stored. Thus they show the actual state of the structure after the particular construction or operation stage. Individual steps in the calculation of stages are linear, the installation and removal of individual entities can be modelled by means of absences and load cases.

Calculation of stages with E modulus change Time dependant analysis by TDA solver

The module TDA in its full version enables the user to solve special construction technologies taking into account creep, shrinkage and ageing of concrete, steel relaxation and long-term losses of prestress.
In the integration with the module for prestressed concrete, the TDA solver is used for the time dependant analysis of the creep of concrete while considering the stress history, its shrinkage and ageing for the calculation of long-term losses of prestress, relaxation and the redistribution of the internal forces and stresses.
The calculation of time dependant analysis (TDA) can be performed according to several standards CSN 736207, CSN 731201, EN1992-1-1 for buildings and also according to the EN1992-2 for bridges.



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Analysis 3D>2D>3D

The module 3D>2D>3D allows for the combination of time dependant analysis TDA with other types of calculation. This is called Sequential analysis.

This procedure can be useful in the analysis of a torsional effect on a bridge structure in combination with TDA.

The principle can be summed as:
- The user defines a structure as Frame XYZ type.
- The time dependant analysis is performed on a 2D frame XZ and the combinations are filled with results (limiting conditions are checked).
- Live loads, PNL (physical non linear) or PGNL (physical and geometrical non linear) are analysed on the frame XYZ. All results are available for frame XYZ.

Limiting conditions are
- All nodes in the structure have to be in the XZ-plane.
- Rotation of the member is not allowed.

Design and check

Concrete beams

Scia Engineer performs checks of prestressed and non prestressed concrete beams in accordance with EN1992-1-1, combined with the check of fire resistance according to EN1992-1-2 and also special checks of mechanical resistance according to EN1168. The available checks include namely:
- Resistance of the cross-section subjected to flexure and normal force:
  - Response of the cross-section subjected to ultimate load.
  - Ultimate capacity derived from the interaction diagram/area.
- Shear resistance.
- Torsional resistance (in interaction with bending and shear).
- Check of shear at the interface between concrete cast at different times and design of required reinforcement at the joint.
- Calculation and check of crack width (calculation of decompression stress).
- Calculation and check of allowable stress of concrete and prestressing steel.
- Calculation and check of allowable principal tensions.
- Check of mechanical resistance of hollow core slabs.
- Check of end zones for beams and design of additional reinforcement.
- Check of deflections of fully prestressed concrete.
- Design of non-prestressed reinforcement (longitudinal and shear) in prestressed and non prestressed cross-section.
- Bill of reinforcing and prestressing steel.

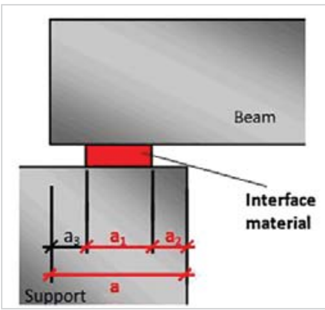
Continuous beam

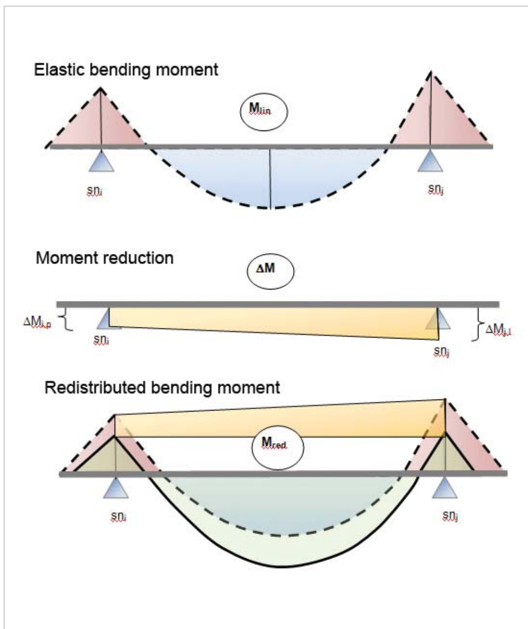
In order to make the design and analysis of continuous beams formed from precast simple beams monolithically composed at supports more effective, a new type of member “continuous beam” has been implemented in Scia Engineer.

Among others, it enables the user to optimise the design bending moments obtained by a linear elastic analysis through the limited redistribution of bending moments according to EN 1992-1-1.

This results in a decrease of the bending moment in a support and an increase of the moment in mid span in order to get the maximum utilisation of the reinforcement designed for the precast member in the stage when it acts as a simple beam. Reducing the number of bars or decreasing the length of non prestressed reinforcement lead to huge savings in the mass production of these members.
Moments calculated after the redistribution can be compared with originally calculated values.

The check of the degree of redistribution according to 5.5(4) EN1992-1-1 itself is divided tin the check of members predominantly subjected to flexure, check of ratio of adjacent spans and check of ratio of redistributed moment to elastic moment. Alternatively, conditions for plastic analysis without the need of the calculation of the rotation capacity can be





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adopted. It concerns checks of the height of the compression zone, class of reinforcing steel and ratio of the moment at the internal support to the moment in the span according to 5.6.2(2) EN1992-1-1.

Furthermore, the continuous beam offers the calculation of the effective flange width of a T cross-section and its subsequent introduction to the static model. The calculation of the effective flange width is carried out according to EN 1992-1-1 with an option to specify the distance between the points of zero moments by performing the calculation of internal forces.

The part of the flange of the T cross-section between the points of zero hogging moments of the continuous beam can be in the static model excluded from action.

Check of end bearings for beams

The check of bearings for precast elements is performed according to chapter 10.9.5 EN1992-1-1. The program adopts three basic types of bearing – dry direct bearing, direct bearing into mortar and what is called non direct bearing.

The calculated dimensions of bearings are compared with the values recommended in the standard. Moreover, this module allows the user to design additional longitudinal and shear reinforcement for end sections of the beam. The analysis of this beam section is performed using the strut and tie method.

Design and check of columns

The module for check and design of columns provides the user with a complete solution for non prestressed and also prestressed columns. Scia Engineer enables the user to define, check and design additional reinforcing steel in pre tensioned concrete columns.

The secondary effect of prestressing is not considered in the calculation. Multi phased cross sections of columns are not supported. The program performs the design and check of columns loaded in one or two directions, and also the checks of circular columns.

High-rise buildings

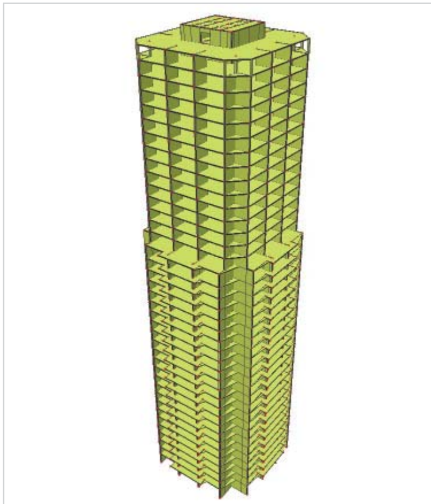
Designers of high-rise buildings will appreciate the option to calculate the P-Delta effect and the implementation of stiffness modifiers.

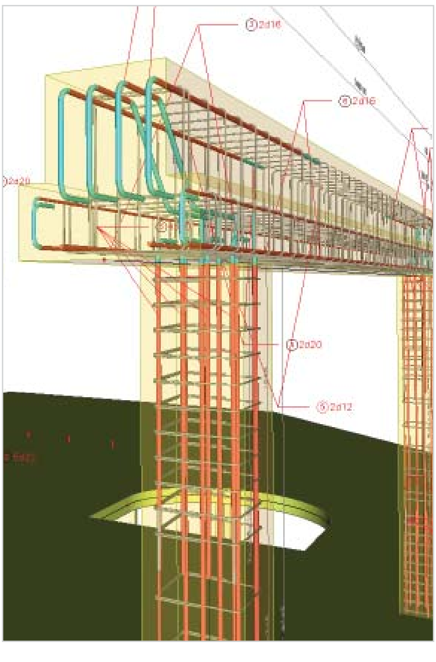
P-Delta effect in dynamic calculations

In the analysis of high-rise buildings, the displacement of a whole storey to the deformed position causes the second order moment. The additional second order moment is equal to the weight of all storeys “P” multiplied by its horizontal displacement “Delta”. That is why it is called P-delta effect. The P-Delta effect for a static analysis was already considered in previous versions of the program as a part of the geometrically non linear analysis. In the dynamic analysis this effect can be taken into account using the sequential analysis, when the dynamic or seismic calculation is executed after the geometrically non linear calculation . After the non linear calculation, the structure is deformed and this state of the structure is used as the initial state for further analysis.

Stiffness modifiers and integration strips

In the context of high-rise buildings, also the feature called “stiffness modifiers” can be used for 1D and 2D members. These modifiers simulate cracking in concrete (decrease of column stiffness, softening of slabs in surrounding of rigid core). Through modifiers, the program also can increase or decrease the stiffness or self weight in the static and dynamic analysis. Also integration strips can be very useful to convert 2D results into 1D.





Advantages

Advantages provided by the Scia Engineer solution

Complete solution

Scia Engineer is a complete tool for the design and check of reinforced and prestressed elements in buildings and bridge constructions.

Investment return

Purchase costs of a new program have a small effect on the return of investments in software. The most important factor is the increase in productivity. A high quality program and appropriate training are a guarantee for productivity growth and success of Scia Engineer users.

User adaptability

Buildings can be parameterised and easily re-used in subsequent projects. These user parameterised templates increase the overall working productivity.

Safety

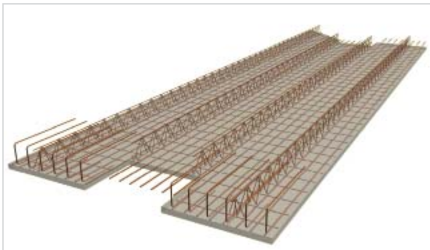
Check of compliance with EN 1992-1-1 for buildings, checks of fire resistance according to EN 1992-1-2. Check of mechanical properties of precast hollow core slabs according to EN1168 including amendment A1.

All in one platform

In compliance with your wishes it is possible to combine mutually, within the same project, the various Eurocodes. For bars as well as for plates and for any kind of material: steel, concrete, aluminium. This way, constructions are analyzed in one go, e.g. in a 3D model. Also switching to other design codes (e.g. EC ENV, NEN, DIN…) is possible. This allows the user to compare design codes or to convert older projects to the Eurocode EN and vice versa.

Export / Import (BIM)

Scia Engineer is not only a calculation system, but it is also a platform which forms the background for other engineering applications. Results can be exported to many used formats for further analysis: RTF (Word), MS, Excel©, PDF (also 3D). Complete drawings (reinforcement, installation…) can be exported to a wide variety of formats: DWG, DXF and VRML. Support of IFC and XML. Roundtrip between Scia Engineer and Allplan, which is used among others by designers of precast structures.
Scia Engineer also supports the interface with many other programs in the market such as: ETABS, Tekla, Revit.



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